Methodology to Integrate Algae Wastewater Treatment Technologies to Avoid Emissions from Grey Infrastructure Wastewater Management Systems v1

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1. Methodology Overview

This *Methodology* can be used by *Project Proponents* to generate carbon credits by utilizing algae-integrated treatment systems for wastewater nutrient removal, thereby avoiding greenhouse gas (GHG) emissions associated with the construction and operation of conventional nutrient removal infrastructure. By reducing nutrient loading to traditional treatment processes, algae-integrated treatment systems can effectively lower direct GHG emissions in subsequent treatment steps, while also minimizing energy-intensive operations and chemical use resulting in the avoidance of emissions.

This methodology establishes a standardized approach to quantify and verify the emission reduction benefits of algae-integrated wastewater treatment systems. Project Proponents using this methodology will calculate the reduction in GHG emissions associated with reduced direct emissions and avoided energy and materials as compared to a business-as-usual case where gray infrastructure would have been constructed to meet capacity and/or regulatory discharge limits.

Calculation of GHG Reductions and Issuance of Credits

The primary credit-generating activity under this methodology is the selection and implementation of algae-integrated nutrient removal systems by wastewater treatment facilities, which avoid decades of GHG emissions associated with constructing and operating conventional nutrient removal infrastructure (grey infrastructure). To mitigate the risk that the counterfactual scenario—construction and operation of gray infrastructure—occurs, credits under this methodology are issued ex-post in annual increments over the anticipated lifetime of the avoided infrastructure upgrade.

On each anniversary of the start of the crediting term, Project Proponents will calculate the actual avoided GHG emissions based on the life cycle analysis methods outlined in their Project Plan. These calculations will account for reductions in direct GHG emissions within the wastewater treatment plant boundary resulting from the installation of the algae-integrated system. Additionally, life cycle inventory data, including the latest carbon intensity information for grid electricity, will be used to quantify avoided emissions from reduced electricity and material consumption compared to traditional gray infrastructure.

The carbon credits generated under this methodology are based on verified GHG emissions reductions achieved by replacing conventional gray infrastructure with algae-integrated treatment systems. While these systems are often designed to assist wastewater treatment facilities in meeting water quality compliance requirements, credit issuance is strictly tied to GHG reductions and remains independent of regulatory compliance outcomes.

This means that if a wastewater treatment plant fails to meet compliance limits due to external factors—such as increased influent nutrient loads or operational changes—it does not impact the issuance of carbon credits, as long as the algae-integrated system continues to meet or exceed the performance of the gray infrastructure baseline relative to project objectives.

The responsibility for implementation, operation, and regulatory compliance remains with the facility, ensuring that the methodology focuses solely on the quantification and verification of avoided GHG emissions rather than wastewater discharge compliance. Algae-integrated treatment systems have demonstrated their reliability as alternatives to gray infrastructure used for nutrient removal. Regulatory frameworks typically provide facilities with sufficient time to prove the effectiveness of innovative solutions, ensuring that the emissions reductions achieved are both robust and permanent. The 20-year lifetime emissions calculated under this methodology serve as a reliable foundation for the issuance of carbon credits, aligning with industry standards for infrastructure crediting.

Geographic Scope

This *Methodology* and associated credit class document titled “GHG & Co-Benefits in Watershed Carbon v1.0” (hereafter referred to as *Credit Class)* are designed to be globally applicable, supporting the adoption of algae-integrated nutrient removal systems across diverse wastewater treatment contexts. It establishes a standardized framework for quantifying and verifying GHG reductions while accommodating regional variations in environmental, regulatory, and operational factors. The methodology applies to municipal and industrial wastewater treatment facilities, as well as to areas in developing regions where algae-integrated treatment systems can provide sustainable alternatives to conventional gray infrastructure. To ensure accuracy and applicability, Project Proponents are required to incorporate geographically specific data, including local energy grid emissions factors, regional emissions factors for chemical production, and applicable water quality and environmental regulations. This ensures the methodology can adapt effectively to diverse settings while upholding rigorous and consistent standards for carbon credit generation and verification.

Background on Algae-Integrated Nutrient Removal

Nutrient pollution, primarily from point-source discharges such as municipal and industrial wastewater treatment facilities, poses a significant threat to water quality and aquatic ecosystems. Excessive nitrogen (N) and phosphorus (P) in water bodies lead to eutrophication, resulting in harmful algal blooms, oxygen depletion, and habitat degradation. In the United States, nutrient pollution is one of the most widespread and challenging environmental problems, affecting numerous rivers, lakes, and coastal waters.

To combat these issues, regulatory agencies have implemented stricter nutrient discharge limits for wastewater treatment plants. The U.S. Environmental Protection Agency (EPA) reports that setting permit limits and treating wastewater to meet specific effluent standards can substantially reduce N and P loading from these facilities, thereby protecting local and downstream water quality.

Algae-integrated nutrient removal systems offer a sustainable alternative to traditional gray infrastructure for meeting these stringent discharge requirements. By leveraging the natural bio-assimilation capabilities of algae along with other biological nutrient removal mechanisms (such as nitrification-denitrification), these systems effectively reduce nutrient concentrations in effluents, thereby lowering the risk of eutrophication. Additionally, algae-integrated treatment systems can decrease nutrient recirculation, lowering GHG emissions associated with conventional nutrient removal processes, which are often energy-intensive and/or reliant on chemical processes. Implementing algae-integrated treatment solutions aligns with the EPA's emphasis on innovative solutions to address nutrient pollution challenges.

