APPLICATION FOR COMPONENT ADDITION TO NRCS

NRCS Practice Standard 629

For Acceptance of Nitrogen Fixation Technology by Plasma Injection

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Nitrogen Fixation Technology by Plasma Injection

REQUEST

As environmental, regulatory, and legal pressures surrounding nutrient management on dairy farms continue to grow, an increasing number of technologies are being introduced as potential solutions. However, dairy producers often navigate these options with information primarily provided by technology vendors, making it challenging to assess their effectiveness objectively. To address the needs identified by both the USDA's Natural Resources Conservation Service (NRCS) and dairy farmers, Washington State University, in partnership with Newtrient, developed a standardized evaluation protocol. This framework, adapted from the criteria outlined in Appendix A of the NRCS Conservation Practice Standard (CPS) Waste Treatment (629), is designed to provide impartial, data-driven assessments of nutrient removal technologies. By offering a structured approach, this protocol supports dairy farmers in making informed decisions when considering technology adoption on their operations.

Newtrient has evaluated Nitrogen Fixation Technology by Plasma Injection using the CPS 629 framework and is submitting this preliminary report to raise awareness about this emerging technology. This report introduces the technology and highlights its potential for future inclusion under NRCS Conservation Practice Standard 629 (Waste Treatment). While the technology, developed by a Norwegian company, is still under development and not yet ready for U.S. deployment, we believe it could be a strong candidate for inclusion once commercial units are available domestically.

Though successfully trialed in Europe, its application on U.S. dairy farms is still under evaluation. As commercial deployment progresses in the U.S., further assessments will be necessary to validate its effectiveness in domestic agricultural settings. By presenting this technology to NRCS now, Newtrient aims to provide early insight into its potential, particularly for smaller dairies. As the technology advances toward commercialization, we look forward to continued collaboration to evaluate its suitability for NRCS conservation programs.

BRIEF DESCRIPTION OF COMPONENT CLASS

Nitrogen Fixation Technology by Plasma Injection is designed to enhance manure management by converting livestock waste into a more stable, nitrogen enriched organic liquid fertilizer. This technology applies plasma to manure, increasing its nitrogen content while reducing emissions of methane (CH_4), ammonia (NH_3), and nitrous oxide (N_2O) during storage and application. By stabilizing nitrogen in the manure, this process minimizes nutrient losses, improves fertilizer efficiency, and may reduce both reliance on and costs associated with synthetic fertilizers. As an emerging solution in nutrient management, this technology presents a promising opportunity for improving air and water quality while optimizing the value of manure as an agricultural resource.

DETAILED DESCRIPTION

Nitrogen Fixation Technology by Plasma Injection is an advanced manure treatment system designed to enhance nitrogen retention while reducing emissions of key environmental pollutants. The system operates within a compact, containerized unit, utilizing ambient air compression and a high-voltage plasma torch to convert atmospheric nitrogen (N_2) and oxygen (O_2) into reactive nitrogen oxides (NOx). These compounds are then absorbed into separated liquid manure through a venturi and recirculation process, where they react with the waste until a targeted pH level—typically around 5.0—is achieved. This controlled acidification process results in the formation of nitrogen enriched organic liquid fertilizer.

By lowering the pH, the technology inhibits microbial methane generation while promoting ammonium (NH_4^+) stability, significantly reducing ammonia volatilization. This dual effect helps mitigate environmental concerns related to air and water quality while improving nutrient retention in manure. Additionally, by preserving nitrogen in a more stable and plant-available form, the technology enhances manure's fertilizer value and supports more efficient nutrient utilization, potentially decreasing reliance on and costs associated with synthetic alternatives.

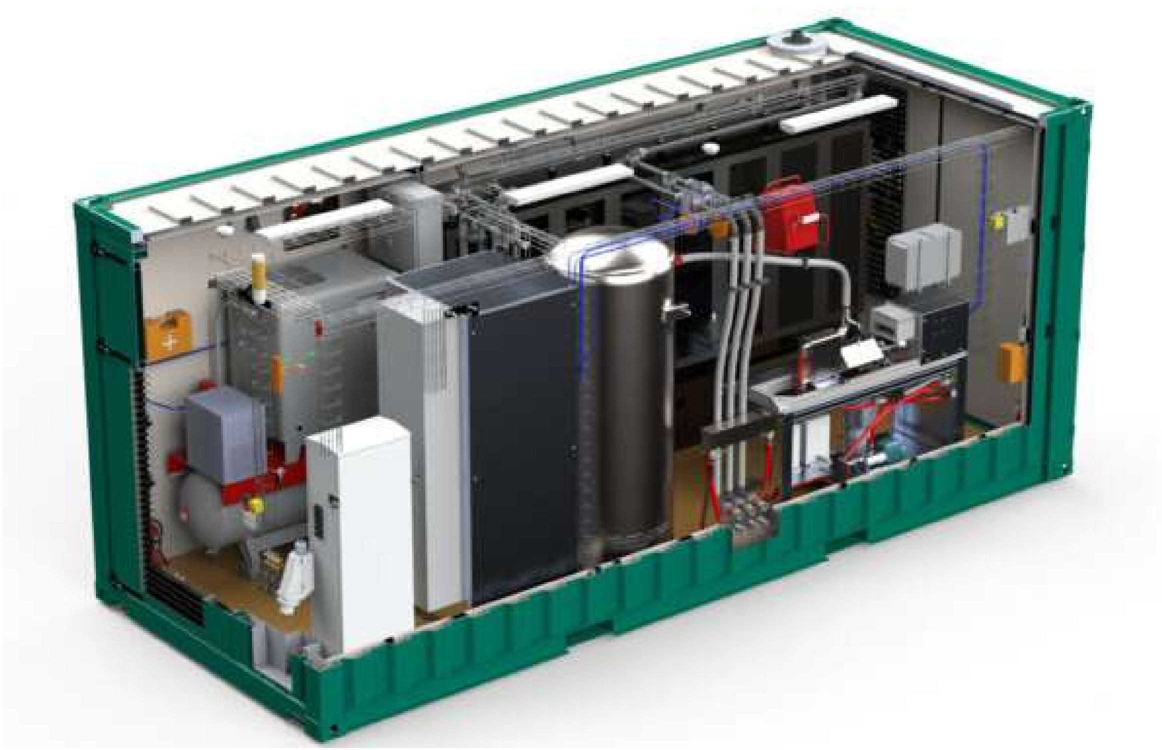


Figure 1: N2 - Applied System diagram. *Source: https://n2applied.com/the-technology/*

THE PROCESS

The N2 Applied technology operates in two primary phases: plasma generation and absorption.

Phase 1: Plasma Generation – In this initial step, electricity is utilized to dissociate N_2 and O_2 molecules found in the atmosphere. This process results in the formation of reactive nitrogen gas from the atomic nitrogen (N) and oxygen (O) recombining to form NOx.

Phase 2: Absorption – The reactive nitrogen gas, NOx, is then absorbed into the liquid component of organic materials, such as livestock slurry or biogas digestate, forming an acidic solution. This interaction converts the nitrogen into a form that is readily available for plant uptake. This NOx is mixed with the manure effluent until the desired acidic (pH) set point is reached.

The introduction of reactive nitrogen enhances the organic material by enriching it with nitrogen that plants can readily use, while also stabilizing ammonium nitrogen to minimize losses. Furthermore, by suppressing microbial activity, the plasma treatment effectively prevents the generation of methane — a potent greenhouse gas (GHG). This ensures that both organic carbon and nitrogen remain intact during storage, allowing them to be utilized in the field, where they contribute to building long-term soil health and fertility. (N2 Applied, 2024).

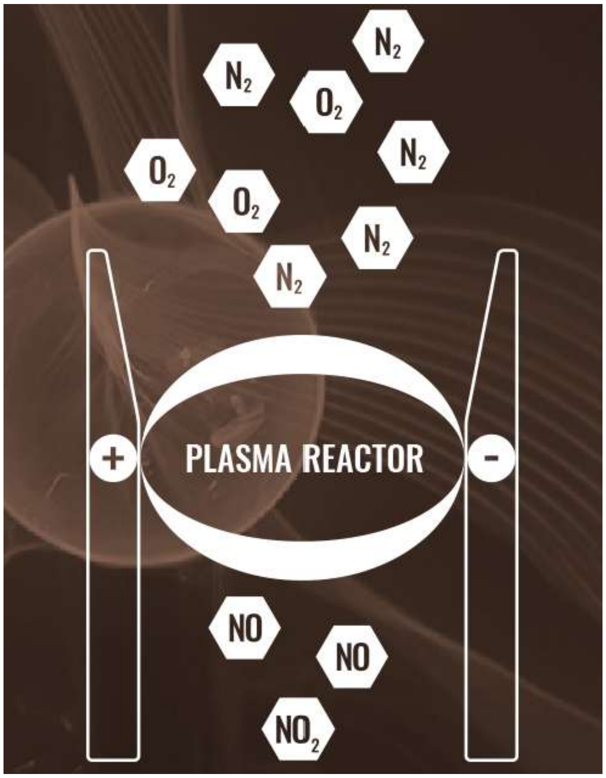


Figure 2: N2 - Applied Plasma Technology. *Source: https://n2applied.com/the-technology/*

HOW PROPOSED SYSTEM ACCOMPLISHES PURPOSES OF THE STANDARD

The proposed Nitrogen Fixation Technology by Plasma Injection (N2 Applied) aligns with NRCS Waste Treatment (Code 629) by enhancing nutrient retention in manure while addressing key environmental concerns. This technology uses high-voltage plasma to convert atmospheric nitrogen and oxygen into reactive nitrogen oxides, which are absorbed into separated liquid manure, lowering its pH. This process inhibits methane generation and promotes ammonium stability over ammonia, significantly reducing harmful emissions. By improving nitrogen retention and reducing volatilization, this technology enhances the manure's value as a nitrogen-rich organic fertilizer, reducing the need to purchase synthetic fertilizer alternatives to offset nutrient losses. Additionally, it mitigates air and water quality concerns associated with traditional manure storage and land application practices, supporting more sustainable nutrient management on dairies. This makes the technology a promising candidate for inclusion under NRCS Practice Standard 629 as it moves toward commercial availability in the U.S.

Newtrient (https://www.newtrient.com/), a company sponsored by the dairy industry and committed to enhancing value and sustainability in manure management, has conducted a thorough assessment of technology systems and practices within the field, focusing on their impact on critical environmental metrics, specifically water quality. The information in this report is based on a Cornell University evaluation of the demonstration unit at CoBar Dairy in Mount Upton, New York, where two vertical cylindrical poly tanks (1,100 gallons each) were filled with approximately 800 gallons each of the nitrogen enriched organic liquid fertilizer and untreated separated manure liquids to simulate long-term manure storage and two horizontal steel flowthrough tanks (11,000 gallons each) received nitrogen enriched organic liquid fertilizer and slurry at comparable production rates. Airflow across the surface of these tanks was maintained to align with industry recommendations (VERA, 2018). Manure sampling was conducted three times a week. There is currently no other U.S.-based research available to address the topics discussed in this report.

In support of this discussion, Appendix A offers a brief discussion on the significant impact of nitrogen fixation technology by plasma injection on key environmental indicators related to water quality, air emissions, and other relevant factors aligned with the objectives of Standard 629. Also, Appendix B presents data from the demonstration unit installation, offering visual representations and nutrient profiles that demonstrate the positive influence of integrating a Nitrogen Fixation Technology by Plasma Injection system within a comprehensive manure management approach. Additionally, Appendix C contains the final report of the study conducted by Cornell University, providing further insights into the effectiveness and benefits of Nitrogen Fixation Technology by Plasma Injection.

<u>Reducing nutrient content, organic strength</u>

The N2 Applied technology increases nitrogen retention in manure, particularly in the form of nitrate, which rose significantly in treated manure. The pH of the manure was reduced from 6.70 to 5.26, promoting ammonium stability and reducing methane generation. However, there was minimal change in organic strength, as moisture and solids content remained largely unchanged. While nitrate levels were sustained for much of the study, some nitrogen loss occurred during certain periods, likely due to microbial denitrification.

<u>Reducing odor and gaseous emissions</u>

The nitrogen fixation technology by plasma injection significantly reduced NH_3 emissions in comparison to the untreated slurry. Emissions from the static slurry tank ranged from 0 to 430 ppm with an average of 67 ppm, whereas emissions from the static nitrogen enriched organic liquid tank were consistently lower, averaging less than 10 ppm throughout the trial. During the initial N2 Applied unit run, NH_3 emissions were detected from both nitrogen enriched organic liquid and slurry tanks, but in the second run, NH_3 emissions were only measured initially in the nitrogen enriched organic liquid, and later, no emissions were detected, while slurry emissions were typically detected throughout the study. This suggests that the N2 Applied technology may be effective in reducing ammonia volatilization, particularly when compared to untreated slurry. NOx emissions, primarily from the nitrogen enriched organic liquid tanks, ranged from 2 to 20 ppm in static tanks and exceeded 100 ppm in flowthrough tanks with a lower pH setpoint. Notably, NOx emissions were not detected in the slurry tanks, further indicating the potential of N2 Applied technology to reduce gaseous emissions. However, both the N2 Applied unit and nitrogen enriched organic liquid storage are potential sources of NOx emissions, requiring careful monitoring. GHG emissions, including carbon dioxide (CO_2) and CH_4, were also measured, with CO_2 emissions from slurry tanks typically twice as high as those from nitrogen enriched organic liquid tanks. Similarly, CH_4 emissions were significantly lower from the nitrogen enriched organic liquid compared to slurry, demonstrating the N2 Applied technology's potential for mitigating GHG emissions.

Facilitating desirable waste handling and storage

The N2 Applied process plays a key role in facilitating desirable waste handling and storage by transforming certain manure slurry constituents. While the solid-liquid separation process, conducted prior to N2 Applied, removes approximately 12.5% of the raw manure mass as separated solids, the N2 Applied treatment primarily impacts the nitrogen content and pH of the slurry. The process elevates nitrogen levels, particularly nitrate, and reduces the pH of the slurry from 6.70 to around 5.26 (or another desired setpoint pH). These changes improve the handling and storage of the manure by potentially reducing odors and improving the stability of the waste, even though the treatment does not significantly alter the moisture or solids content of the slurry itself.

Producing value added byproducts that facilitate manure and waste utilization

A key enhancement from the N2 Applied treatment is the substantial increase in nitrogen content, particularly in the form of nitrate. This transformation is especially valuable for agricultural purposes, as the higher nitrate levels make the treated manure slurry a more effective fertilizer and nutrient source for crops through enhanced plant availability. The process also leads to a dramatic reduction in the slurry's pH, which not only improves the stability and safety of the manure but also reduces the likelihood of foul odors, making it more acceptable for storage and application. The increased nitrate concentrations and lowered pH contribute to better handling characteristics, creating a more user-friendly byproduct that is easier to manage and apply to fields. Moreover, the solid-liquid separation process preceding the N2 Applied treatment ensures that the manure is effectively divided into two components: solids and liquids. The separated solids, which contain a higher concentration of organic material, can be repurposed for composting, soil enhancement, bedding, or as a valuable biomass feedstock, while the liquid component, enriched with elevated nitrate levels, serves as a nutrient-rich liquid fertilizer.

RANGE OF VOLUMETRIC AND MASS FLOW CAPACITIES AS WELL AS HYDRAULIC RETENTION TIME

The following section provides an overview of key parameters related to the performance of the N2 Applied system in manure management:

- *Volumetric Flow*: The N2 Applied unit demonstrated a volumetric flow rate that ranged between 25-55 gallons of nitrogen enriched organic liquid per hour. Throughout the study period, production fluctuated, with an average daily volume ranging from 534 gallons/day (roughly equivalent to 30 lactating cows' worth of manure per day) to a peak of 1,055 gallons/day during the initial phase of treatment. Exact rates of production were challenging to determine as they often varied day by day and over the study period.

- *Mass Flow*: During operation, the N2 Applied unit produced approximately 25 to 55 gallons of nitrogen enriched organic liquid per hour. Using a standard slurry density of 8.4 pounds per gallon, this equates to a mass flow rate ranging from 210 to 462 pounds per hour. Production rates varied throughout the study period due to factors such as pH setpoints, manure consistency, and system adjustments.

- *Hydraulic Retention Times (HRT):* The hydraulic retention time (HRT) during the treatment process varied based on the changes in operational settings, including the pH setpoint adjustments. With reduced pH setpoints in later stages of the study, the HRT was likely impacted, contributing to the decrease in daily production rates, further highlighting the complexity of optimizing the N2 Applied process.

DESIRED FEEDSTOCK CHARACTERISTICS

For optimal performance of the N2 Applied process, the feedstock, primarily raw manure slurry, should have manageable solids and moisture content. The solid-liquid separation process plays a crucial role, with approximately 12.5% of the raw manure mass removed as solids and the remaining 87.5% as liquids. The separated manure liquids typically had an average solids content of 5.69±0.58%, which is ideal for the N2 Applied system, as it ensures sufficient nitrogen transformation and effective treatment. Maintaining the appropriate solids content, moisture level, and pH balance—ideally around 5.0—supports efficient nitrogen conversion and nitrogen enriched organic liquid production. Buffering capacity is also important to ensure stable pH levels during treatment, preventing disruptions to the process and optimizing byproduct quality.

EXPECTED SYSTEM PERFORMANCE

The N2 Applied system is designed to enhance manure management by efficiently transforming dairy manure into a more usable form. The system's performance can be evaluated based on its ability to alter the physical form and handling characteristics of dairy manure, influence nutrient fate and availability for agricultural use, contribute to pathogen reduction, and mitigate impacts on air and water quality.

- *Changes in form or handling characteristics*
    - The N2 Applied process significantly alters the form and handling characteristics of dairy manure, enhancing its manageability. By reducing the pH of the manure slurry, the system helps to stabilize the material, making it less prone to odors and easier to handle during storage and application. Additionally, the solid-liquid separation process removes a portion of the solids from the raw manure, leaving behind a more liquid-based product that is easier to pump and transport. These changes make the manure more adaptable for various agricultural applications, improving its efficiency as a nutrient source while minimizing environmental impact.
- *Nutrient fate or end use projections*
    - The N2 Applied process significantly alters the nutrient composition of manure, particularly enhancing its nitrogen content, which improves its suitability as a fertilizer or soil amendment. While moisture and solids content remained largely unchanged, the treatment process notably increased nitrogen levels across all constituents, with the most significant change being in nitrate content. Nitrate levels in the treated manure, referred to as nitrogen enriched organic liquid, rose from trace amounts in the separated manure liquids to 0.17%, making it a more valuable nitrogen source for agricultural use. This enhancement is particularly beneficial for crops, as nitrates are more readily available for plant uptake. Additionally, the pH of the manure slurry was dramatically reduced from 6.70 to 5.26, further improving nutrient stability and reducing the risk of volatilization. During the trial, when the pH setpoint was adjusted to 4.5–5.0, the resulting nitrogen enriched organic liquid pH for the flow through tank was 5.03. These changes in nutrient composition and pH not only make the manure more efficient for agricultural application but also help to reduce

the environmental impact of manure management by enhancing nutrient availability while minimizing nutrient losses.

- *Macro-nutrient reductions or transformations*
    - No substantial changes were observed in other macro-nutrients such as phosphorus, potassium, and sulfur, suggesting that while the N2 Applied process enhances nitrogen content, it does not significantly alter the overall profile of these other key macro-nutrients.
- *Pathogen reductions or eliminations*
    - Although direct measurements or detailed analysis of pathogen reduction were not included in the study, the N2 Applied treatment process could have a beneficial effect on pathogen control due to the substantial changes in pH levels during the treatment. The pH of the manure slurry was significantly reduced initially from 6.70 to an average of 5.26 following the treatment, a condition that is known to influence the viability of many pathogens. A lower pH can inhibit the growth and survival of certain harmful microorganisms, such as bacteria and parasites, which thrive in more neutral pH environments.

      However, for a more thorough understanding of the pathogen reduction capabilities of the N2 Applied process, further testing would be required to measure specific pathogen loads before and after treatment, considering common pathogens in manure such as *E. coli*, *Salmonella*, and *Campylobacter*. Such data would provide more definitive conclusions regarding the system's effectiveness in pathogen reduction.
- *Air emissions*
    - The N2 Applied treatment process demonstrated notable reductions in NH_3 emissions, a key challenge in manure management. Ammonia emissions from the static slurry tank were measured between 0 and 430 ppm, with an average of 67 ppm, while emissions from the static nitrogen enriched organic liquid tank were significantly lower, ranging from 0 to 2 ppm initially, with a peak of 208 ppm later in the study. The average NH_3 emissions from the nitrogen enriched organic liquid tank remained below 10 ppm for most of the trial. This indicates that the N2 Applied system may be effective in minimizing ammonia volatilization, a critical factor in air quality and nitrogen retention.

      In terms of NOx, which include nitric oxide and nitrogen dioxide, emissions were observed from both the Nitrogen enriched organic liquid static and flowthrough tanks but not from the slurry tanks. NOx emissions fluctuated between 2 and 20 ppm for most of the trial, with elevated levels (>100 ppm) during the second run of the N2 Applied unit, when the pH setpoint was lowered. In tests of the N2 Applied unit's exhaust, NOx emissions were routinely measured above 250 ppm, suggesting a potential area for further investigation and optimization.

GHG emissions, specifically CO_2 and CH_4, were also measured during the study. Carbon dioxide emissions were generally higher from the slurry tanks compared to the nitrogen enriched organic liquid tanks, with CO_2 levels from the static nitrogen enriched organic liquid tank approximating ambient air concentrations. Methane emissions, a potent GHG, were measured at significantly higher levels in the slurry compared to the nitrogen enriched organic liquid. For the static tanks, CH_4 levels from the slurry ranged from 54 to 768 ppm, while emissions from the nitrogen enriched organic liquid never exceeded 3 ppm. In the flowthrough tanks, CH_4 levels were elevated in the nitrogen enriched organic liquid, ranging from 0 to 1,000 ppm, but were still much lower than those observed in the slurry, which often exceeded 1,000 ppm, with some readings surpassing 10,000 ppm. These findings suggest that the N2 Applied process may reduce methane emissions compared to traditional slurry storage, although there are still notable emissions, particularly from the slurry phase.

Overall, the N2 Applied system appears to offer some reduction in ammonia and methane emissions, with potential for further optimization to reduce nitrogen oxide emissions, especially during lower pH settings.

- *Water quality*
    - The N2 Applied treatment process could have a positive impact on water quality, particularly in terms of nutrient runoff and water quality. By treating manure slurry and enhancing nitrogen content through the conversion to nitrate, the N2 Applied process creates a more stable form of nitrogen, which could reduce the risk of nitrate leaching into groundwater and runoff into surface waterways. Additionally, by lowering the pH of the manure slurry, the process may reduce the potential for nitrogen losses through volatilization, helping to keep more nutrients in the manure for agricultural use. This is particularly important in preventing nutrient runoff, which can lead to eutrophication in nearby water bodies.

PROCESS MONITORING AND CONTROL SYSTEM REQUIRMENTS

Process monitoring and control systems are crucial for optimizing the performance of the N2 Applied System. These systems enable real-time monitoring and control of key parameters, ensuring efficient and effective operation.

- *Required monitoring*— To ensure the optimal performance of the N2 Applied System, several parameters must be continuously monitored, including:
  - **pH levels** in the manure slurry and nitrogen enriched organic liquid tanks to track the effectiveness of the nitrogen conversion process.
  - **Foam levels** to detect potential overflows or operational issues, with sensors to ensure proper treatment and to avoid excess foam buildup and downtimes.
  - **Tank levels** to manage the flow and ensure consistent manure supply and treatment efficiency.
  - **Temperature** within the unit and control panel to prevent overheating and equipment malfunction and ensure sufficient ventilation.
  - **Gas emissions** (e.g., ammonia and nitrogen oxides) from both the slurry and nitrogen enriched organic liquid tanks to monitor air quality and ensure minimal environmental impact.
  - **Plasma torch power output** to track degradation of the torch's copper core, ensuring timely refurbishment and/or replacement when the power output falls below set thresholds.
- *Required control*— The N2 Applied System must include controls for the following aspects:
  - **pH control** to maintain the optimal range for treatment, preventing destabilization of the nitrogen enriched organic liquid and ensuring efficient nitrogen conversion.
  - **Temperature control** to regulate internal heat, particularly in the control panel and air compressor, and to avoid overheating and promote adequate ventilation.
  - **Foam management** to regulate foam levels and prevent system malfunctions, ensuring smooth and continuous operation and efficient treatment.
  - **Pump and flow control** to manage the manure slurry and liquid flow into the N2 Applied unit, ensuring consistent supply and preventing cavitation or clogging in the system.

    - **Defoamer control** to manage foam buildup, activated by readings from the foam indication sensor, and to ensure proper consistency of the defoamer for effective use.
    - **Mixing tower control** to ensure the proper integration of plasma with the manure, with periodic monitoring to avoid solids build-up and ensure proper functionality.
- *Equipment included for monitoring*— The N2 Applied System is equipped with several key monitoring devices:
    - **Sensors** for pH, foam, and tank levels, with the foam level indicator being sensitive to environmental temperature changes.
    - **Gas analyzers** for NH_3, NOx, and CH_4 emissions, to monitor air quality and reduce environmental impact.
    - **Temperature sensors** inside the unit and control panel to prevent overheating, encourage ventilation, and ensure optimal performance.
    - **Power output sensors** for monitoring the plasma torch's efficiency and indicating when refurbishment is needed due to power degradation.
- *Equipment included for controlling*— The system is designed with equipment to manage various operational parameters:
    - **Air compressor** with a high-quality commercial unit to provide the required air supply for the N2 Applied treatment process.
    - **Control panel** with software to adjust settings remotely and manage operational parameters, although early software issues required troubleshooting.
    - **Exhaust fans and vents** to control heat buildup in the unit and improve ventilation, particularly for the control panel and air compressor.
    - **Valves and flow regulators** to manage the compressed air supply and maintain the correct air pressure for system operation.
    - **Defoamer** to manage foam levels in the treatment tank, introduced based on readings from the foam indication sensor.
    - **Mixing towers** to ensure proper integration of plasma with the manure, which may require periodic cleaning to prevent solids build-up and ensure efficient operation.

TYPICAL OPERATIONS/MAINTENANCE PLAN WITH MONITORING REQUIREMENTS AND REPLACEMENT SCHEDULE

The N2 Applied System is designed to efficiently treat manure slurry by enhancing nitrogen content through the conversion to nitrate, while minimizing environmental impacts such as ammonia and methane emissions. Proper operation and maintenance are essential to ensure the system runs efficiently, meets environmental standards, and has a long service life. Below is a typical operations and maintenance plan for the N2 Applied system based on the demonstration unit trial information, outlining monitoring requirements and a recommended replacement schedule for key components.

System Monitoring

- **Foam Levels:**
  - **Monitoring Requirement:** Daily monitoring of foam levels in the treatment tank to prevent overflow and ensure efficient treatment. Sensors should be checked for proper calibration and functionality.
  - **Action:** If foam exceeds threshold levels, adjust system parameters to reduce foam generation or check for faults in foam level sensors.
  - **Defoamer Control:** Ensure adequate defoamer is available and used according to foam levels. Monitor for coagulation or consistency issues.
- **Tank Levels:**
  - **Monitoring Requirement:** Regular monitoring of manure slurry and nitrogen enriched organic liquid tank levels to ensure consistent flow and treatment.
  - **Action:** Verify that tank levels are within operational limits and ensure no blockages in flow lines.
- **pH Levels:**
  - **Monitoring Requirement:** Daily check of pH levels maintain optimal conditions for the nitrogen conversion process.
  - **Action:** Adjust pH as necessary using control systems to keep the levels in the optimal range for treatment.
- **Gas Emissions (Ammonia, Nitrogen Oxides, Methane):**
  - **Monitoring Requirement:** Continuous monitoring of gas emissions including ammonia, nitrogen oxides, and methane, using appropriate gas analyzers.

    - **Action:** If emissions exceed acceptable limits, perform an immediate inspection to diagnose causes such as pH imbalances or inadequate treatment.
- **Temperature:**
    - **Monitoring Requirement:** Daily monitoring of internal temperatures, especially within the control panel and air compressor, to ensure proper ventilation and prevent overheating.
    - **Action:** If temperature exceeds safe operating limits, verify that vents and fans are functional, and the system is properly ventilated.
- **Mixing Towers**:
    - **Monitoring Requirement**: Regular inspection of the mixing towers to ensure proper integration of plasma with manure. Monitor for solids build-up, especially after periods of system inactivity.
    - **Action**: If solids build-up is detected, clean mixing towers and associated components to maintain proper function.
- **Plasma Torch:**

  Monitoring Requirement: Regular monitoring of plasma torch power output to detect performance degradation. The actual power output should be compared to the power set point for any sudden drops.

  Action: If a significant drop in power output is observed (e.g., 45 kW set point, 38 kW actual), the plasma torch needs to be refurbished and/or replaced. This involves shutting down the unit, removing the torch, refurbishing or replacing the copper core, and restarting the unit.

Replacement Schedule

1. Foam Level Sensor:

- **Replacement Frequency:** As needed (generally after 1-2 years of operation or when faults are detected).

2. Gas Emissions Sensors (Ammonia, Nitrogen Oxides, Methane):

- **Replacement Frequency:** Annually or when emissions readings become inconsistent or inaccurate.

3. Control Panel and Air Compressor Components:

- **Replacement Frequency:** Annually or as needed when components show signs of failure or inefficiency (e.g., temperature control issues, faulty components).

4. Power Supply Components (Voltage Converters, Power Supply Cables):

- **Replacement Frequency:** Every three years or when faults are detected (especially for systems related to voltage conversion).

5. Pumps and Valves:

- **Replacement Frequency:** Annually or as required, depending on wear and usage conditions.

6. Defoamer:

- **Replacement Frequency:** As needed, based on usage, typically every six months or more frequently if foam levels require higher-than-usual defoamer application.

7. Mixing Towers:

- **Replacement Frequency:** Periodic cleaning and maintenance (annually or after periods of inactivity), with component replacement as necessary if wear or solids build-up affects performance.

8. Plasma Torch:

- **Replacement Frequency:** Refurbishment is required every 12-14 days of operation, depending on usage (for the demonstration unit). The copper core needs to be sharpened, smoothed, or replaced as necessary.
- **Action:** Monitor power output regularly for significant drops to determine when refurbishment is needed. This process requires system shutdown and some component replacement costs but takes less than one hour to complete.

CHEMICAL INFORMATION

- The N2 Applied system does not use any chemicals in its operation.

ESTIMATED INSTALLATION AND OPERATION COST

<u>Equipment and Installation Capital Costs</u>

As the commercial N2 Applied unit is not yet available in the U.S., detailed data regarding equipment and installation capital costs is currently unavailable. Since the system is still undergoing trials and development, cost structures for equipment and installation will be finalized closer to the commercial release. It is expected that capital costs will vary based on factors such as system configuration, farm size, and specific site conditions. Further information will be provided as the system is introduced to the U.S. market and more data becomes available.