This methodology provides a standardized framework for quantifying and verifying the GHG emission reductions achieved through algae-integrated nutrient removal systems. Facilitating the generation of carbon credits incentivizes wastewater treatment facilities to adopt these sustainable technologies, thereby contributing to improved water quality and compliance with stricter nutrient discharge regulations while reducing GHGs from traditional infrastructure.

Monitoring Requirements

Monitoring the performance of algae-integrated nutrient removal systems is essential to ensure the credibility and accuracy of carbon credits generated under this methodology. While many programs have traditionally relied on modeling to estimate environmental benefits, this methodology requires direct measurements to improve transparency and maintain the quality of credits. Project Proponents must measure key parameters such as nutrient concentrations in influent and effluent, direct GHG emissions, and system energy and material usage. Monitoring shall occur at regular intervals, with nutrient and GHG measurements taken monthly and energy and material usage tracked continuously. Standardized sampling protocols and calibrated equipment must be used to ensure data quality with annual reporting required to verify the results. This approach ensures that the carbon credits issued are based on reliable, real-world performance data.

Project Developer/Owner Obligations

This methodology is intentionally broad to ensure applicability across diverse wastewater treatment contexts, geographies, and regulatory frameworks. As a result, significant responsibility rests with Project Developers and Owners to create a comprehensive

Project Plan Document that translates the methodology's guidance into actionable and verifiable project-specific activities. This document must detail the system design, implementation, and monitoring strategies to ensure consistency with the methodology's requirements and achieve credible results.

An outline of the methodology structure is provided in the following figure.

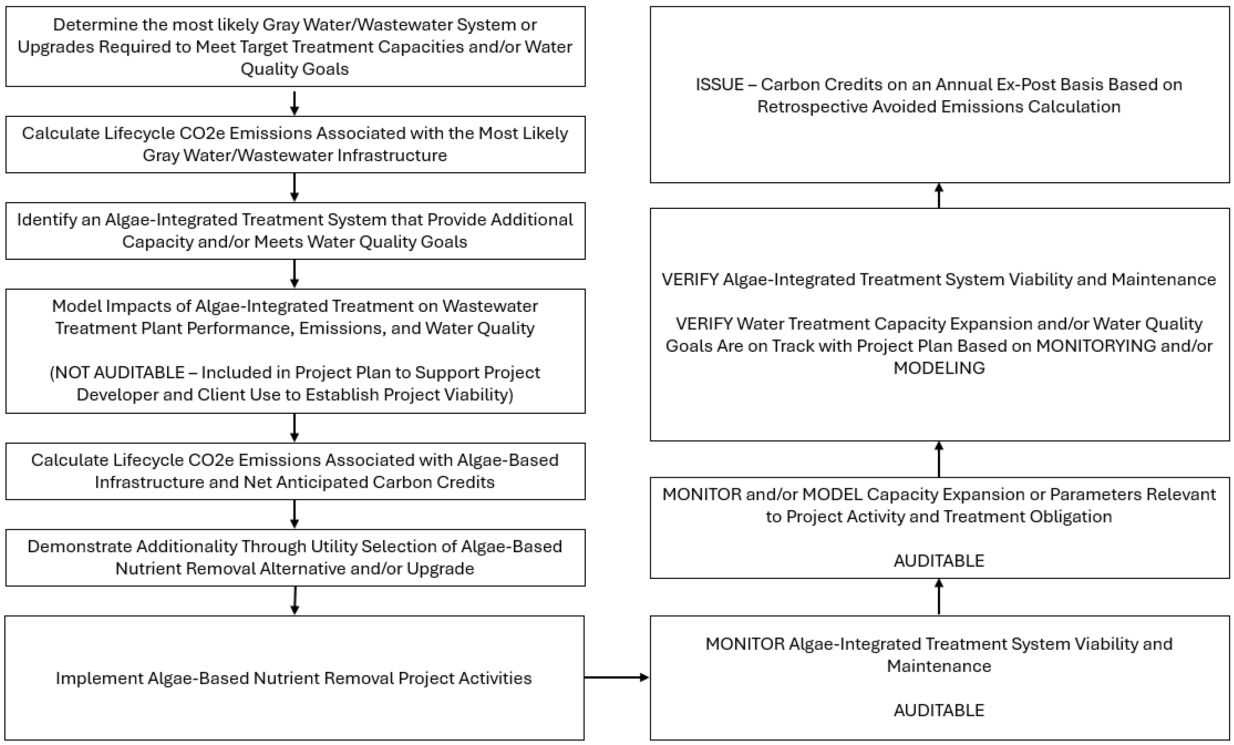

Figure 1: Methodology Overview

1.1 Scope

The methodology guides Project Proponents through the calculation of GHG emissions avoided by implementing algae-integrated nutrient removal systems in municipal or industrial wastewater treatment. It provides a framework for estimating avoided emissions, encompassing direct GHG emissions as well as emissions associated with energy consumption and material use avoided in the construction, upgrades, and operation of conventional nutrient removal infrastructure. The methodology covers avoided emissions from the deployment of algae-integrated treatment solutions in wastewater through:

1. System efficiency improvements (reduced energy and chemical use) or capacity expansion without the construction and operation of additional gray infrastructure