Operation and Maintenance Costs (O&M)

- ***Electrical***— As of 2024, if operated year-round, the studied demonstration unit and its components would consume approximately 260,000 kWh, with a peak demand of 60 kW. At the farm's electricity rate of $0.07/kWh and a demand charge of $12/kW, the estimated annual electricity cost would be $26,840. With an annual processing capacity of 208,415 gallons, the electricity cost alone would be about $0.13 per gallon.
- ***Labor*—** Detailed labor cost data for operating the N2 Applied unit is not currently available. However, based on observed maintenance and operational requirements, labor needs may include routine monitoring, system adjustments, and periodic maintenance tasks such as plasma torch refurbishment and/or replacement, foam sensor checks, and cleaning of mixing towers. The total labor cost will depend on factors such as farm labor rates, frequency of maintenance, and operational duration.
- ***Maintenance Replacement*—** Specific maintenance cost data for the N2 Applied unit is not available. However, expected maintenance tasks include plasma torch refurbishment every 12–14 days as shown in the demonstration unit, periodic cleaning of mixing towers and tanks, and replacement of sensors, valves, and other key components as needed. The total maintenance cost will depend on part replacement frequency, material costs, and technician labor rates.

EXAMPLE WARRANTY

Warranty information for the N2 Applied unit is not currently available. However, a typical equipment warranty may include:

- **Coverage Period:** 1–3 years for major components, with extended coverage for specific parts.
- **Covered Components:** Control panel, plasma torch, air compressor, sensors, and valves.
- **Exclusions:** Routine wear-and-tear items such as the plasma torch copper core, filters, and defoamer supply.
- **Service Support:** Manufacturer-provided technical support and potential on-site service options.

Actual warranty terms would need to be confirmed with N2 Applied upon commercial availability in the U.S.

RECOMMENDED RECORD-KEEPING FOR N2 APPLIED SYSTEM

Effective record-keeping is essential for ensuring the optimal performance, reliability, and longevity of the N2 Applied system. Proper documentation supports troubleshooting, maintenance, regulatory compliance, and warranty claims. Below are the recommended record-keeping practices:

1. Purchase and Installation Records

- **Purchase Details:** Maintain copies of the purchase invoice, including the serial number, purchase date, and system specifications.
- **Installation Documentation:** Record installation details, including the date, site modifications, and the name of the installer or service provider.

2. Maintenance and Service Logs

- **Routine Maintenance:** Log all scheduled maintenance, such as cleaning, inspections, and adjustments, along with the date and technician's name.
- **Repairs and Replacements:** Document any repairs, replaced components, and service provider details.
- **Service Agreements:** Keep copies of contracts outlining maintenance schedules and scope of work.

3. Operational Records

- **System Runtime:** Track operating hours to help schedule maintenance and detect potential wear-related issues.
- **Performance Metrics:** Maintain records of downtimes, throughput rates, nitrogen conversion efficiency, foam control effectiveness, and deviations from expected performance.

4. Warranty and Claims

- **Warranty Documentation:** Store a copy of the warranty agreement, including coverage details and expiration dates.
- **Claims History:** Log warranty claims, including issue descriptions, manufacturer communications, and resolutions.

5. Compliance and Safety Records

- **Regulatory Compliance:** Keep records of any required inspections, certifications, or environmental compliance documentation.
- **Safety Checks:** Document regular safety inspections and corrective actions taken to maintain safe operation.

6. Training and Usage Records

- **Staff Training:** Record all operator training sessions, including topics covered, dates, and attendees.
- **Usage Guidelines:** Maintain documentation on best practices for operating the system to prevent misuse and ensure efficiency.

7. Document Storage and Backup

- **Organized Filing:** Store all records systematically, either digitally or in a secure physical location.
- **Backup Procedures:** Regularly back up digital files to prevent data loss and ensure long-term accessibility.

ALTERNATIVES FOR THE USE OF BYPRODUCTS

The N2 Applied system enhances manure management by treating slurry with plasma to increase nitrogen content and reduce emissions. The process results in treated manure with distinct properties that can be repurposed in various ways to improve sustainability and operational efficiency.

1. Nitrogen Enriched Organic Fertilizer

The N2 Applied process converts manure into a nitrogen enhanced fertilizer with higher nitrogen retention and reduced ammonia emissions. This treated manure can be applied directly to fields, improving nutrient efficiency, minimizing risk for nutrient volatilization, leaching, or runoff, and reducing reliance on synthetic fertilizers.

2. Soil Improvement and Regenerative Agriculture

The treated manure from the N2 Applied system retains valuable organic matter and nutrients, making it a beneficial soil amendment. It enhances soil structure, improves moisture retention, and supports regenerative farming practices by promoting long-term soil health.

3. Emission-Reduced Manure Spreading

Compared to raw slurry, the N2 Applied-treated manure has significantly lower ammonia emissions, making it a more environmentally friendly option for land application. Farmers can apply it with reduced risk of nitrogen loss through volatilization, leaching, or runoff, increasing nutrient uptake efficiency for crops.

4. Integration with Cover Cropping Systems

The stable nitrogen form in the treated manure makes it well-suited for use in cover cropping systems. It provides a controlled release of nutrients that supports cover crop growth, enhances soil fertility, and prevents nutrient runoff, leaching, or volatilization.

5. Potential for Circular Economy Applications

Further research and development may explore additional uses, such as integrating treated manure into precision fertilization systems or developing custom fertilizer blends for specific crop needs.

INDEPENDENT VARIFIABLE DATA DEMONSTRATING RESULTS/CREDENTIALS

Appendix A is a summary of the expert opinion and technical data available for this class of technology and how it relates to key performance indicators within NRCS Standard 629. This information is available through Newtrient.

Appendix B provides a summary of data from a Newtrient-managed third-party review of an N2 Applied demonstration unit at CoBar Dairy in Mount Upton, NY. The data comes from a system performance analysis conducted by Cornell University but has not been peer-reviewed.

Appendix C contains the full Cornell University report detailing the third-party review at CoBar Dairy.

CONTACT INFORMATION—VENDOR

The list below includes a single company based in Norway, as this is a novel technology that is not yet commercially available in the U.S.

1. **N2 Applied Technology Center**
   Address: Strand Gård Vestsida 71, 3622 Svene Norway
   Phone: +47 41 50 74 14
   Website: https://n2applied.com/
   Company Information: N2 Applied, a Norwegian based technology company with an international team that has expertise in agriculture, technical engineering, business development, and sustainability, has developed a technology that enables local production of fertilizer from liquid organic substrates. N2's scalable process enables fertilizer production to be re-distributed to the end-user, the

farmer thereby cutting long and expensive supply chains, and reducing the need for chemical fertilizer production. The solution also provides on-farm emission reductions of methane, ammonia, and odor.

2. **GEA United States – ProManure E2950**
   Address: 20903 W. Gale Ave., Galesville, WI 54630 USA
   Phone: (608) 582-2221
   Website: https://www.gea.com/en/
   Company Information: GEA is a worldwide leader in milking, manure, and livestock housing equipment solutions. They are dedicated to saving producers time, labor, and money through increased efficiency, management assistance information, and leading-edge technology. As an integrated group, GEA strives to meet the needs of all farm sizes and management styles, enabling maximum profitability and opportunities for future growth.

CONTACT INFORMATION—USER

Currently, there are no commercial installations or users of N2 Applied technology in the U.S.

OTHER CONSIDERATIONS

The NRCS documentation specifies that a third-party review shall contain 15 specific items that comprise the report above, but as part of working with the farm(s) and the technology provider during the evaluation period there are often other important and valuable learnings that may be helpful for NRCS and others as they consider this technology. Below is a list of Other Considerations that should be included in the evaluation of this technology:

1. Solid-Liquid Separation
The N2 Applied system requires the upstream removal of coarse manure fibers greater than 3 mm. Both separators and conveyance systems must be maintained to ensure efficient operation. Regular maintenance is necessary to prevent system failures due to inadequate removal of solids.

2. Integration with Farm Systems
Successful integration of the N2 Applied system with existing farm infrastructure is critical. Challenges arose from the European-origin equipment, which created power and energy connection issues. The farm’s three-phase power supply had unbalanced loads, causing connection difficulties and operational inefficiencies. Voltage transformation and frequency conversion required for the European equipment to meet

U.S. grid specifications added further complexity, leading to several system faults and errors.

3. Manure Supply System

The lack of proper manure supply infrastructure on the farm presented significant operational hurdles. Key components, such as the manure supply pump, solid-liquid separator, and conveyance systems, were either undersized or lacked essential features (e.g., properly installed chopper blades on the lift pump). These deficiencies resulted in pump cavitation, clogged lines, equipment failures, and overall supply issues, highlighting the importance of adequate infrastructure for optimal system performance.

4. Nitrogen Enriched Organic Liquid Tank Stabilization

During the trial, the nitrogen enriched organic liquid tank experienced destabilization, leading to a rapid pH increase and excessive foaming. This was likely caused by inconsistent operation of the system, potentially exacerbated by solids greater than 3 mm being conveyed into the N2 Applied unit. It's also possible that microbial denitrification occurred due to slow pH drift and loss of nitrogen, influenced by seasonal temperature changes that impact denitrification in agricultural processes.

5. Ventilation and Overheating

The temperature inside the N2 Applied unit, particularly in the control panel area, was too high during initial operation, causing unanticipated downtime. The air compressor and transformers contributed significant heat, necessitating modifications to the unit for proper ventilation. Vents were added, and exhaust fans were installed to manage heat. It is anticipated that future units may require a temperature-controlled space to avoid similar issues. Additionally, heat recovery during summer operations could be a viable option, as excess heat is currently released into the atmosphere.

6. Controls, Software, and Sensors

The initial control software issue prevented remote operational monitoring and setting of parameters, leading to unexpected downtime. Rural internet disruptions further complicated remote access, requiring an alternative internet provider. Several sensors experienced issues, such as the tank level sensor, which needed replacement, and the foam level sensor, which malfunctioned multiple times due to sensitivity to ambient temperature changes. These sensor issues contributed to operational challenges, including foam accumulation in the treatment tank during temperature fluctuations.

7. Air Compressor and Supply

The air compressor provided with the unit was not suitable and required replacement at startup. Additionally, a valve issue in the compressed air supply system needed repair. A high-quality, commercial-grade air compressor is necessary to ensure the efficient operation of the system and prevent ongoing technical challenges.

Conclusion

The N2 Applied technology offers significant promise in advancing manure treatment and environmental sustainability in agricultural operations. By transforming manure into a more efficient fertilizer and reducing harmful emissions such as NH_3 and CH_4, it presents a valuable opportunity for improving both the environmental footprint and operational efficiency of dairy farms. The nitrogen enriched organic liquid byproduct produced through this process is rich in nitrogen, offering potential for enhanced soil fertility and agricultural productivity. The technology's ability to mitigate GHG emissions from manure storage and treatment provides clear environmental benefits, particularly on air and water quality.

Despite these advantages, the evaluation of the system revealed several areas for further improvement and study. The analysis of static tank conditions suggests that while nitrogen enriched organic liquid remains enriched in nitrogen and reduces emissions for several months, its longer-term stability, especially in colder months, was not fully evaluated. Throughout the study, the pH of stored nitrogen enriched organic liquid gradually increased, and late-stage NH_3 emissions indicated potential stability concerns, particularly with nitrogen enriched organic liquid buffered to a pH of 5.5 or higher.

Moreover, intermittent operation and challenges with the integration of the N2 Applied unit and its supporting systems made it difficult to accurately assess the system’s efficacy and economic feasibility. A more comprehensive study of a commercial Gen 0 unit under continuous operation is necessary to fully evaluate treatment effects, production rates, and cost structures. The limited data from the trial suggests that the system may not be economically viable without substantial carbon credit incentives and cost savings, though it is expected that the Gen 0 unit will improve efficiency, potentially lowering operating costs.

Further, both the N2 Applied unit and the storage of nitrogen enriched organic liquid have the potential to generate NOx emissions, which require careful monitoring to avoid negative environmental impacts. Finally, agronomic trials of nitrogen enriched organic liquid, coupled with field emissions monitoring, are crucial to ensure that it can enhance crop yield and quality without contributing to elevated emissions of NH_3, N_2O, or other gases. These trials will be essential to fully assess the environmental and economic benefits of the technology.

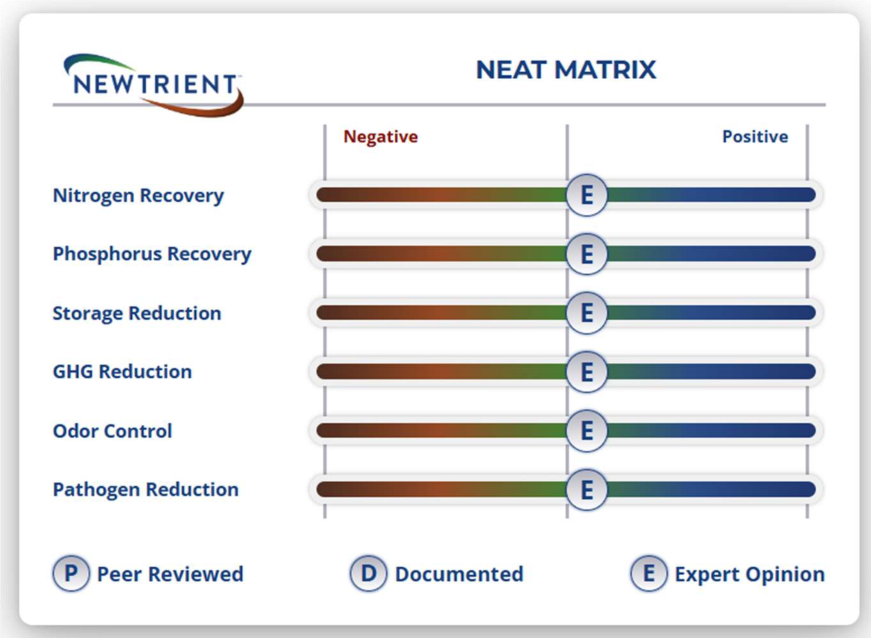
In conclusion, while the N2 Applied system holds great potential for sustainable manure management and emission reduction, further research, optimization, and real-world trials are needed to maximize its effectiveness, commercial viability, and environmental benefits for dairy farming operations.

REFERENCES

VERA (2018) VERA Test Protocol: Covers and other Mitigation Technologies for Reduction of Gaseous Emissions from Stored Manure. Version 3:2018-07

Appendix A

NEWTRIENT CRITICAL ANALYSIS – NITROGEN FIXATION TECHNOLOGY



Overall Summary

Nitrogen fixation technology with plasma injection is designed to better manage manure by elevating and preserving plant-available nitrogen in manure while reducing environmentally significant gases, namely methane (CH_4) and ammonia (NH_3). Using a high voltage plasma torch, the technology splits nitrogen (N_2) and oxygen (O_2) molecules in the air to produce NOx gas. This gas is absorbed into manure slurry through a venturi and recirculation process, reacting with the waste to reach an acidified pH, typically targeting 5.0. Such a process generates a nitrogen enriched organic product, which can be used as a sustainable fertilizer.

The nitrogen enriched organic liquid product from the system is enriched with readily available nitrogen, reducing the risk of excessive nitrogen leaching or runoff into surface or groundwater during storage or field applications, thereby protecting local waterways. By acidifying the liquid manure, the technology suppresses the microbial production of CH_4 and encourages the formation of less volatile ammonium (NH_4^+) rather than NH_3, therefore enhancing nutrient utilization efficiency and greenhouse gas mitigation.

Nitrogen fixation technology with plasma injection can be adapted for small farms, using air and electricity to convert manure into a sustainable, nutrient-rich resource. This fertilizer reduces the reliance on commercial fertilizer to offset lost nutrients, most notably nitrogen, from volatilization, leaching, or runoff. The circular and scalable nature of the system provides downstream cost saving benefits for sustainable manure and nutrient management.

Appendix B

Third-Party Review of N2 Applied Nitrogen Fixation Technology with Plasma Injection at CoBar Dairy – Mount Upton, NY (Report Summary)

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JUNE 2024

BACKGROUND

Dairy farms generate significant amounts of manure, which must be managed in ways that minimize environmental impacts such as greenhouse gas (GHG) emissions and nutrient runoff and leaching. Traditional manure storage and land application practices often result in the release of methane (CH_4), ammonia (NH_3), and nitrous oxide (N_2O), all of which contribute to air and water quality concerns.

The N2 Applied plasma technology was developed to address these environmental challenges by treating and enriching manure with nitrogen, creating a nitrogen enriched organic (NEO) liquid. This process is intended to reduce emissions during storage and provide a more stable, nitrogen-rich nutrient fertilizer product, which could reduce the need for synthetic fertilizers.

In 2023, a demonstration unit of the N2 Applied plasma system was deployed at CoBar Dairy in Mount Upton, New York. This evaluation was conducted over several months to assess the system's performance, particularly its ability to reduce GHG and NH_3 emissions from dairy manure. The test compared emissions from untreated slurry and the NEO produced by the system, using both static and flowthrough manure treatment tanks. The study also measured the energy consumption and economic feasibility of the system, evaluated operational challenges and maintenance requirements, and monitored the long-term stability of the NEO product.

INTRODUCTION

The N2 Applied technology is a cutting-edge manure treatment system designed to elevate and preserve nitrogen levels in manure while simultaneously reducing the emissions of environmentally significant gases, specifically CH_4 and NH_3. This innovative system is housed in a shipping container and utilizes ambient air compression along with a high-voltage plasma torch to convert atmospheric nitrogen (N_2) and oxygen (O_2) gases into reactive nitrogen oxides (NOx). The generated NOx is then absorbed into separated liquid manure through a venturi and recirculation process, reacting with the waste until a targeted pH decrease of typically 5.0 is achieved. From this process, the acidified NEO is produced.

This treatment process effectively lowers the pH, which inhibits the microbial generation of CH_4 and promotes the formation of ammonium (NH_4+) over the more volatile NH_3. Consequently, this technology mitigates emissions that are harmful to both air quality and surrounding water systems while enhancing the efficiency of nutrient utilization in manure.

The N2 Applied technology holds unique potential for enhancing dairy manure management and may be particularly beneficial for small farms. While this system has been trialed in Europe, its evaluation on U.S. dairy farms had not previously been conducted, making this study at CoBar Dairy a significant step in assessing its applicability and effectiveness in North American agriculture.

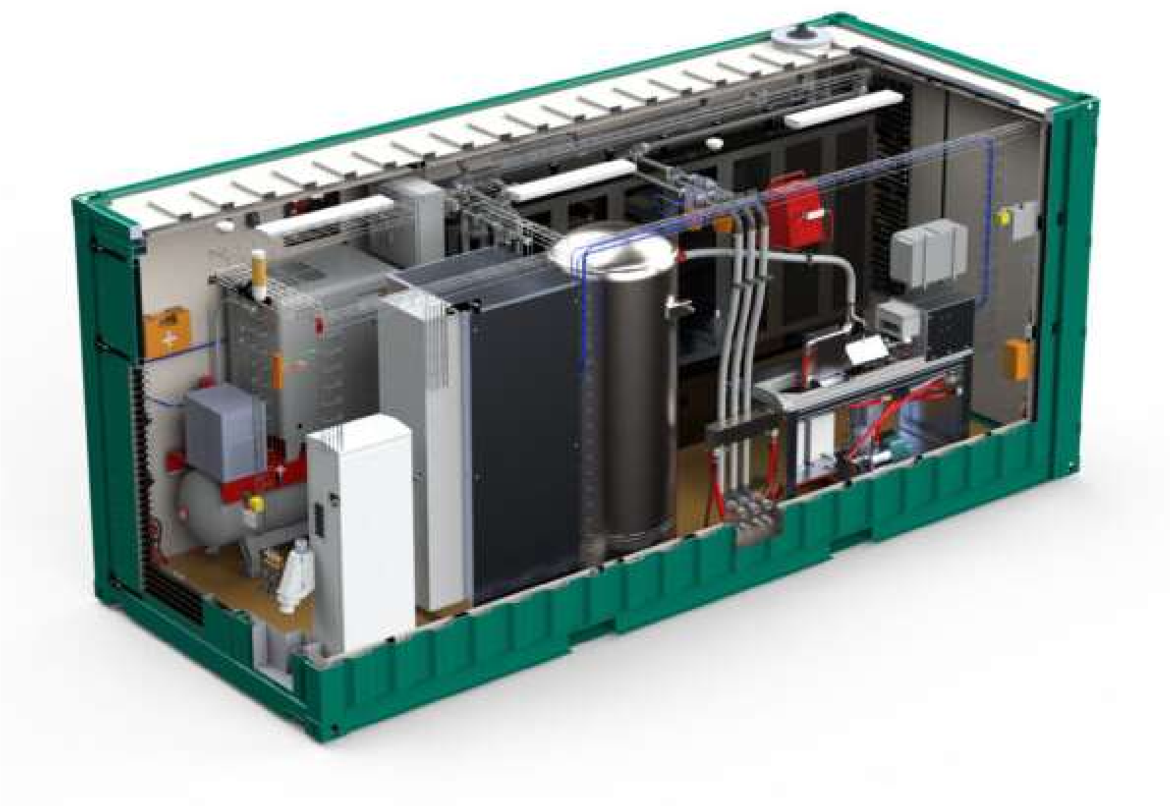

Figure 1: N2 - Applied System diagram
Source: https://n2applied.com/the-technology/

THE PROCESS

The N2 Applied technology operates in two primary phases: plasma generation and absorption.

Phase 1: Plasma Generation – In this initial step, electricity is utilized to dissociate N_2 and O_2 molecules found in the atmosphere. This process results in the formation of reactive nitrogen gas from the atomic nitrogen (N) and oxygen (O) recombining to form NOx.

Phase 2: Absorption – The reactive nitrogen gas, NOx, is then absorbed into the liquid component of organic materials, such as livestock slurry or biogas digestate, forming an acidic solution. This interaction converts the nitrogen into a form that is readily available for plant uptake. This NOx is mixed with the manure effluent until the desired acidic (pH) set point is reached.

The introduction of reactive nitrogen enhances the organic material by enriching it with nitrogen that plants can readily use, while also stabilizing ammonium nitrogen to minimize losses. Furthermore, by suppressing microbial activity, the plasma treatment effectively prevents the generation of CH4 – a potent greenhouse gas. This ensures that both organic carbon and nitrogen remain intact during storage, allowing them to be utilized in the field, where they contribute to building long-term soil health and fertility (N2 Applied, 2024).

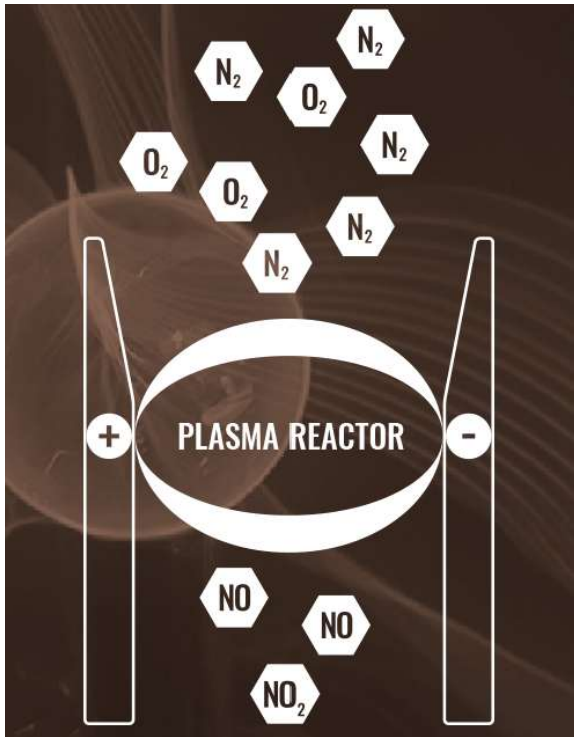

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Figure 2: N2 - Applied Plasma Technology
Source: https://n2applied.com/the-technology/

METHODOLOGY

During the 2023 growing season, Cornell University led a pilot research-scale study at CoBar Dairy utilizing the N2 Applied demonstration unit (model MK 4.4) operated by ProStar Energy. The N2 Applied unit was initiated on May 15, 2023, and dairy manure was scraped multiple times daily into a below-grade circular concrete storage structure. A lift pump transferred the manure to a screw press solid-liquid separation system, from which the separated liquids were treated in the N2 Applied unit. Approximately 20 gallons of separated manure liquids were processed in a sequential batch until the pH fell below a setpoint, initially set at 5.5 and later adjusted to 5.0 on August 16, 2023. When operational, the N2 Applied unit treated slurry to produce approximately 25-55 gallons of NEO each hour. During the first continuous runtime (May 15 - June 23), about 15,000 gallons of NEO were generated. In the second continuous runtime (August 7 - September 17), around 20,000 gallons were produced. Early in the study, production rates reached 1,055 gallons/day, but later averaged 534 gallons/day—roughly equivalent to the manure from 30 lactating cows per day. This was significantly lower than the expected processing capacity of 200 cows per day, likely due to challenges with solid-liquid separation and manure buffering capacity. It should be noted that the demonstration unit was designed using European electrical systems, which may have contributed to some of the capacity issues. The resulting NEO was pumped out for farm crop usage, while the separated solids served as soil amendments.

To simulate long-term manure storage, on May 20, 2023, two vertical cylindrical polytanks (1,100 gallons) were filled with approximately 800 gallons each of NEO and untreated separated manure liquids. Airflow across the surface of these tanks was maintained to align with industry recommendations (VERA, 2018). Two horizontal steel flowthrough tanks (11,000 gallons) received NEO and slurry at comparable production rates, with overflows directing slurry to long-term storage while NEO overflowed into a collection tote.

Manure sampling began on May 24, 2023, and was conducted three times a week through September 2023. Samples included raw manure, separated liquids, NEO effluent, and slurry, which were transported to A&L Great Lakes Laboratories for analysis of pH, total solids, nitrogen fractions, phosphorus, and potassium. Air emissions were monitored starting May 22, 2023, using gas analyzers to measure concentrations of CH_4, NH_3, NOx, O_2, carbon dioxide (CO_2), and hydrogen sulfide (H_2S).

Key sampling events included the large NEO tank filling on June 16, 2023, and the large slurry tank filling on June 22, 2023. The N2 Applied unit was turned off due to manure shortages on June 23, 2023, and restarted on June 30, 2023. However, the large NEO tank foamed and destabilized on July 2, 2023, likely as a result of the emission of nitrogenous gases. The unit was restarted at a pH of 4.5 on August 7, 2023, and adjustments were made to reach a pH of 5.0 on August 16, 2023. The large tanks were full by August 25, 2023. The study concluded when the N2 Applied unit foamed out of the exhaust vent and was turned off on September 17, 2023.

Temperature loggers recorded data in the filled small static and large flowthrough tanks hourly, which generally tracked ambient temperatures but were usually warmer. Energy usage for the N2 Applied unit was tracked through a newly installed three-phase utility service, with total electricity consumption monitored via utility meters to ensure accurate reporting of power requirements for the system, considering the discrepancies of power consumption between Europe and the U.S

DISCUSSION OF RESULTS

This study provides valuable insights into the application of N2 Applied technology for dairy manure management. This comprehensive analysis evaluated the efficiency of the N2 Applied unit in producing NEO and its impact on nutrient reduction from liquid manure.

KEY BENEFITS OF N2 APPLIED TECHNOLOGY

Enhanced Nutrient Profiles: The N2 Applied technology significantly enhances the nutrient profile of dairy manure, particularly increasing its nitrogen content. During the treatment process, total nitrogen in the NEO increased by approximately 57% in static tanks and 45% in large tanks, primarily due to elevated nitrate levels. This transformation from trace amounts to 0.17% nitrate in NEO allows for better nutrient availability when applied to crops, promoting healthier soil, improved plant growth, and decreased risk for nutrient runoff and leaching into waterways. Figures 3 and 4 illustrate these changes in nitrogen content, emphasizing the technology's effectiveness in nutrient enrichment.

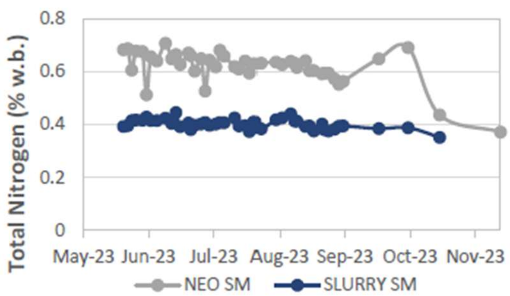


Figure 3. Total N in NEO and slurry in static tanks

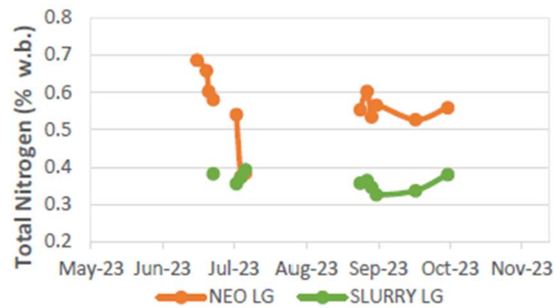


Figure 4. Total N in NEO and slurry flowthrough tanks

Chemical Stability: One of the critical benefits of the N2 Applied process is its ability to dramatically reduce the pH of manure from 6.70 to as low as 5.03. Throughout the study, a consistent pH differential was maintained, ensuring the stability of the NEO produced. Figures 5 and 6 show the pH levels over time, highlighting the treatment's effectiveness in pH management and nutrient stability. A consistent 5.5 or lower pH was maintained in the static manure tanks throughout the study, although a rapid pH rise was observed in October and November, while the flowthrough tanks showed a stable pH between inflows and outflows, except for a sudden increase in the large (LG) NEO tank in late June. The physical properties of the manure slurry, such as moisture and solids content, remain largely unchanged, ensuring that the slurry's handling characteristics are maintained (Table 1).

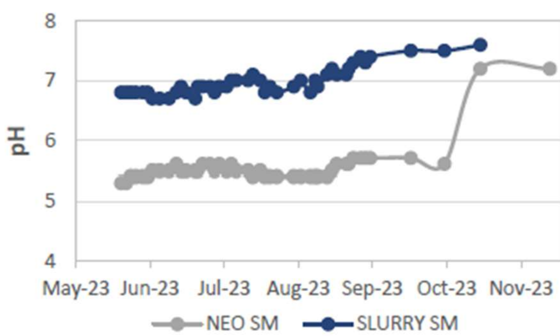


Figure 5: pH of NEO and slurry in static tanks

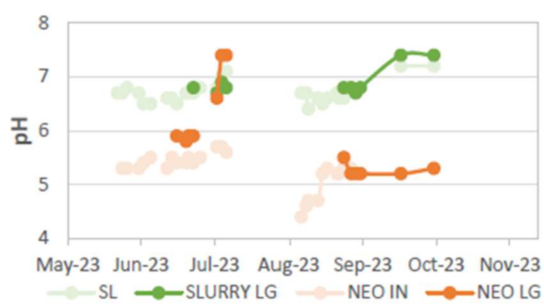


Figure 6: pH of NEO and slurry in flowthrough tanks

Table 1: Average ± standard deviation percentage (wet basis) of moisture content, total solids, total Kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4-N), organic nitrogen (Org-N), nitrate nitrogen (NO_3-N), total nitrogen (TN), phosphorus (P), potassium (K), and pH for each sample from May 20 to Sept 17. n = number of samples.