2. Enabling wastewater treatment facilities to hit discharge regulatory requirements without the construction of additional gray infrastructure
3. Reduction in direct GHG emissions (nitrous oxide (N2O) and methane (CH4)) from reduced N loading to conventional treatment processes and reduced biosolids generation and subsequent end-of-life emissions due to reduced organic loading to anaerobic digesters and landfills
4. Avoided GHGs from the production of algae-based products that replace traditional products

1.2. Normative References

The methodology refers to the latest approved versions of the following tools:

1. ISO 14040: ISO 14040:2006 outlines the principles and framework for conducting a life cycle assessment (LCA). It covers key elements such as defining the goal and scope of the LCA, performing the life cycle inventory analysis (LCI) phase, conducting the LCIA phase, and interpreting the results during the life cycle interpretation phase. Additionally, it addresses reporting and critical review processes, identifies the limitations of LCA, explains the interconnections between the LCA phases, and establishes conditions for the use of value choices and optional elements.
2. TRACI v2.1: The Tool for the Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) is an environmental impact assessment tool. It provides characterization factors for Life Cycle Impact Assessment (LCIA), industrial ecology, and sustainability metrics. Characterization factors quantify the potential impacts that inputs and releases have on specific impact categories in common equivalence units. Impact categories include ozone depletion, climate change, acidification, eutrophication, smog formation, human health impacts, and ecotoxicity. Resource uses of fossil fuels are also characterized.
3. NREL Cambium 2022 Mid-Scenario: Cambium data sets contain modeled hourly emission, cost, and operational data for a range of possible futures of the U.S. electricity sector through 2050, with metrics designed to be useful for forward-looking analysis and decision support.
3. CapdetWorks: CapdetWorks is a tool for fast and accurate preliminary design and cost estimation of wastewater treatment plant construction projects. Eliminate cumbersome and time-consuming spreadsheet-based design algorithms.
4. Benchmark Simulation Model No. 2 (BSM2): BSM2 is a comprehensive simulation tool designed for efficient and accurate modeling of wastewater treatment processes. It streamlines performance evaluation and optimization by replacing manual and spreadsheet-based calculations with a robust, user-friendly platform. BSM2 supports advanced analysis of treatment plant operations, facilitating better decision-making and system design.

5. EPA Water Quality Standards Handbook (2017)
6. EPA CWA Methods for laboratory analytical methods.

1.3 Definitions

For the purpose of this methodology, the following definitions apply:

1. Carbon Credits: A measured or estimated unit of pollutant reduction per unit of time at a specified location, as adjusted by discount factors, trading ratios, reserve requirements, and baseline requirements. For this methodology, the word 'credits' will be used to describe the units of avoided GHG emissions.
2. Exceedance: The difference between a regulated facility's actual discharge and its effluent limit.
3. Point Source: Any discernible, confined, and discrete conveyance that discharges pollutants, as defined in 33 U.S.C. § 1362. Point sources are subject to federal or state regulation under the CWA.
4. Clean Water Act (CWA): The primary federal law in the United States governing water pollution, codified at 33 U.S.C. §§ 1251–1387.
5. Additionality: In an environmental market, the benefit secured through the payment is deemed additional if it would not have been generated absent the payment provided by the market system. Please refer to the corresponding Credit Class document for this definition of additionality specific to this Methodology.
6. Life Cycle Inventory (LCI) data: Refers to the collection and quantification of inputs and outputs associated with a product, process, or system throughout its life cycle. This data includes the raw materials, energy consumption, emissions, waste, and other resource flows involved in all stages of a system's lifecycle, including construction, operation, and end-of-life disposal.
7. Life Cycle Assessment (LCA): Methodology used to evaluate the environmental impact of a process or product. The methodology can utilize standard published LCI data. This data quantifies the environmental impact of standard products or processes.
8. Gray Infrastructure: Traditional engineered structures and facilities such as concrete tanks, pumps, and chemical systems designed for water treatment processes. Gray infrastructure is typically associated with higher energy consumption and material use compared to nature-based solutions.
9. Baseline: Defined as the gray infrastructure system that would need to be built and or operated to achieve the required capacity and/or discharge requirements for the treatment facility.
10. Point-Source Discharge: A single, identifiable source of pollutants, such as a pipe or channel, that releases substances directly into a water body. Point sources are regulated under the Clean Water Act (CWA).

11. Bioavailability: The degree to which nutrients, such as nitrogen and phosphorus in algae-based fertilizers, are available for plant uptake and utilization. Bioavailability is an important factor in determining the efficacy of algae-derived fertilizers.

12. Secondary treatment: involves biological processes to remove dissolved organic matter and suspended solids remaining after primary treatment. Microorganisms (such as bacteria) are used to degrade organic pollutants in aerated environments (e.g., activated sludge, trickling filters). The goal is to reduce Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), and other contaminants.

13. Tertiary treatment: also known as advanced treatment, is an additional purification step after secondary treatment to remove remaining contaminants such as nutrients (nitrogen and phosphorus), heavy metals, or pathogens. Techniques include filtration, disinfection (e.g., UV light or chlorination), and chemical precipitation to meet specific water quality standards for reuse or discharge.

14. Side stream treatment: targets wastewater generated within the treatment process itself, such as effluent from sludge dewatering or digester supernatant. This concentrated stream is treated separately, often to remove high levels of ammonia, phosphorus, or other pollutants, before being returned to the main treatment flow. Common methods include struvite precipitation, anaerobic digestion, or biological nutrient removal.