Sample	n	Moisture	Solids	TKN	NH_4-N	Org-N	NO_3-N	TN	P	K	pH
Raw manure	25	90.71 ± 1.25	9.29 ± 1.25	0.36 ± 0.03	0.16 ± 0.03	0.20 ± 0.03	0.000 ± 0.000	0.36 ± 0.03	0.06 ± 0.00	0.27 ± 0.02	6.67 ± 0.21
Separated manure liquids	27	94.31 ± 0.58	5.69 ± 0.58	0.37 ± 0.04	0.18 ± 0.03	0.20 ± 0.03	0.001 ± 0.003	0.37 ± 0.04	0.06 ± 0.01	0.27 ± 0.02	6.70 ± 0.18
NEO, N2 Applued unit outflow	27	94.15 ± 0.59	5.85 ± 0.59	0.46 ± 0.04	0.16 ± 0.01	0.30 ± 0.04	0.166 ± 0.044	0.63 ± 0.06	0.06 ± 0.01	0.28 ± 0.03	5.26 ± 0.32
Slurry, lg. flowthrough tank outflow	9	94.13 ± 0.78	5.87 ± 0.78	0.36 ± 0.02	0.19 ± 0.02	0.17 ± 0.01	0.002 ± 0.004	0.36 ± 0.02	0.05 ± 0.01	0.28 ± 0.03	6.86 ± 0.21
NEO, lg. flowthrough tank outflow	12	94.07 ± 0.69	5.93 ± 0.69	0.44 ± 0.05	0.16 ± 0.02	0.28 ± 0.04	0.115 ± 0.059	0.55 ± 0.09	0.05 ± 0.01	0.28 ± 0.01	5.93 ± 0.80
Slurry, sm. static tank	40	94.21 ± 0.28	5.79 ± 0.28	0.40 ± 0.02	0.23 ± 0.01	0.17 ± 0.02	0.002 ± 0.007	0.40 ± 0.02	0.06 ± 0.01	0.30 ± 0.01	6.96 ± 0.21
NEO, sm. static tank	40	93.41 ± 0.20	6.59 ± 0.20	0.48 ± 0.03	0.17 ± 0.01	0.32 ± 0.03	0.143 ± 0.041	0.63 ± 0.04	0.06 ± 0.00	0.30 ± 0.01	5.49 ± 0.12

Emissions Reduction: The N2 Applied technology dramatically reduces NH_3 emissions, with levels from NEO tanks averaging less than 10 ppm, compared to an average of 67 ppm from static slurry tanks. This reduction contributes to improved air quality and minimizes the potential for environmental contamination. Furthermore, the technology also showed lower levels of CH_4 emissions from NEO tanks, averaging no more than 3 ppm, while slurry emissions frequently exceeded 1,000 ppm. Figures 7 and 8 detail these findings, underscoring the environmental benefits of using N2 Applied in dairy manure management.

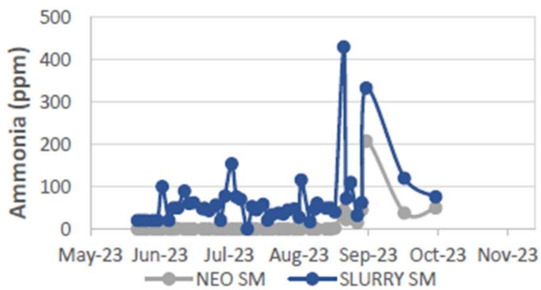


Figure 7: NH3 from NEO and slurry static tanks

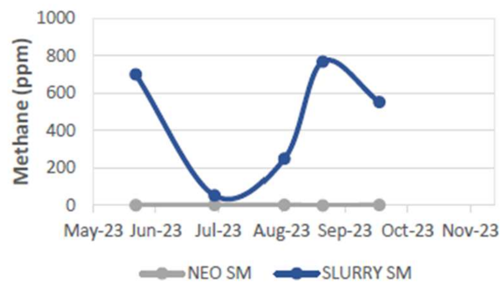


Figure 8: CH4 from NEO and slurry static tanks

Energy Efficiency and Economic Viability: The N2 Applied technology demonstrates operational efficiency with an electricity consumption rate of 1.25 kWh per gallon of NEO produced. With projected annual electricity costs of the demonstration unit to be approximately $26,840 for continuous operation, the system presents a potentially feasible economic model for dairy farms. The anticipated efficiency improvements in newer models, described by the technology provider, may further reduce operational costs. Figure 9 provides insight into the power usage patterns, reinforcing the economic viability of adopting this technology in manure management.

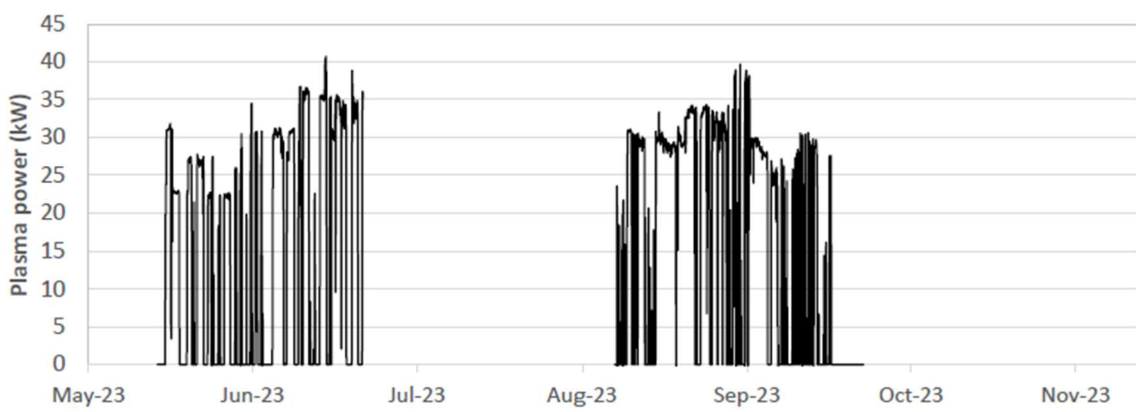


Figure 9: Machine-reported plasma torch DC power draw

EVALUATION KEY ISSUES AND CHALLENGES

Regular Maintenance: The N2 Applied unit requires regular maintenance to ensure optimal performance. One critical component is the plasma torch, which uses significant power to create a plasma of compressed ambient air injected into the manure. The torch's copper core degrades with use and needs refurbishment every 12 to 14 days. This process involves stopping the unit, refurbishing or replacing the copper core, and restarting the unit, which incurs downtime and maintenance costs. Additionally, the unit uses defoamer to manage foaming events, with approximately 15 gallons used over six months. Faults in the foam indication sensor led to increased defoamer usage, occurring twice during this study, and required consistency checks. The mixing towers within the unit also need periodic cleaning to remove solids build-up, especially after long periods of inactivity. This involves disassembling, power washing, drying, and reassembling the components.

Integration and System Compatibility: Integrating the European-designed N2 Applied unit with the U.S. farm system posed several challenges. The unbalanced loads and the need for voltage and frequency conversion led to faults and system errors. The farm also lacked the necessary infrastructure, requiring the setup of pumps, separators, and conveyance systems. Many of the components chosen were undersized or improperly installed, causing pump cavitation, clogs, and manure supply issues. These integration challenges highlighted the importance of system-level compatibility for successful manure treatment

Operational Stability: Operational stability was another key issue, particularly with the destabilization of the NEO. Inconsistent operation and potential comingling of untreated slurry led to denitrification in the large flowthrough NEO tank, causing a rapid pH increase and foaming. Seasonal temperature changes may have also contributed to this instability. Additionally, the unit experienced overheating issues, particularly in the control panel, due to heat generated by the air compressor and transformers. Ventilation improvements performed during the study, such as installing vents and exhaust fans, were necessary to prevent downtime.

Controls and Sensors: The N2 Applied unit faced several issues with controls and sensors. Initial software problems prevented remote monitoring and control, requiring a new internet service provider. Sensor faults, particularly with the foam level indicator, led to operational disruptions and required replacements. The foam level sensor was sensitive to substantial ambient temperature changes, causing foam to overflow from the unit's exhaust during overnight temperature drops. Furthermore, the original air compressor was inadequate and needed replacement, and valve issues with the compressed air supply required repairs. These challenges underscored the need for reliable controls and high-quality components to ensure smooth operation.

IMPLICATIONS

Key findings indicate that the N2 Applied technology effectively enriches nitrogen in manure and reduces NH_3 and CH_4 emissions during the summer months. However, long-term stability, especially in colder months, remains unassessed, with late-trial NH_3 emissions suggesting potential stability issues. Operational challenges and intermittent use hindered a full evaluation of the unit's efficacy and economic viability. Continuous operation of the new, commercial Gen 0 unit is needed to accurately assess treatment effects, production rates, and costs. Initial estimates suggest the system may be cost-prohibitive without substantial carbon credit incentives, though improved efficiencies in the Gen 0 unit are expected. Additionally, both the N2 Applied unit and NEO storage are potential sources of NOx emissions, requiring careful monitoring. Agronomic trials and field emissions monitoring are necessary to ensure NEO can enhance crop yield and quality without increasing emissions of NH_3, N_2O, or other pollutants. Despite these challenges, the N2 Applied technology shows significant promise for sustainable manure and nutrient management with further optimization and continuous operation trials

For additional information on the vendor, environmental impacts, financial implications, and N2 Applied technology visit the N2 Applied Vendor Snapshot on the Newtrient website.

REFERENCES

N2 Applied (2024) https://n2applied.com/the-technology/

VERA (2018) VERA Test Protocol: Covers and other Mitigation Technologies for Reduction of Gaseous Emissions from Stored Manure. Version 3:2018-07

This study was funded by the New York Farm Viability Institute (NYFVI) and the Natural Resources Conservation Service (NRCS) through a Conservation Innovation Grant (CIG). The views and findings presented in this publication are those of the author(s) and do not necessarily reflect the official views or policies of NRCS or the U.S. Department of Agriculture.

Appendix C

Third-Party Review of N2 Applied Nitrogen Fixation Technology with Plasma Injection at CoBar Dairy – Mount Upton, NY (Full Report)

Evaluating Potential Environmental Benefits of a Prototype N2 Applied Technology - Final Report

June 12, 2024

Prepared by

Dr. Jason Oliver, Dairy Environmental Systems Engineer

Cornell University, Dept. Animal Science, PRO-DAIRY, Dairy Environmental Systems

Lauren Ray, Agricultural Sustainability & Energy Engineer

Cornell University, Dept. Animal Science, PRO-DAIRY, Dairy Environmental Systems

Prepared for

Newtrient, LLC, as part of a research project "Evaluating Environmental and Economic Benefits of Nitrogen Conservation through the N2 Applied Technology" funded by the New York Farm Viability Institute; funds also supplied by PRO-DAIRY and USDA NRCS Conservation Innovation Grant.

Acknowledgement of key collaborators

Cornell Cooperative Extension: Nicole Tommell, Erik Smith, Ashley Bound, Ashley McFarland

Host Farm: CoBar Dairy

On-Site Operators: Gareth Coates, Scott Barnes

Introduction

The N2 Applied technology is a manure treatment system that can elevate and preserve nitrogen levels in manure while reducing the emission of environmentally important gases – namely methane (CH_4) and ammonia (NH_3). The N2 Applied technology is arranged in a shipping container and utilizes ambient air compression and a high voltage plasma torch to create nitrogen oxides (NOx) from atmospheric nitrogen and oxygen gases. This NOx is then absorbed into separated liquid manure using a venturi and recirculation until a setpoint pH decrease is achieved. The treatment process and lowering of the pH inhibit microbial generation of CH_4 and favor the formation of ammonium (NH_4^+) over the more volatile NH_3, thus mitigating these emissions. This treatment process has unique potential for dairy manure management and may be applicable to small farms. While this technology has been trialed in Europe, evaluation on US dairy farms had not previously been done.

Methods

Treatment system

During the growing season of 2023, CoBar Dairy farm near Rockdale, NY, hosted a pilot, research scale N2 Applied unit (model MK 4.4), owned by ProStar Energy. Dairy manure from the farm was scraped multiple times a day into a below-grade, circular, concrete storage structure. Near the influent, a lift pump was installed to feed a solid-liquid manure separator (Bauer, S300). Separated manure liquids were pumped to and treated in the N2 Applied unit in a sequential batch process, where approximately 20 gal. of separated manure liquids were processed until the pH fell below the setpoint, after which the treated manure, referred to as nitrogen enriched organics or "NEO", was pumped out and a new batch of separated manure liquids brought in. The original pH setpoint for the N2 Applied unit was 5.5, this was later changed to 5.0. Separated manure solids were not treated and used as soil amendments by the farm.

Small-tank manure storage mesocosms

To mimic long-term manure storages, one vertical, cylindrical polytank (1,100 gal.) was filled with approximately 800 gal. of NEO and another with approximately 800 gal. of untreated separated manure liquids ("slurry") on May 20, 2023. Each tank was equipped with a ventilator (SEAFLO, SFIB2130-01) and 3 in. inlet vent to generate an airflow across the surface of 0.22 – 0.67 mph, in line with recommendations of VERA (2018). No additional material was added to these tanks during the study.

Large-tank flowthrough systems

To monitor the treatment process, two horizontal, cylindrical steel tanks (11,000 gal.) were plumbed to receive either freshly produced NEO, or slurry at approximately the same production rate as the NEO. Like the small tanks, each of these tanks was outfitted with a ventilator (SEAFLO, SFBB1-32003) and 4 in. inlets to generate an airflow across the surface of 0.22 – 0.67 mph. Additionally, overflows were placed approximately 2 ft. from the top of each tank, with the slurry gravity overflowing to a long-term manure storage, while the NEO overflowed to a collection tote where it was pumped to a frac tank for farm crop usage.

Temperature

During the study, temperature loggers (OnSet, HOBO U22-001) were suspended mid-depth in all of the tanks and recorded hourly. Another logger (Onset, HOBO U23-001A) housed in a solar shield near by the tanks was used to record air temperature and relative humidity.

Manure sampling

Three times a week, as available, during the duration of the study (May-Sept. 2023) 500 mL samples of the raw manure, separated liquids, NEO effluent, slurry and NEO from both the small and large tanks were collected. A couple samples from the static tanks were also collected in mid Oct. and Nov. Samples were either collected directly from influent and effluent flows or in the case of the small tanks, samples were retrieved with PVC manure collector built according to University of Minnesota recommendations. Samples were refrigerated and shipped on ice within a week to A & L Great Lakes Laboratory where sample pH, total solids, nitrogen (Kjeldahl, ammonium, organic, nitrate, and total), phosphorus, and potassium were measured.

Air emissions monitoring

During site visits, prior to manure sampling, air concentrations of CH_4, NH_3, NO_x, as well as carbon dioxide (CO_2), oxygen (O_2), and hydrogen sulfide (H_2S) were measured in the ambient and exhaust of the ventilation system of each tank using a suite of gas analyzers and gas analytical tubes. Most routinely, a Sewerin (Multitec 540) was used to monitor CO_2, CH_4, and H_2S and Sensidyne tubes used to measure NH_3 and NO_x. The NO_x Sensidyne tubes were also used to test the N2 Applied unit exhaust. As available, more sensitive gas analyzers were used, including the Ventis (Pro5) for CO_2, CH_4, NH_3, and H_2S and the

LICOR (7810) for CO_2 and CH_4. On a couple occasions, the LICOR (7820) was used to measure nitrous oxide (N_2O). Their detection ranges are outlined in Table 1.

Table 1. Gas analytical instrumentation, detection ranges and sensitivity.

Gas	Detection range (resolution)	Instrument
NH_3	1-200 ppm (0.2 ppm) 0-500 ppm (1 ppm)	Sensidyne 105SE Industrial Scientific Ventis Pro
N_2O	0-100 ppm (0.2 ppb)	Licor-7820
NO_x	1-30 (0.2 ppm) 20-250 (2 ppm)	Sensidyne 175U Sensidyne 175SA
H_2S	0-5,000 ppm (1 ppm) 0-500 ppm (0.1 ppm)	Sewerin 545 Industrial Scientific Ventis Pro
CH_4	0-100% (0.1%) 0-5% (0.01 %) 0-100 ppm (0.25 ppb)	Sewerin 545 Industrial Scientific Ventis Pro Licor-7810
CO_2	0-100% (1%) 0-5% (0.01 %) 0-10,000 ppm (1.5 ppm)	Sewerin 545 Industrial Scientific Ventis Pro Licor-7810

Operator and machine data

Close communication with the on-site N2 Applied unit operator and with the technology provider informed the operation and maintenance requirements. Machine data logged by the N2 Applied unit included (pH, production rates, energy usage, etc.), was also collected and summarized. Machine data was missing or incomplete during the period of June 21st to August 7th.

Energy usage

A new 3-phase utility service was installed on the farm to supply power to the N2 Applied unit and all supporting equipment, including feed pumps and solid-liquid separation components. The utility meter associated with this service reported total electricity usage on screen and totalized in bills every 2 months. Peak power demand by month was also reported in utility bills. The N2 Applied machine data included the direct current (DC) power usage of the plasma torch within the unit, the largest power usage of all components associated with the system. The utility meter was read out during each site visit starting in mid-July to better track electricity usage, after discovering that the utility reported no hourly data in the billing.

Results & Discussion:

Operational Data

Timeline of Key Events

05/15/2023	N2 Applied unit was started.
05/20/2023	Filled small tanks and started project.
05/22/2023	Started monitoring emissions.
05/24/2023	Started sampling manure.
06/16/2023	Large NEO tank full.
06/22/2023	Large slurry tank full.
06/23/2023	N2 Applied unit turned off due to manure shortages.
06/30/2023	N2 Applied unit restarted.
07/02/2023	Large NEO tank foamed/destabilized.
08/07/2023	N2 Applied unit restarted at pH 4.5.
08/16/2023	N2 Applied unit adjusted to pH 5.0.
08/25/2023	Large tanks full
09/17/2023	N2 Applied unit foamed out exhaust vent and turned off.

Treatment rates

When the N2 Applied unit was operating, it would treat slurry to produce approximately 25-55 gal. of NEO each hour. During the first continuous runtime of the N2 Applied unit (May 15 - June 23), approximately 15,000 gal. of NEO were generated and during the second continuous runtime (Aug 7 – Sept. 17) approximately 20,000 gal. of NEO were generated (Figure 1). Exact rates of production were hard to determine as they often varied day to day and over the study period. Early in the study (e.g., June), production rates reached 1,055 gal./d. Later in the study, when the pH setpoint was reduced to 5.0, daily production rates reached 960 gal./day, but the average was much lower at 534 gal./day (roughly equivalent to 30 lactating cows worth of manure per day). This is substantially lower than the reported ability to process 200 cows' worth of manure per day, potentially due to challenges and issues discussed later, including solid-liquid separation operation and manure buffering capacity.

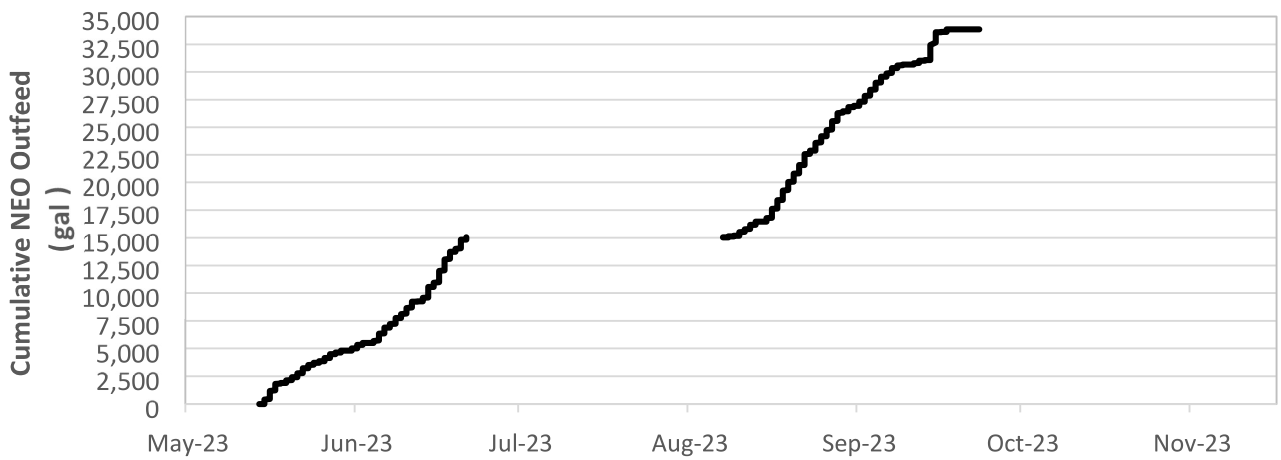


Fig. 1. Cumulative NEO outfeed during the trial based on N2 Applied machine collected data.

Temperature

Temperatures in the filled small static tanks and in the filled large flowthrough tanks were similar and roughly tracked ambient temperatures though were usually warmer (Figure 2).

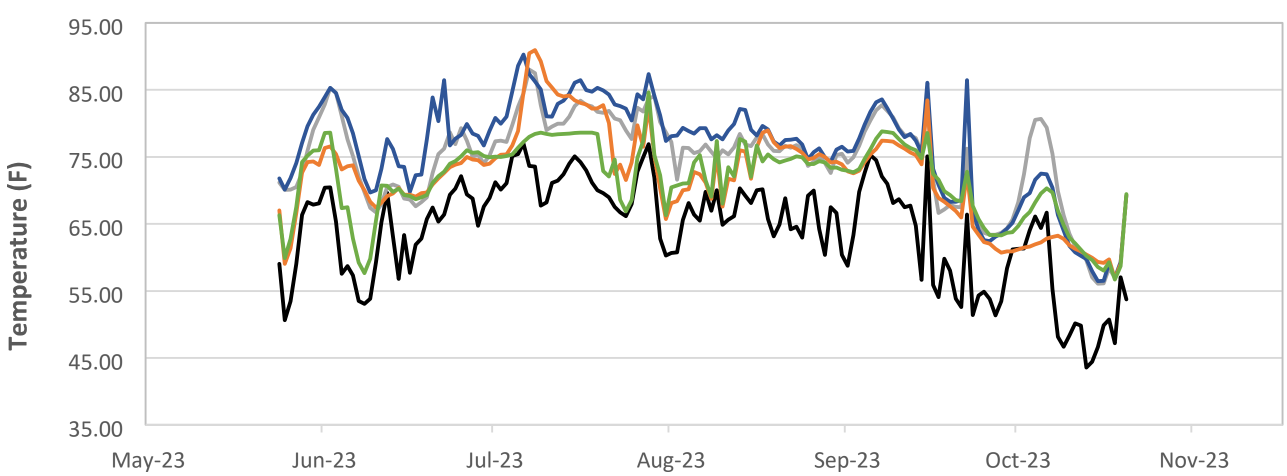


Figure 2. Ambient and manure slurry temperatures.

Manure constituents and pH

Separation efficiency

The solid-liquid separator removed approximately 12.5% of the mass of the raw manure as separated manure solids, while approximately 87.5% of the mass continued as separated manure liquids. Separated manure liquids had an average solids content of 5.69±0.58% (Table 2), while separated solids has an average solids content of 26.49±0.95%.

N2 Applied process effects

The N2 Applied treatment process substantially changed some manure slurry constituents while leaving others unaltered (Table 2). There were minimal changes to the moisture and solids content of the manure slurry. Nitrogen content increased substantially for all constituents, except ammonium. Nitrate was particularly elevated from trace amounts in separated manure liquids to 0.17% in NEO. There was no noteworthy change to other nutrients. The pH of the manure was dramatically reduced by the treatment process from 6.70 to 5.26. During the first portion of the trial when the pH setpoint was 5.5, the resulting NEO pH was 5.45, while during the second portion of the trial when the pH setpoint was 4.5 to 5.0, the resulting NEO pH was 5.03.

Table 2. Average ± standard deviation percentage (wet basis) of moisture content, total solids, total Kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4-N), organic nitrogen (Org-N), nitrate nitrogen (NO_3-N), total nitrogen (TN), phosphorus (P), potassium (K), and pH for each sample from May 20 to Sept 17. n = number of samples.

Sample	n	Moisture	Solids	TKN	NH_4-N	Org-N	NO_3-N	TN	P	K	pH
Raw manure	25	90.71 ± 1.25	9.29 ± 1.25	0.36 ± 0.03	0.16 ± 0.03	0.20 ± 0.03	0.000 ± 0.000	0.36 ± 0.03	0.06 ± 0.00	0.27 ± 0.02	6.67 ± 0.21
Separated manure liquids	27	94.31 ± 0.58	5.69 ± 0.58	0.37 ± 0.04	0.18 ± 0.03	0.20 ± 0.03	0.001 ± 0.003	0.37 ± 0.04	0.06 ± 0.01	0.27 ± 0.02	6.70 ± 0.18
NEO, N2 Applued unit outflow	27	94.15 ± 0.59	5.85 ± 0.59	0.46 ± 0.04	0.16 ± 0.01	0.30 ± 0.04	0.166 ± 0.044	0.63 ± 0.06	0.06 ± 0.01	0.28 ± 0.03	5.26 ± 0.32
Slurry, lg. flowthrough tank outflow	9	94.13 ± 0.78	5.87 ± 0.78	0.36 ± 0.02	0.19 ± 0.02	0.17 ± 0.01	0.002 ± 0.004	0.36 ± 0.02	0.05 ± 0.01	0.28 ± 0.03	6.86 ± 0.21
NEO, lg. flowthrough tank outflow	12	94.07 ± 0.69	5.93 ± 0.69	0.44 ± 0.05	0.16 ± 0.02	0.28 ± 0.04	0.115 ± 0.059	0.55 ± 0.09	0.05 ± 0.01	0.28 ± 0.01	5.93 ± 0.80
Slurry, sm. static tank	40	94.21 ± 0.28	5.79 ± 0.28	0.40 ± 0.02	0.23 ± 0.01	0.17 ± 0.02	0.002 ± 0.007	0.40 ± 0.02	0.06 ± 0.01	0.30 ± 0.01	6.96 ± 0.21
NEO, sm. static tank	40	93.41 ± 0.20	6.59 ± 0.20	0.48 ± 0.03	0.17 ± 0.01	0.32 ± 0.03	0.143 ± 0.041	0.63 ± 0.04	0.06 ± 0.00	0.30 ± 0.01	5.49 ± 0.12

Treatment effects on slurry pH

A roughly 1.5 pH differential was maintained in the static manure tanks throughout the duration of the study (Figure 3), though collections from Oct and Nov. show a rapid pH rise. There was a similar differential observed

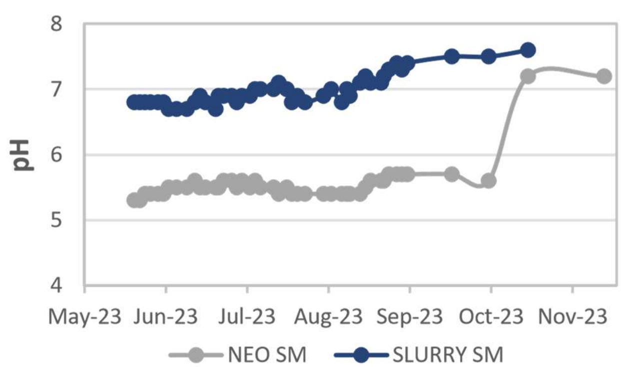


Fig. 3. pH of NEO and slurry in static tanks.

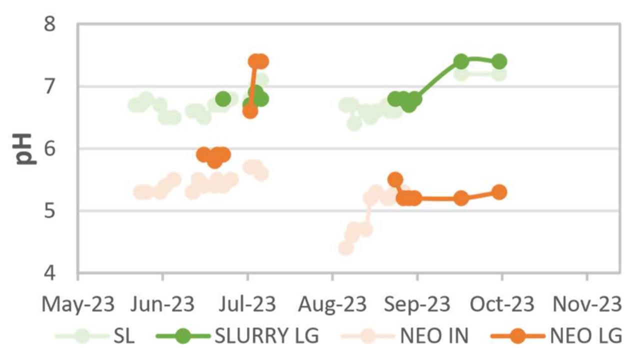


Fig. 4. pH of NEO and slurry in flowthrough tanks.

between the inflows (SL, NEO in) of the flowthrough tanks and in their outflows (Slurry lg, NEO lg.) except in late June when the pH of the NEO lg. rapidly increased (Figure 4).

Treatment effects on slurry nitrogen content

There was an approximate 57% increase in the total nitrogen content in the NEO verses slurry of the static tanks (Figure 5), and a 45% increase in the large tanks, outside of late June, where the NEO lost the enriched nitrogen (Figure 6). This increase was due in large part to elevated nitrate, which increased from trace amounts by several orders of magnitude following the NEO treatment. While elevated nitrate was sustained in the static tanks for almost the duration of the study (Figure 7), enriched nitrate was lost in Oct. in the static tanks and in late June from the flowthrough tanks (Figure 8). Following the restart period, the elevated nitrate was preserved. Similar patterns were also observed for ammonium (Figures 9 & 10) total Kjeldahl nitrogen (Figures 9 & 10) and organic nitrogen (Figures 11 & 12). We are unsure what triggered the rapid loss of nitrogen. It is assumed to be related to a denitrification event that may have been related to a slow loss of buffering capacity and pH drift, microbial changes due to mixing of untreated slurry with NEO or even temperature.

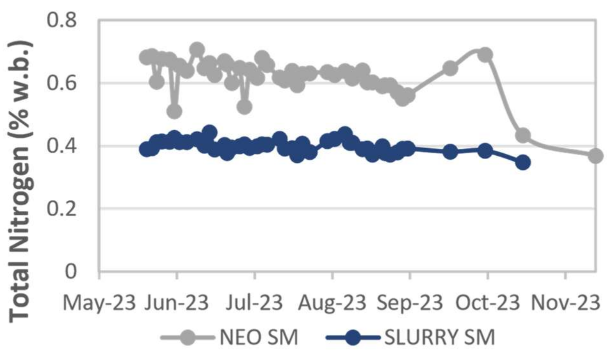


Fig. 5. Total N in NEO and slurry in static tanks.

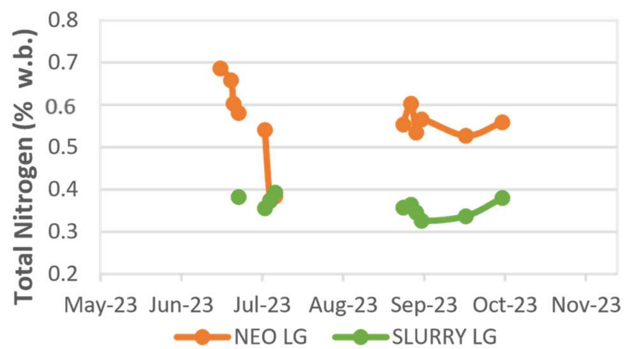
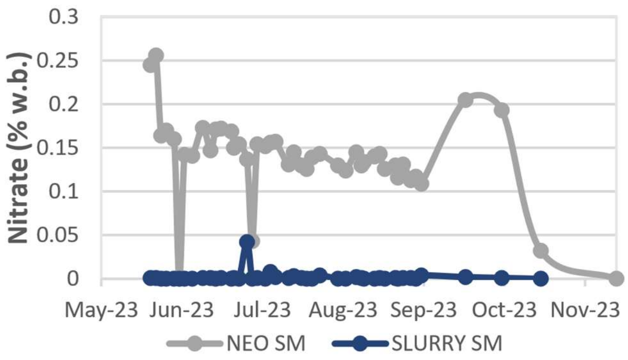


Fig. 6. Total N in NEO and slurry in flowthrough tanks.