2. Project Boundary

The project boundary for this methodology is defined as the physical and operational scope of the wastewater treatment facility where the algae-integrated nutrient removal system is implemented. This includes all processes and infrastructure directly involved in nutrient removal and associated GHG emissions.

Specifically, the project boundary encompasses:

- **Influent and Effluent Points:** The facility's input and output flows where nutrient concentrations are measured to determine the performance of the algae-integrated treatment system.
- **Treatment Processes:** All components of the nutrient removal system, including existing gray infrastructure, the algae-integrated treatment system itself, and any supporting infrastructure.
- **Energy and Material Inputs:** Any electricity or material consumption directly associated with the operation of the nutrient treatment system and related processes.
- **GHG Emission Sources:** Direct emissions (e.g., N_2O) from treatment processes and indirect emissions from energy and material use within the facility.

The project boundary includes upstream and downstream activities not directly controlled by the facility, such as the production of materials used in the system or the final disposal of effluent or biosolids which is explicitly required for LCA. This clear delineation ensures that all measurable GHG reductions occur within the defined operational scope of the wastewater treatment facility.

3. Calculating Net GHG Reduction

The net GHG reduction is calculated by comparing the emissions of the required gray infrastructure baseline to those of the algae-integrated treatment system using a rigorous and ethical LCA methodology. Emission calculations for both gray and algae-integrated systems must adhere to standard LCA practices, ensuring consistency in functional units and system boundaries. An LCA study comprises four key phases: (a) defining the goal and scope, (b) conducting an inventory analysis, (c) performing an impact assessment, and (d) interpreting the results. Before initiating the LCA, the architecture of the technologies being compared must be clearly defined to ensure accurate and meaningful analysis.

3.1 Gray Infrastructure New Build or Upgrade vs. Algae-Integrated Infrastructure Analysis

A thorough evaluation of gray and algae-integrated treatment options is essential for Project Proponents to assess the environmental impacts of both approaches and estimate net emissions reductions. The methodology allows for flexibility in baseline selection while ensuring that the chosen baseline represents a realistic and defensible business-as-usual scenario. The appropriate selection and validation of the baseline scenario must be supported by documentation of the following:

1. **Definition of Project Objectives:** Project Proponents must define the primary drivers for evaluating traditional treatment options and algae-integrated alternatives, which may include improving water quality, increasing capacity, achieving regulatory compliance, or enhancing cost efficiency. Project objectives must be quantified using clearly defined metrics, such as the targeted increase in flow capacity, nutrient discharge concentrations, or other relevant performance indicators.
2. **Conduct a Site Analysis:** A detailed assessment of the existing infrastructure must be conducted to determine the technical and operational constraints influencing baseline selection. This ensures that the baseline reflects a plausible and facility-specific alternative rather than a theoretical assumption. This includes:
    a. Evaluating current treatment capacity and nutrient removal performance.
    b. Identifying regulatory drivers that may necessitate new infrastructure investments.

    c. Reviewing facility master plans or feasibility studies that outline potential treatment upgrades.

3. **Baseline Scenario Validation:** Identify gray infrastructure and algae-integrated treatment technologies that can deliver comparable performance in meeting the project objectives. Both options must be capable of achieving similar water quality outcomes. Project Proponents must provide sufficient empirical evidence justifying the selection of the baseline scenario using at least one of the following approaches:
    a. **Documentation of Comparable Facilities:** Project Proponents may justify the baseline gray infrastructure solution by referencing recently constructed wastewater treatment facilities that address similar project objectives. When using this approach, Project Proponents must demonstrate that the comparable facilities are representative in terms of treatment objectives, scale, and regulatory requirements. To ensure relevance, preference should be given to facilities located in the same or similar geographic regions. Consideration of regional factors—such as climate, regulatory environment, and influent characteristics—helps ensure that the selected comparison is contextually appropriate. Relevant documentation may include:
        i. Construction specifications, including process flow diagrams and unit operations.
        ii. Operating parameters, such as influent/effluent characteristics and treatment efficiency.
        iii. Energy consumption and chemical usage records.
    b. **Independent Engineering Analysis:** If direct comparisons to existing facilities are unavailable or insufficient, an independent engineering analysis (often called a ‘Facility Plan’ or ‘Alternatives Analysis’ must confirm that the selected baseline:
        i. Reflects standard industry practice for the region and application.
        ii. Is appropriately scaled for the facility’s treatment requirements.
        iii. Uses technology choices consistent with those typically employed for similar wastewater treatment challenges.

       The engineering analysis should, where possible, leverage existing feasibility studies or facility master plans that the wastewater treatment plant has already conducted prior to considering algae-integrated treatment. This ensures that the baseline is aligned with actual infrastructure planning and decision-making processes for the project.
4. **Perform an LCA**: Analyze the GHG emissions associated with the construction, operation, and decommissioning of the selected baseline (gray infrastructure) and the algae-integrated alternative. Both LCAs must adhere to ISO 14040 standards to ensure accuracy and consistency.

3.1.1 Calculating the Environmental Impact of Water Treatment

To calculate the environmental impact of gray and algae-integrated treatment infrastructure systems, the following steps must be completed:

1. **Develop an Engineering Process Model**: Create a model that represents all relevant unit process operations and captures energy and material usage throughout the life cycle of the system, including construction, operation, and maintenance.
2. **Conduct GHG Emissions Accounting**: Calculate GHG emissions using appropriate emission factors for energy and material inputs, based on reliable and regionally specific LCI data. The LCA should consider the embodied emissions in the infrastructure that is or would be deployed.
3. **Compare Results**: Analyze and compare the LCA outcomes for both gray and algae-integrated treatment systems, quantifying the difference in terms of carbon dioxide equivalence (CO2e).

3.1.1.1 LCA Goal and Scope Definition

In the context of evaluating the environmental impact of gray infrastructure and algae-integrated infrastructure, the Goal and Scope Definition phase involves the following steps:

1. **Defining the Goal:** Clearly outline the purpose of the LCA. The primary goal is to evaluate and compare the environmental impacts of a gray infrastructure new build, upgrade, or increased operational burden against those of a comparable algae-integrated treatment system. This comparison aims to identify the most sustainable option for meeting the water quality requirements of the treatment facility. A critical component is ensuring that both technologies achieve the same capacity expansion and/or water quality discharge. If multiple water quality objectives are required, it is acceptable for one technology to overperform on one pollutant, provided it does not underperform on others.
2. **Establishing the Scope:** Define the scope of the study to ensure all relevant processes and impacts are included in the analysis. This involves identifying system boundaries that encompass the entire gray infrastructure system, the algae-integrated treatment system, and all associated energy and resource inputs and outputs. System boundaries must be consistent across both technologies and focus solely on direct impacts (e.g., direct emissions, operational energy use, and material consumption).
3. **Defining the Functional Unit:** Establish the functional unit as a quantifiable measure of system performance. For this study, the functional unit is defined as a volume of water treated to the target objectives. This provides a standardized metric to compare the performance of the two systems.

4. **Identifying Impact Categories:** Determine the impact categories to be analyzed. Global warming potential as measured by GHG emissions is expected to be the impact of focus. The accounting process must include all GHGs, with results presented in terms of CO2e with the appropriate equivalence factors used.
5. **Specifying Data Requirements:** Define the data requirements to ensure the analysis is based on accurate and relevant information. This includes data on energy and resource inputs and outputs, emissions, and waste for both gray and algae-integrated treatment systems. It is critical to account for the evolution of emissions over time, particularly for electricity or other materials which are expected to change significantly in the future.
6. **Establishing Assumptions:** Document all assumptions made during the LCA to ensure transparency and verifiability. Assumptions may include the expected life cycle of gray infrastructure upgrades, maintenance requirements of algae-integrated treatment systems, and anticipated energy and resource savings. All assumptions should be validated and subject to sensitivity analysis to confirm they do not significantly skew the results.

By following these steps, the Goal and Scope Definition phase ensures the life cycle analysis is comprehensive, transparent, and scientifically rigorous, establishing a strong foundation for subsequent phases of the study.

3.1.1.2 Functional Unit and System Boundaries

The functional unit is defined as 1 cubic meter (m3) of treated water. System boundaries must include all relevant processes, such as construction, operation, and end-of-life disposal, ensuring consistent comparisons between gray and algae-integrated treatment infrastructure.

3.1.1.3 Phase 1: Life Cycle Inventory (LCI)

The LCI phase involves collecting data on system inputs (e.g., materials, energy) and outputs (e.g., emissions). Key steps include:

- Developing process flow diagrams
- Collecting emissions data from reliable databases such as eGRID or Ecoinvent
- Ensuring transparency and reproducibility in reporting
- Accounting for important regional variations in LCI data where relevant

3.1.1.4 Phase 2: Life Cycle Assessment (LCA)

Combine LCI data to assess GHG emissions, including all greenhouse gasses as CO2e using the latest equivalence factors from the Intergovernmental Panel on Climate Chante (IPCC).

3.1.1.5 Phase 3: Interpretation

Critically evaluate results, perform sensitivity analyses, and ensure consistency with existing literature or technical reports.

3.1.1.6 Grid Energy Mix GHG Updates

Include current grid projections, such as NREL Cambium data, and update models every five years to reflect grid evolution in terms of decarbonization.

3.1.1.7 Uncertainty Quantification

Calculate credits as the difference in emissions between gray and algae-integrated treatment systems.

Recognizing that all environmental impact assessments contain inherent uncertainty, this methodology incorporates uncertainty quantification and reporting to ensure transparency, accuracy, and compliance with the Regen Registry's Program Guide (Section 5.4.1: Accuracy). Project Proponents are required to estimate and disclose uncertainty metrics in monitoring reports, particularly for key calculations that determine credit issuance, such as GHG emissions quantification and LCA results.

1. **Sources of Uncertainty:** Uncertainty in emissions reductions and credit generation can arise from various sources, including:
    a. Measurement variability – Fluctuations in sensor readings for direct emissions monitoring (e.g., N2O, NH3).
    b. Data quality and representativeness – Limitations in the completeness and accuracy of facility-specific or literature-based LCI data.
    c. Modeling assumptions – Uncertainty introduced by assumptions in life cycle assessments, particularly for baseline comparisons.
    d. Emission factors and conversion efficiencies – Variability in published regional and global emission factors (e.g., IPCC guidelines, NREL Cambium grid emission data).
    e. Operational performance variability – Seasonal changes, maintenance cycles, or degradation of system efficiency over time.
2. **Uncertainty Quantification Methods:** Project Proponents must apply standardized methods for uncertainty estimation, aligning with best practices in

LCA (ISO 14044), carbon credit issuance (IPCC 2006 Guidelines), and emissions modeling (EPA's Uncertainty Analysis Framework). Depending on project context and data availability, one or more of the following approaches may be used, with justification provided for the selected method(s):

   a. Statistical Uncertainty Analysis: Where possible, quantitative uncertainty assessments must be conducted using:
   b. Monte Carlo analysis – Stochastic simulations that provide a probability distribution of outcomes by running thousands of iterations with variable inputs.
   c. Sensitivity analysis – Evaluation of how variations in key parameters (e.g., nutrient removal efficiency, system degradation rates) influence GHG reduction estimates.
   d. 95% confidence intervals (CI) – Reporting of uncertainty ranges for emission reduction estimates to provide stakeholders with a confidence level in reported outcomes.

3. **Uncertainty Reporting Requirements:** To ensure compliance with Regen Registry's accuracy and transparency guidelines, Project Proponents must include uncertainty metrics in their Monitoring Reports, covering:
   a. Estimated uncertainty range (%) for total avoided emissions and carbon credit issuance.
   b. Description of uncertainty sources, specifying which parameters contribute most to overall uncertainty.
   c. Justification for uncertainty treatment, including the methodology used for quantification (e.g., statistical analysis, expert judgment, data variability).
   d. Confidence level and error margins, where applicable, to contextualize the reliability of reported GHG reductions.
   e. Additionally, where uncertainty exceeds a predefined threshold (e.g., 20% relative uncertainty in emission reductions), the Project Proponent must manage uncertainty using buffer pools (see section 3.1.1.8).
4. **Continuous Improvement and Periodic Review:** As monitoring and verification progress, uncertainty estimates should be updated over time to reflect improved data availability, measurement accuracy, and methodological advancements. Project Proponents are encouraged to:
   a. Recalibrate uncertainty estimates based on operational performance and real-world emissions data.
   b. Incorporate new scientific findings or updated emission factors as they become available.
   c. Refine credit calculations as more precise data and improved monitoring techniques emerge.

By incorporating uncertainty quantification, transparent reporting, and conservative credit adjustments, this methodology ensures that GHG reductions and carbon credit issuance remain scientifically robust, verifiable, and aligned with best practices in emissions accounting and sustainability assessments.

3.1.1.8 Conservative Approaches to Reporting

Best practices in LCA reporting require clear documentation of functional units, system boundaries, process flow, foundational models, and performance assumptions. The reported results must enable reproducibility and provide a robust basis for GHG reduction claims that can be verified through Monitoring, Verification and Reporting.

To ensure the integrity and credibility of carbon credit issuance, this methodology requires conservative crediting approaches that minimize the risk of overestimating emissions reductions. Project Proponents must apply conservative assumptions and adjustments in baseline emissions estimates and credit calculations, particularly in cases where uncertainty is significant. The following requirements must be met:

To ensure the integrity and credibility of carbon credit issuance, this methodology employs balanced and scientifically grounded crediting approaches that reduce the risk of overestimating emissions reductions while ensuring that achievable reductions are fairly accounted for. Project Proponents must apply reasonable assumptions and adjustments in baseline emissions estimates and credit calculations, particularly in cases where uncertainty is significant. The following requirements must be met:

1. **Robust Baseline Emissions Estimates:** Baseline emissions must be estimated using data-driven assumptions that reflect the best-supported scenario for potential GHG reductions.
    - If multiple valid emission factors or performance assumptions exist, values should be selected based on scientific consensus and representativeness rather than defaulting to the most conservative estimate.
    - When facility-specific data is unavailable, default values must be drawn from recognized sources (e.g., IPCC, EPA, or peer-reviewed studies) and reflect the average or central tendency of reported emissions benchmarks.
    - If uncertainty in baseline estimates exceeds a predefined threshold (e.g., 20% relative uncertainty), Project Proponents must provide justification for selected assumptions and may be required to apply uncertainty adjustments rather than default conservatism factors.
2. **Buffer Pools Based on Uncertainty Levels:** A portion of issued credits must be set aside in a buffer pool when uncertainty in emissions reductions exceeds an acceptable threshold.
    - The buffer pool percentage must be proportional to the level of uncertainty in emissions estimates. For example:

i. 5-10% buffer pool for low uncertainty (≤10% variation in emissions estimates).
ii. 10-20% buffer pool for moderate uncertainty (10-20% variation).
iii. 20%+ buffer pool for high uncertainty (>20% variation).

- Buffer pool allocations should be periodically reassessed and adjusted as more accurate operational and monitoring data becomes available.
- In cases where system performance declines significantly over time, buffer credits may be used to compensate for underperformance before adjusting future credit issuance.

By incorporating conservative baseline assumptions and uncertainty-adjusted buffer pools, this methodology ensures credit issuance is robust, credible, and aligned with best practices in carbon markets.

3.2 Temporal Resolution

The time horizon of the analysis for this methodology is set at a minimum of 20 years, consistent with standard practices in sustainability assessments and the operational lifespan of conventional gray infrastructure. Embodied emissions associated with system infrastructure will be amortized over the assumed 20-year life of the facility. Recognizing that algae-integrated nutrient removal systems may provide benefits beyond this period, there is an option to extend credits after the initial evaluation period. If the projected lifespan of the facility upgrade exceeds 20 years, the crediting period may be extended accordingly to reflect the continued environmental and operational value of the system and no longer require the inclusion of embodied emissions.

To ensure the long-term reliability and effectiveness of algae-integrated treatment systems over extended project durations, additional guidance is provided for system durability, performance tracking, and credit period flexibility.

1. **System Durability Documentation:** To account for potential degradation of treatment efficiency over time, Project Proponents must provide documentation on system durability and maintenance expectations, including:
   a. Manufacturer specifications for critical components, such as reactor materials, aeration systems, and harvesting mechanisms.
   b. Performance data from existing installations, where available, to demonstrate long-term operational stability.
   c. Expected maintenance and replacement schedules for key system components, ensuring that system performance remains consistent throughout the crediting period.
2. **Performance Tracking Requirements:** Given the long-term nature of these projects, ongoing performance monitoring is required to verify that algae-

integrated systems continue to meet expected treatment efficiency and emissions reductions. Project Proponents must:

   a. Implement regular efficiency testing protocols, including annual verification of demonstrated system performance relative to the defined project objective(s).
   b. Define thresholds for credit adjustments, ensuring emissions reduction calculations are recalibrated if system performance declines beyond acceptable limits.
   c. Implement degradation monitoring and reporting, systematically tracking changes in system performance over time and evaluating any observed declines against predefined performance thresholds.

3. **Credit Period Flexibility:** To ensure that credit issuance reflects actual system performance, the methodology allows for credit period extensions and adjustments based on continued verification of system reliability. This includes:
   a. Clear criteria for extending crediting periods beyond 20 years if performance data supports sustained emissions reductions.
   b. Requirements for continued monitoring, including updated assessments of system efficiency and operational sustainability.
   c. Adjustment factors for aging systems, based on performance data or incorporating reasonable performance degradation assumptions when necessary.

By integrating these documentation, tracking, and adjustment mechanisms, this methodology ensures that long-term emissions reductions remain credible, verifiable, and aligned with real-world system performance.

4.0 Algae-Integrated Treatment Project Activity Design

Algae-integrated nutrient removal projects can vary significantly in concept and design depending on geographic, regulatory, and operational contexts. Example project types are outlined in the corresponding Credit Class for this Methodology. In some regions, established methods and legal requirements may dictate aspects of the project design, while in others, custom or novel approaches may be necessary to meet local needs.

This Methodology calculates GHG emissions reductions based on the avoided construction and/or operation of conventional gray infrastructure and reduced reliance on grid electricity and chemicals used in status-quo nutrient removal processes. By substituting these high-emission and chemically-intensive processes with algae-integrated treatment, Project Proponents can achieve water quality goals while minimizing GHG impacts.

Project Proponents are required to apply the life cycle analysis outlined in the previous section to account for and subtract GHG emissions associated with the algae-integrated treatment system itself.

The design and evaluation of the two proposed solutions—1) gray infrastructure new build or retrofit expansion, and 2) algae-integrated treatment solutions—will initially rely on wastewater treatment models. The models may be used to simulate the system's effectiveness under various configurations, including its placement within the treatment sequence, such as secondary, tertiary, or side stream treatment. Models must be widely accepted within the scientific community and appropriate for the specific geographic and environmental context.

A sensitivity analysis should be conducted to identify key inputs and assumptions driving the model results, with assumptions associated with high-impact variables rigorously examined to ensure accuracy and certainty. This will support reducing uncertainties and guiding necessary adjustments to the project design or monitoring plan. Project Proponents must conservatively compare the modeled impacts of the algae-integrated treatment system to baseline conditions, ensuring that the project maintains or improves water quality outcomes.

Clear documentation of modeling methods, assumptions, results, and any associated limitations or uncertainties is required to ensure transparency and credibility. This documentation will form the basis for verifying project outcomes and issuing carbon credits. While the guidance in this section is not auditable by third-party verifiers, it serves as a critical reference for ensuring robust project activity design and implementation.

5.0 Implementing the Algae-integrated Treatment Removal System

The Project Proponent, in collaboration with key stakeholders such as wastewater treatment facility staff and regulatory agency representatives, must establish site selection priorities and secure necessary approvals from facility operators and relevant authorities. Proper planning and consensus are essential to ensure successful implementation.

Site preparation involves preparing the facility for the installation of the algae-integrated treatment system. Depending on the configuration, this may include retrofitting existing infrastructure, installing supporting equipment, or adjusting site conditions to optimize system performance.

Once site preparation is complete, the algae-integrated treatment system should be installed according to detailed design plans. The installation process must comply with all relevant regulations, permits, and Best Management Practices (BMPs) to ensure the system's functionality and environmental performance.

6.0 Monitoring, Reporting, and Verification (MRV)

This section outlines the procedures and protocols for monitoring, reporting, and verifying the impacts of algae-integrated nutrient removal systems on GHG emissions, nutrient management, and other environmental benefits. These activities are consistent with the Credit Verification and Release Schedule described in the associated Credit Class document for this methodology.

The MRV framework includes key metrics critical to the evaluation of system performance and GHG reduction impacts. These metrics must be monitored, reported, and verified using standardized and widely accepted protocols.

6.1 Key Metrics and Monitoring Requirements

1. **N2O Emissions Monitoring:** Real-time N2O emissions monitoring is essential to quantify the reduction in direct GHG emissions from subsequent treatment steps due to nutrient removal by algae-integrated systems. For real-time N2O emissions measurement, sensors should be deployed and calibrated following established protocols. Adhering to these protocols ensures accurate and reliable N2O emissions data. Data generated from sensors should also be used to validate modeled predictions of N2O emissions from algae-integrated systems.
    a. **Protocols:** The USDA Agricultural Research Service (ARS) provides comprehensive guidelines on chamber-based trace gas flux measurements, which include N2O. Additionally, the "Nitrous Oxide Chamber Methodology Guidelines" offer standardized procedures for N2O measurement and calibration.
    b. When real-time monitoring of the other parts of the treatment train are not available, industry standards for N2O emissions can be used (IPCC).
2. **NH3 Emissions Monitoring:** Ammonia (NH3) sensors should be used to measure emissions from the algae-integrated system and any changes in NH3 emissions in subsequent treatment steps within the wastewater treatment plant. NH3 can act as a precursor to N2O formation through nitrification and denitrification pathways, emphasizing the importance of accurate monitoring.
    a. **Mechanism**: NH3 is converted to N2O during the microbial processes of nitrification (oxidation to nitrite and nitrate) and denitrification (reduction to N2O and N2) in aerobic and anaerobic environments.
    b. **Monitoring Protocols**: Established NH3 monitoring protocols, such as those from the Standard Methods for the Examination of Water and Wastewater, should be followed.
3. **Electricity Use Monitoring:** Electricity consumption should be monitored at the plant or equipment level to verify reductions achieved by replacing energy-intensive processes with algae-integrated systems. Submeters can be installed for

specific equipment, or overall plant electricity use can be tracked. Data should align with regulatory energy monitoring standards.

4. **Material Consumption Monitoring:** Reductions in chemical usage (e.g., for nutrient removal or pH control) should be quantified through facility bookkeeping records or similar monitoring tools. Records should detail changes in chemical procurement and use to verify environmental benefits.
5. **Biosolids Production and Disposal:** Biosolids haul away data should be collected to verify any reductions in biosolids production due to decreased organic loading from algae-integrated nutrient removal systems. Facility data on biosolids generation, transport, and disposal must be documented.
6. **Biofertilizer Composition:** If the algae biomass is converted into biofertilizer, the bioavailability of N and P in the algae-based fertilizer must be verified using established laboratory protocols.
    a. **Protocols**: Examples include AOAC International methods for fertilizer analysis and testing. These methods ensure reliable data on nutrient availability in the final product.
7. **Water Quality Monitoring:** Effluent nutrient concentrations, particularly N (e.g., nitrate, ammonium) and P, should be monitored using standard wastewater protocols.
    a. **Protocols**: Widely accepted methods include the US EPA's Water Quality Criteria and the Standard Methods for the Examination of Water and Wastewater.

6.2 Setting Baselines and Targets

The Project Proponent must establish baseline metrics for all monitored parameters before the implementation of the algae-integrated system. Baseline values should reflect average conditions over a suitable period to account for seasonal and operational variability. Targets for improvements should align with local water quality regulations and project objectives, as described in the Project Plan.

6.3 Monitoring Locations and Frequency

Monitoring must be conducted at key locations, including:

- **Influent and Effluent Points**: To measure nutrient reductions and GHG impacts directly attributed to the algae-integrated treatment system.
- **Subsequent Treatment Steps**: To evaluate changes in emissions and energy use downstream of the algae-integrated treatment system.

Data collection frequency should adhere to regulatory requirements but must occur at least monthly for critical metrics like N2O, NH3, and nutrient concentrations.

6.4 Data Accuracy and Reporting

To ensure the credibility of credits generated:

- **Calibration**: Monitoring equipment must be regularly calibrated according to manufacturer specifications and industry standards.
- **Quality Control**: Data quality must be ensured through validation techniques, such as duplicate sampling and cross-comparisons with laboratory analyses.
- **Annual Reporting**: All monitoring data and analyses must be summarized in an annual report, including documentation of methodologies, raw data, and modeled results.

6.5 Supporting Technology Required

Monitoring the performance of algae-integrated nutrient removal systems requires a combination of advanced technologies and traditional methods to ensure reliable and accurate data collection. In-situ sensors play a critical role in providing real-time measurements of key parameters such as N2O and NH3 emissions, as well as nutrient concentrations in influent and effluent streams. These sensors allow for continuous monitoring and verification of GHG reductions and nutrient removal efficiencies. Laboratory analysis complements sensor data by validating results and providing detailed assessments, such as the bioavailability of N and P in algae-based fertilizers, using established protocols.

Electricity metering, either at the equipment or plant level, is essential for tracking reductions in energy consumption achieved by the algae-integrated system. Submetering specific to the system can isolate its impact compared to conventional processes. Mechanistic and statistical models may also be employed to simulate the system's performance under different operational conditions, providing additional insights and supporting scenario analysis.

Regular calibration and maintenance of all monitoring equipment are critical to ensuring accuracy and reliability. Sensors and meters must be calibrated according to manufacturer specifications, and quality control procedures should be in place to address data inconsistencies. By integrating these technologies, the methodology ensures robust data collection and verification, supporting the credibility of carbon credits generated under the protocol.