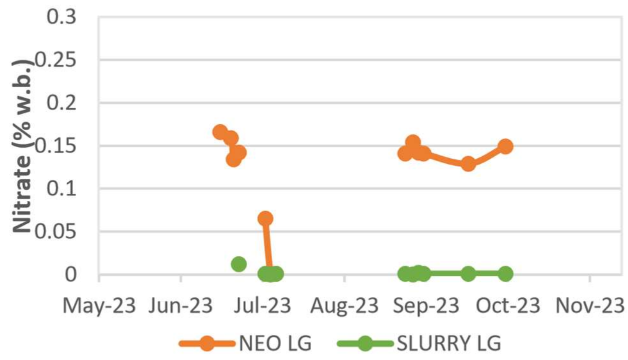
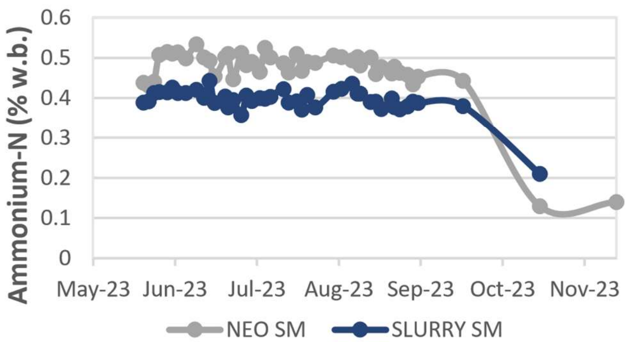


Fig. 7. NO_3-N in NEO and slurry in static tanks.

Fig. 8. NO_3-N in NEO and slurry in flowthrough tanks.



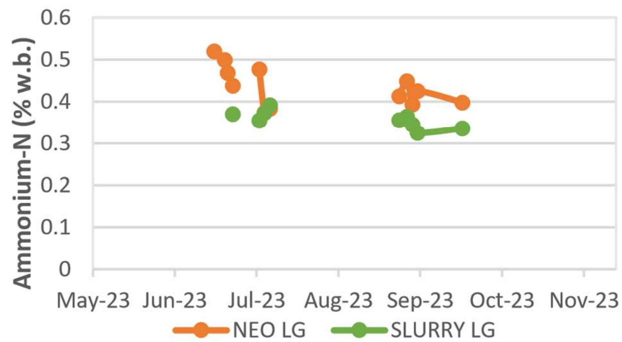


Fig. 9. NH_4-N in NEO and slurry in static tanks.

Fig. 10. NH_4-N in NEO and slurry in flowthrough tanks.

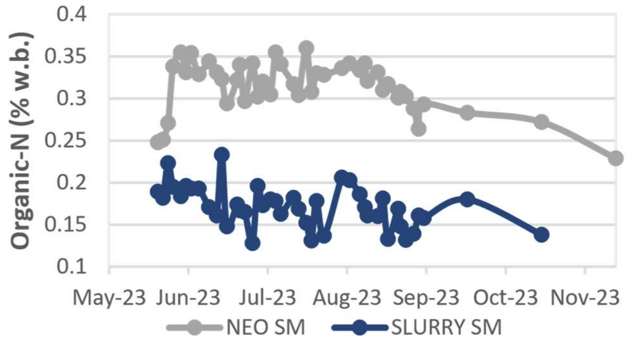


Fig. 11. Org-N in NEO and slurry in static tanks.

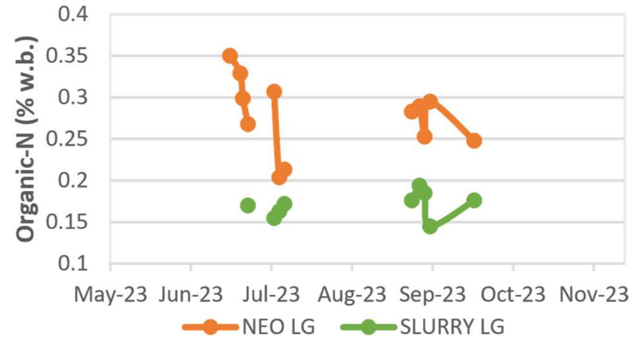


Fig. 12. Org-N in NEO and slurry in flowthrough tanks.

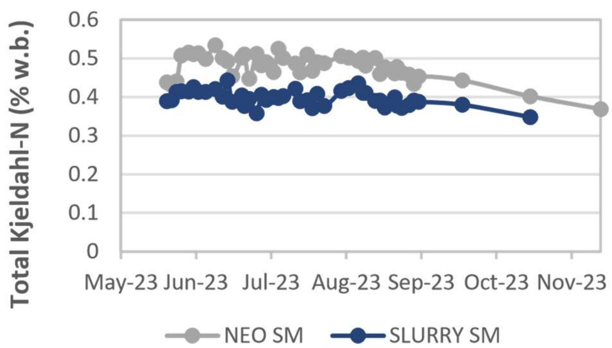


Fig. 13. TKN in NEO and slurry in static tanks.

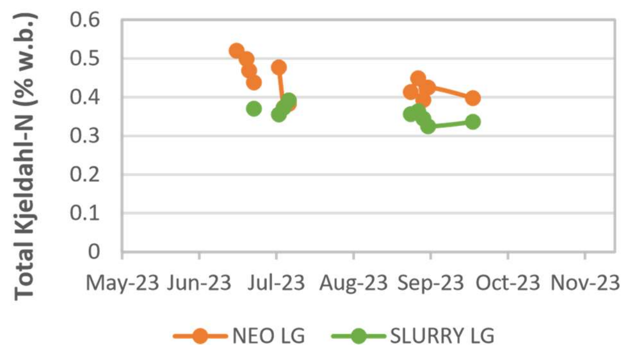
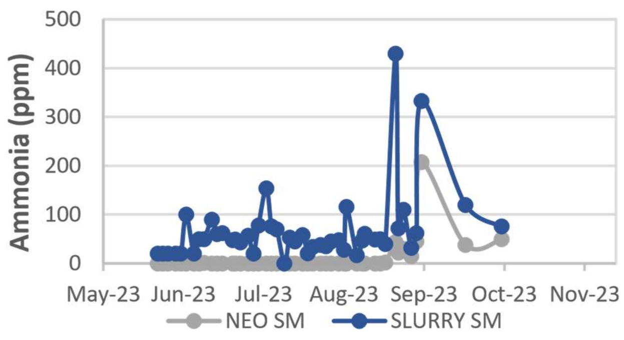


Fig. 14. TKN in NEO and slurry in flowthrough tanks.

Nitrogenous and greenhouse gas emissions

Ammonia emissions

Ammonia emissions from the static slurry tank ranged from 0 to 430 ppm with an average of 67 ppm (Figure 15). Emissions from the static NEO tank were 0 to 2 ppm in the exhaust of the static NEO tanks until Aug 18, at which point they did increase, though always less than the slurry, to a maximum of 208 ppm. Emissions from the static NEO tank averaged < 10 ppm over the duration of the trial. During the initial N2 Applied unit run, NH_3 emissions were measured from both NEO and slurry tanks (Figure 16). In the second run of the N2 Applied unit, NH3 emissions were only measured initially from the NEO, and then were not detected, while slurry emissions were typically detected.



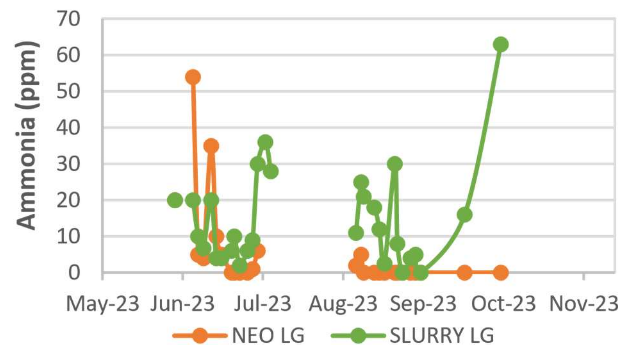
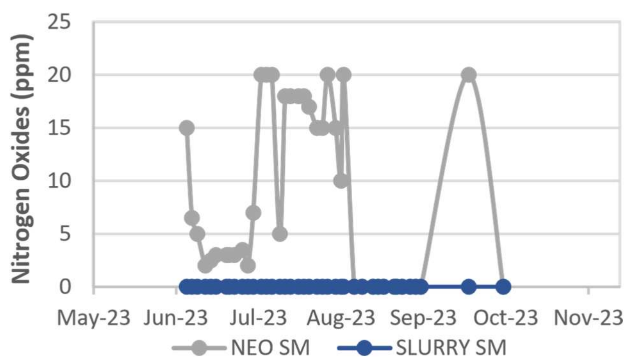


Fig. 15. NH_3 from NEO and slurry static tanks.

Fig. 16. NH_3 from NEO and slurry flowthrough tanks.

Nitrogen oxide emissions

Nitrogen oxides (nitric oxide and nitrogen dioxide) were emitted from both NEO static and flowthrough tanks but were not detected from either slurry tank (Figures 17 & 18). From the static tank, NOx emissions fluctuated between 2 and 20 ppm for most of the trial, while from the larger flowthrough tanks emissions were similar from the initial continuous run but were elevated, typically > 100 ppm, during the second run when the pH setpoint was lower. When the exhaust of the N2 Applied unit was tested for NO_x emissions, levels routinely exceeded the detection limit of 250 ppm.



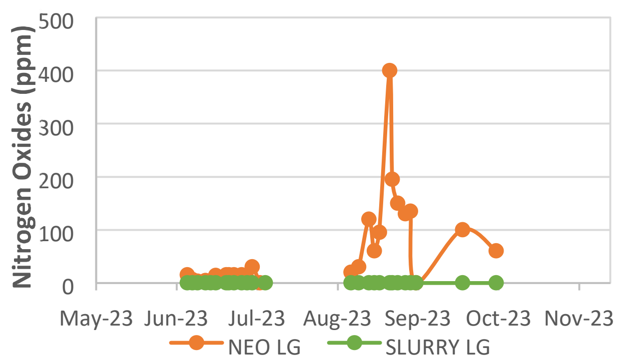


Fig. 17. NO_x from NEO and slurry static tanks.

Fig. 18. NO_x from NEO and slurry flowthrough tanks.

Greenhouse gas emissions

The greenhouse gases CO_2 and CH_4 were measured routinely. The Sewerin gas analyzer used during each visit had limited resolution of CO_2 at the low levels observed. The measurements from the more sensitive Ventis Pro analyzer used on eight trips throughout the study are summarized in Table 3. Generally, CO_2 emissions from slurry tanks were double the emissions from the NEO tanks.

Carbon dioxide levels measured from the static NEO tank approximated ambient levels, with the NEO flowthrough tank having elevated levels compared to ambient, though most of the measurements were during the first run of the N2 Applied unit.

Table 3. Concentrations of CO_2 measured from ambient and tank exhausts using the Ventis Pro analyzer. n = number of samples.

	Ambient	NEO Sm.	Slurry Sm.	NEO Lg.	Slurry Lg.
n	7	8	8	5	6
Average [CO_2] (ppm)	286	338	775	1680	4540
Standard deviation	69	119	139	1705	2464

The Sewerin gas analyzer was sufficient for measuring CH_4 in the larger flowthrough tanks, but the more sensitive LICOR gas analyzer, only available five times during the study period, was required to monitor CH_4 in the static tanks (Table 4).

Table 4. Concentrations of CH_4 measured from ambient and sm. static tanks exhausts using the LICOR 7810 and from the lg. flowthrough tank exhausts using the Sewerin gas analyzer. n = number of samples.

	Ambient	NEO Sm.	Slurry Sm.	NEO Lg.	Slurry Lg.
n	5	5	5	25	27
Average [CH_4] (ppm)	2.4	2.2	464.7	280	3248
Standard deviation	0.7	1.2	304.1	458	4267

For the static tanks, CH_4 was never measured above 3ppm from the NEO, while levels ranged from 54 to 768 ppm from the slurry (Figure 19). For the flowthrough tanks, CH_4 was elevated in the NEO compared to ambient ranging from 0 to 1,000 ppm, but substantially lower than the slurry which was routinely > 1,000 ppm with several readings exceeding 10,000 ppm (Figure 20).

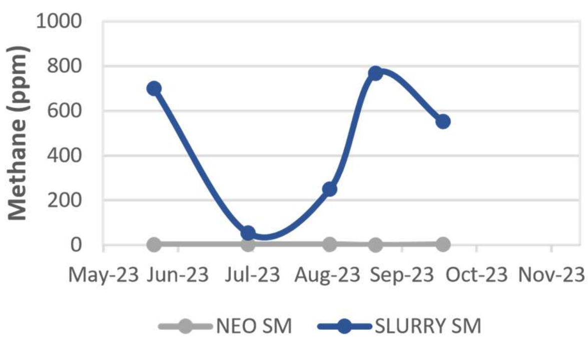


Fig. 19. CH_4 from NEO and slurry static tanks.

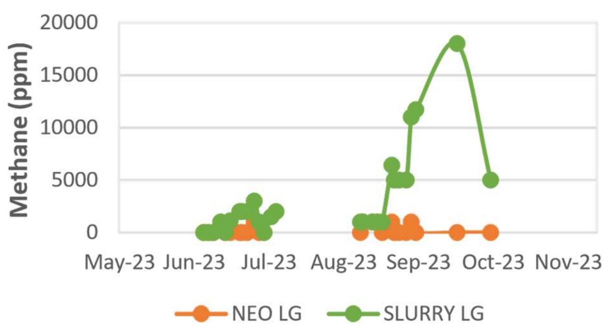


Fig. 20. CH_4 from NEO and slurry flowthrough tanks.

Due to delays in the arrival of the equipment, the LICOR 7820 nitrous oxide (N_2O) analyzer was only used once near the end of the trial (Sept. 18th) and on the small static tanks, as the larger tank was foaming and the N2 Applied unit was shut down. Measurements are reported in Table 5 and do suggest the NEO may have elevated N_2O emissions.

Table 5. Concentrations of N_2O measured from ambient and tank exhausts using the LICOR 7820. NA = not available.

	Ambient	NEO Sm.	Slurry Sm.	NEO Lg.	Slurry Lg.
[N_2O] (ppb)	361	6617	412	NA	NA

Energy and Economics

The MK 4.4 is a 50kW machine. Over the available 4-month billing period of 4/28/23 to 8/29/23 that best aligned with the study period, the total electricity usage of the complete system, including solid-liquid separator and pumps, was 49,665 kWh. Based on the N2 Applied machine data provided, approximately half of this electricity was consumed by the plasma torch, however this included periods of downtime and missing machine data and does not account for the AC to DC power conversion loss. The utility billed peak power demand ranged between 55.6 kW and 62.8 kW. Figure 21 shows the N2 Applied unit machine-reported plasma torch DC power draw over the full period of operation.

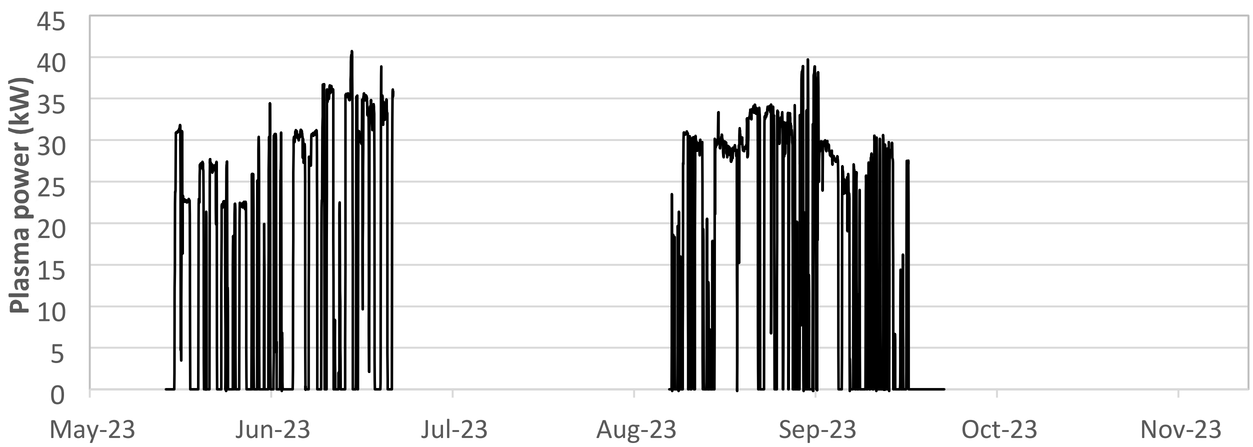


Figure 21. Machine-reported plasma torch DC power draw.

During a 3-week period of what is believed to be normal operation (8/16/23 – 9/5/23), the plasma torch had an average DC power draw of 24.2 kW and a maximum power draw of 39.4 kW.

Approximately 15,000 kWh of electricity usage was indicated from utility meter readings onsite, and 12,000 kWh attributed to the plasma torch (80% of the total) in this same 3-week period. Approximately 12,000 gallons of NEO were produced during this period, indicating electricity usage of the process is

1.25 kWh/gal. The N2 Applied technology provider has described the new, Gen 0 unit as having twice the processing throughput for the same amount of power usage.

If the studied unit and supporting system components were operated year-round, it could be estimated to use 260,000 kWh with a peak demand of 60 kW. At the farm's $0.07/kWh electricity usage rate and $12/kW demand charge, the estimated annual cost of electrical power to supply the manure management system studied would be $26,840. Assuming 208,415 gallons can be processed annually (based on the daily production rate discussed above), the operating cost for just electricity would be nearly $0.13 per gal. It is difficult to evaluate the fertilizer cost savings without an agronomy trial. We have been told that the commercially available units in Europe and the units GEA is making for US markets will have much higher efficiencies and lower operating costs.

Regular Maintenance

Plasma torch

The N2 Applied unit includes a plasma torch (Figure 22) that uses a large amount of power to create a plasma of compressed ambient air injected into the manure. The plasma torch has a copper core that degrades with use and needs to be refurbished. On the unit studied, refurbishment was required every 12 to 14 days. The indication that refurbishment was needed when observing a sudden drop in the actual power output by the plasma torch compared to the power set point. For example, the plasma power set point might be 45 kW and if the actual power output read 38 kW, the torch needed to be refurbished. Refurbishment of the plasma torch on the studied unit involved stopping the unit, removing the torch, sharpening and smoothing the copper core or replacing it, and then reinserting and starting up the unit again. While this process took less than one hour, it did involve a frequent shut down and some component replacement costs. The Gen 0-unit torch has been redesigned to use less copper, have extended life, and easier/faster refurbishment. has been described as having some advantages over the studied unit for the plasma torch maintenance.

Figure 22. Plasma torch used by the prototype N2 Applied unit studied.

Defoamer

A drum of defoamer is required with supply to the N2 Applied unit. A small amount is used within the unit's tank based on a foam indication sensor. During the 6-month period when the studied unit was operating, approximately 15 gallons of defoamer were used. It was observed that more defoamer was used when the foam indication sensor faulted, which happened at least 2 different times. The defoamer coagulated at times and needed to be checked for proper consistency.

Mixing towers

There were 4 mixing towers within the N2 Applied unit studied. The mixing towers interface with the tank within the unit to allow for proper integration of the plasma with the manure. The mixing towers may require periodic cleaning to remove solids build-up. This was observed particularly when the unit had been stopped for a long period of time, such as might happen over the winter. Cleaning the towers, as well as the tank within the unit, involved disassembling the components, power washing the inside surfaces, letting it dry, and then reassembling. An indication of solids build-up and interference with the proper function of the N2 Applied unit was observed when the tank pressure sensor had a higher-than-normal pressure reading.

Solid-liquid separation

The N2 Applied unit requires upstream removal of coarse manure fibers (greater than 3 mm) and both separators and conveyance systems have maintenance requirements.

Issues and Repairs

Integration with the manure systems

System level integration is key to any successfully manure treatment. Several things challenged integration of the N2 Applied unit evaluated with the farm system. The European equipment created power and energy connection issues. The three-phase power brought into the farm for the system had unbalanced loads that challenged connection and smooth operation. This was exasperated by the need to transform voltage and convert frequency for the European equipment to meet the specs of the US grid. Essentially, the tolerances of the incoming power were greater than what the N2 Applied unit could manage and resulted in several faults and unexpected system errors.

Secondly, a manure supply pump, solid liquid separation system and conveyance systems all needed to be setup to operate the N2 Applied unit as the farm lacked this infrastructure (relatively common on some dairy farms). Many of the components chosen were undersized or lacked important features (i.e., a correctly installed chopper blade on the lift pump) that resulted in pump cavitation, clogged lines and equipment, repairs, and ultimately manure supply issues.

Destabilization of the NEO

During the trial, the large flowthrough NEO tank evidently denitrified, resulting in a relatively rapid pH increase and large foaming event, presumably due to the release of nitrogenous gases. The N2 Applied technical team believe this was due to the inconsistent operation of the N2 Applied unit and perhaps some comingling of untreated slurry with the NEO. Inconsistent operation was due partially to challenges integrating the solid liquid separator and it is possible that solids greater than

3mm were conveyed into the N2 unit, which according to the company are too large to be effectively treated. It is also possible that the slow pH drift and loss of nitrogen over time set the stage for microbial denitrification. Seasonal temperature changes may also haver played a role; temperature recognized to impact denitrification processes in agriculture fields.

Ventilation and overheating

The temperature inside the unit container was too hot, particularly for the control panel. This took substantial time to correct, resulting in unanticipated downtime early in the operational period. The air compressor located within the container generates substantial heat. Additionally, the transformers used for the power conversion from the US utility voltage and frequency to the European voltage and frequency utilized by the unit generated significant heat inside the control panel. Vents in both the control panel and the container itself had to be cut, with exhaust fans installed to expel excess heat. Ultimately the container door needed to be left open to improve ventilation. It is our understanding that the Gen 0 unit has partitioned the air compressor, has changed the configuration of control panel, and will be configured for the voltages and frequency of the US grid. It is possible that the Gen 0 unit will require a temperature-conditioned space. There may be opportunities for heat recovery during summer operation; excess heat is currently dumped to the atmosphere.

Controls software and sensors

A unit control software issue occurred at the beginning of the study period that was not allowing remote operational monitoring or setting of parameters which resulted in unexpected down time. This was due to rural internet disruptions and a new internet provider had to provide a service. The tank level sensor needed to be replaced part way through the study period. The foam level indicator sensor faulted 2 or 3 times and needed to be replaced. The foam level sensor seemed to be sensitive to substantial ambient temperature changes, such as a 30°F change over a 24-hour period. During an overnight temperature drop, typical of the region, substantial foam generated in the treatment tank came out of the N2 Applied unit's exhaust.

Air compressor

The original air compressor model was not correct and needed to be swapped out at the startup period. Additionally, there was a valve issue with the compressed air supply that needed repair. A high-quality commercial air compressor is required.

Key take-aways

(1) Evaluation of the static tanks suggest NEO remains enriched in nitrogen with reduced emissions of NH_3 and CH_4 for at least several months during the summer, but longer-term stability of NEO, particularly during colder months was not evaluated. The pH of stored NEO did climb through the study and late during the trial NH_3 emissions were measured, suggesting potential stability limitations, at least for NEO buffered to pH 5.5.

(2) Intermittent operation and the challenges encountered with the N2 Applied unit and support systems studied made it difficult to evaluate the efficacy and economics of operating the treatment

unit. There is a need to study a commercial Gen 0 unit under continuous operation to accurately assess treatment effects, production rates, capital, and operating cost breakdowns. This is particularly important to evaluate the feasibility of the system for dairy farm businesses. Estimated operating costs based on the limited data collected as part of this trial suggest the system is cost prohibitive without substantial carbon credits, though it is likely that the Gen 0 unit will have improved efficiencies.

(3) Both the N2 Applied unit and the storage of NEO are potential sources of NO_x emissions.

(4) There is also a need for agronomic trials of NEO in concert with field emissions monitoring to ensure NEO can improve crop yield and quality while not contributing to elevated emissions of NH_3, N_2O, or other emissions. This is needed to assess the environmental and economic benefits of the technology more fully.

References

VERA (2018) VERA Test Protocol: Covers and other Mitigation Technologies for Reduction of Gaseous Emissions from Stored Manure. Version 3:2018-07

UMN manure collector: https://extension.umn.edu/manure-management/manure-sampling-andnutrient-analysis#sampling-liquid-or-slurry-from-a-deep-pit-817361

Appendix. Example of manure slurry and NEO sample analysis.

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To: NEWTRIENT LLC - SIG GRANT
11510 LAURIE DR
WHEATFIELD, IN 46392-7364

For: CORNELL UNIVERSITY

Attn: MARK STOERMAN

Purchase Order: CORNELL UNIVERSITY

Lab Number: 58069
Sample ID: SEP LIQ SL
Manure Type: DAIRY, LIQUID PIT (20)

Date Sampled: 8/25/2023
Date Received: 8/30/2023
Date Reported: 9/1/2023

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MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal **	First Year Availability @ Pounds Per 1,000 Gal
Moisture	%	94.35	7859	
Solids	%	5.65	471	
Nitrogen, Total Kjeldahl (TKN)	%	0.337	28.1	17.7 *
Nitrogen, Ammonium (NH_4-N)	%	0.160	13.3	13.3 *
Nitrogen, Organic (N)	%	0.177	14.7	4.4 *
Nitrogen, Nitrate (NO_3-N)	%	0.000	0.0	0.0 *
Nitrogen, Total (TKN + NO_3-N)	%	0.337	28.1	17.7 *
Phosphorus (P)	%	0.056	10.6 (as P_2O_5)	10.6 * (as P_2O_5)
Potassium (K)	%	0.287	28.7 (as K_2O)	28.7 * (as K_2O)
pH	-	6.6		

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

Report Approved By: [signature] Approval Date: 9/01/2023
David Henry - Agronomist / Technical Services - CCA

Report Number
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For: CORNELL UNIVERSITY

Attn: MARK STOERMAN

Purchase Order: CORNELL UNIVERSITY

Lab Number: 58070
Sample ID: NEO INFLUENT
Manure Type: DAIRY, LIQUID PIT (20)

Date Sampled: 8/25/2023
Date Received: 8/30/2023
Date Reported: 9/1/2023

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal **	First Year Availability @ Pounds Per 1,000 Gal
Moisture	%	94.58	7879	
Solids	%	5.42	451	
Nitrogen, Total Kjeldahl (TKN)	%	0.429	35.7	33.1 *
Nitrogen, Ammonium (NH_4-N)	%	0.170	14.2	14.2 *
Nitrogen, Organic (N)	%	0.259	21.6	6.5 *
Nitrogen, Nitrate (NO_3-N)	%	0.149	12.4	12.4 *
Nitrogen, Total (TKN + NO_3-N)	%	0.578	48.1	45.5 *
Phosphorus (P)	%	0.051	9.8 (as P_2O_5)	9.8 * (as P_2O_5)
Potassium (K)	%	0.301	30.1 (as K_2O)	30.1 * (as K_2O)
pH	-	5.3		

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

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For: CORNELL UNIVERSITY

Attn: MARK STOERMAN

Purchase Order: CORNELL UNIVERSITY

Lab Number: 58071
Sample ID: NEO LG TANK
Manure Type: DAIRY, LIQUID PIT (20)

Date Sampled: 8/25/2023
Date Received: 8/30/2023
Date Reported: 9/1/2023

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MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal**	First Year Availability @ Pounds Per 1,000 Gal
Moisture	%	94.60	7880	
Solids	%	5.40	450	
Nitrogen, Total Kjeldahl (TKN)	%	0.413	34.4	29.6 *
Nitrogen, Ammonium (NH_4-N)	%	0.130	10.8	10.8 *
Nitrogen, Organic (N)	%	0.283	23.6	7.1 *
Nitrogen, Nitrate (NO_3-N)	%	0.141	11.7	11.7 *
Nitrogen, Total (TKN + NO_3-N)	%	0.554	46.1	41.3 *
Phosphorus (P)	%	0.069	13.2 (as P_2O_5)	13.2 * (as P_2O_5)
Potassium (K)	%	0.284	28.4 (as K_2O)	28.4 * (as K_2O)
pH	-	5.5		

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

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For: CORNELL UNIVERSITY

Attn: MARK STOERMAN

Purchase Order: CORNELL UNIVERSITY

Lab Number: 58072
Sample ID: SLURRY LG TANK
Manure Type: DAIRY, LIQUID PIT (20)

Date Sampled: 8/25/2023
Date Received: 8/30/2023
Date Reported: 9/1/2023

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MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal**	First Year Availability @ Pounds Per 1,000 Gal
Moisture	%	94.87	7903	
Solids	%	5.13	427	
Nitrogen, Total Kjeldahl (TKN)	%	0.356	29.7	19.5 *
Nitrogen, Ammonium (NH_4-N)	%	0.180	15.0	15.0 *
Nitrogen, Organic (N)	%	0.176	14.7	4.4 *
Nitrogen, Nitrate (NO_3-N)	%	0.001	0.1	0.1 *
Nitrogen, Total (TKN + NO_3-N)	%	0.357	29.8	19.6 *
Phosphorus (P)	%	0.048	9.1 (as P_2O_5)	9.1 * (as P_2O_5)
Potassium (K)	%	0.287	28.7 (as K_2O)	28.7 * (as K_2O)
pH	-	6.8		

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

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For: CORNELL UNIVERSITY

Attn: MARK STOERMAN

Purchase Order: CORNELL UNIVERSITY

Lab Number: 58073
Sample ID: NEO SM TANK
Manure Type: DAIRY, LIQUID PIT (20)

Date Sampled: 8/25/2023
Date Received: 8/30/2023
Date Reported: 9/1/2023

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal**	First Year Availability @ Pounds Per 1,000 Gal
Moisture	%	93.59	7796	
Solids	%	6.41	534	
Nitrogen, Total Kjeldahl (TKN)	%	0.463	38.6	31.8 *
Nitrogen, Ammonium (NH_4-N)	%	0.160	13.3	13.3 *
Nitrogen, Organic (N)	%	0.303	25.2	7.6 *
Nitrogen, Nitrate (NO_3-N)	%	0.131	10.9	10.9 *
Nitrogen, Total (TKN + NO_3-N)	%	0.594	49.5	42.7 *
Phosphorus (P)	%	0.062	11.8 (as P_2O_5)	11.8 * (as P_2O_5)
Potassium (K)	%	0.303	30.3 (as K_2O)	30.3 * (as K_2O)
pH	-	5.7		

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

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For: CORNELL UNIVERSITY

Attn: MARK STOERMAN

Purchase Order: CORNELL UNIVERSITY

Lab Number: 58074
Sample ID: SLURRY SM TANK
Manure Type: DAIRY, LIQUID PIT (20)

Date Sampled: 8/25/2023
Date Received: 8/30/2023
Date Reported: 9/1/2023

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal **	First Year Availability @ Pounds Per 1,000 Gal
Moisture	%	94.37	7861	
Solids	%	5.63	469	
Nitrogen, Total Kjeldahl (TKN)	%	0.372	31.0	23.3 *
Nitrogen, Ammonium (NH_4-N)	%	0.240	20.0	20.0 *
Nitrogen, Organic (N)	%	0.132	11.0	3.3 *
Nitrogen, Nitrate (NO_3-N)	%	0.001	0.0	0.0 *
Nitrogen, Total (TKN + NO_3-N)	%	0.373	31.0	23.3 *
Phosphorus (P)	%	0.064	12.1 (as P_2O_5)	12.1 * (as P_2O_5)
Potassium (K)	%	0.311	31.0 (as K_2O)	31.0 * (as K_2O)
pH	-	7.3		

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon