



NEWTRIENT EVALUATION SUMMARY

CONSERVATION INNOVATION GRANT (CIG):

Pyrolysis Technology

Dairy Manure Treatment Innovations – Enhancing Water Quality and Sustainability

University Partner

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BACKGROUND

Sustainable manure management remains one of the central challenges in modern dairy production. Manure contains valuable nutrients such as nitrogen (N), phosphorus (P), and potassium (K), yet when unmanaged, these same nutrients can contribute to runoff, groundwater contamination, and greenhouse gas (GHG) emissions. Traditional practices like storage lagoons or holding ponds and land application provide partial solutions but often fail to capture the full nutrient and energy potential of manure.

In response, farms and research partners are exploring innovative technologies that convert manure into stable, beneficial products. Among these, pyrolysis—the thermochemical conversion of organic matter in an oxygen-free environment—has emerged as a promising approach. The process produces biochar, a carbon-rich, nutrient-dense material known to improve soil structure, enhance nutrient retention, and store carbon long-term.

Spruce Haven Farm in Union Springs, New York, has positioned itself as a leader in this field. Home to approximately 2,000 lactating dairy cows and 1,800 heifers, the farm has integrated several sustainability practices, including anaerobic digestion and nutrient recovery. The addition of a Biomass Controls PBC pyrolysis unit represents the next step in developing a closed-loop manure management system on the farm that seeks not only to treat waste but to generate renewable value from it.

INTRODUCTION

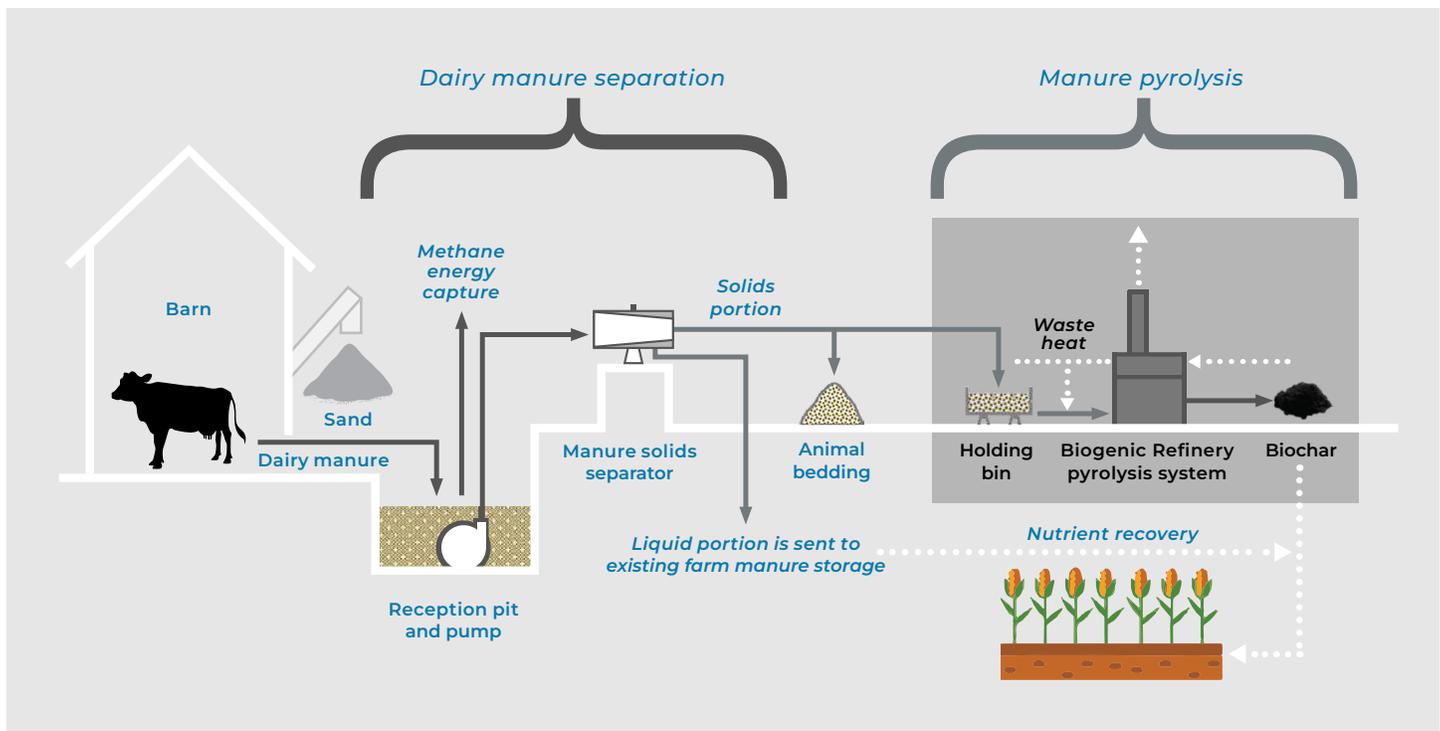
This evaluation focuses on the Biomass Controls pyrolysis system installed as a pilot at Spruce Haven Farm, assessing how effectively it converts dairy manure solids into a high-quality, nutrient-stable biochar. The study examined system performance, operational consistency, and nutrient transformations at multiple stages of processing, with particular attention to N, carbon (C), K, and P retention. Both anaerobically digested and undigested feedstocks were analyzed to determine how prior treatment influences biochar composition.

The research aimed to provide a comprehensive technical and environmental assessment of the pyrolysis system under working farm conditions. In doing so, it offers insight into how

such systems can complement existing anaerobic digesters and nutrient recovery technologies to improve resource efficiency, reduce emissions, and enhance soil health.

FIGURE 1: A GENERAL OVERVIEW OF THE MANURE MANAGEMENT AT SPRUCE HAVEN DAIRY (ADAPTED).

(<https://biomasscontrols.com/project-products/>)



The Process

At Spruce Haven Farm, dairy manure follows a multi-stage treatment pathway (Figure 1) that integrates sand separation, anaerobic digestion, solids separation, drying, and pyrolysis. Following sand separation, manure from freestall barns first enters a reception pit, where it is directed into the anaerobic digester. Methane (CH₄) gas produced during digestion is captured, cleaned, and added to the gas pipeline for energy use. After digestion, the manure is pumped to a screw press separator, which divides the stream into liquid effluent and pressed solids.

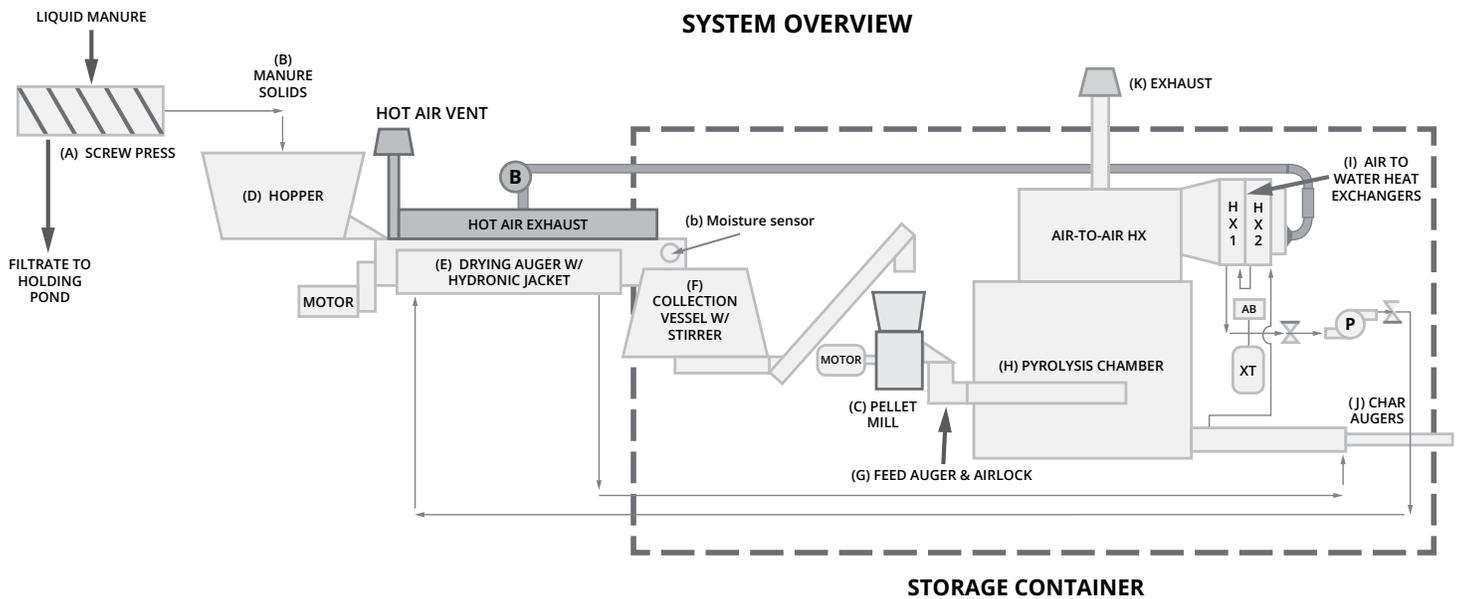
The solids with 65%-75% moisture were stored in a hopper and then fed into a prototype hydronic jacket dryer that uses recaptured thermal energy from the pyrolysis unit to reduce moisture content. Once dried, these solids enter

the Biomass Controls pyrolysis system via a feed auger that conveys them into the pyrolysis chamber. Inside the chamber, the material is thermochemically transformed at moderately high temperatures in an oxygen-free environment, breaking down volatile compounds and leaving behind carbon-rich biochar (Figure 2).

The hot air and gases generated during this process are harnessed to assist in drying subsequent batches, improving thermal efficiency and reducing external energy input. The system's design includes feedback loops for heat recovery, automated augers for controlled feeding, and a biochar collection system for finished product handling. The pyrolysis unit operates most effectively at a feedstock moisture range of 35%–40%, producing a consistent and nutrient-dense biochar.

FIGURE 2: SCHEMATIC OF THE PYROLYSIS UNIT SET UP IN USE AT SPRUCE HAVEN FARM.

Currently, the pellet mill is not being used. (Provided by Lucinda Lu, Cornell University).



METHODOLOGY

Samples throughout the treatment process were collected twice daily over a 24-day period during June and July 2025. Sampling included multiple manure treatment stages: liquid inflow, liquid digestate outflow, wet solids from the screw press, dried solids after the prototype hydronic jacket dryer, and final biochar output. Both anaerobically digested and undigested manure streams were evaluated.

A total of 24 samples were analyzed for each category (16 digested, 8 undigested). Samples were frozen immediately upon collection and shipped to A&L Laboratories in Fort Wayne, Indiana for analysis using the M7 Manure Package, which measures parameters including moisture, total N, ammonium (NH_4^+), P, K, C, and ash content. Statistical analyses were conducted using SYSTAT v13.2, with Analysis of Variance and Tukey pairwise comparisons applied to identify significant differences among the sample categories.

Operationally, the pilot unit was evaluated for stability, throughput, and drying efficiency. The study tracked the system's ability to maintain appropriate moisture content, prevent feed inlet plugging, and sustain continuous operation under typical farm conditions.

DISCUSSION OF RESULTS

The results from the evaluation of the Biomass Controls prototype pyrolysis system at Spruce Haven Farm provide important insights into its performance as a manure management and nutrient stabilization technology. Data collected from multiple processing stages—ranging from raw inflow manure to final biochar—offer a detailed understanding of how nutrient concentrations, moisture content, and carbon composition change throughout the treatment sequence.

This section summarizes those findings to assess the system's overall efficiency, nutrient transformation performance, and operational consistency under working farm conditions. By comparing digested and undigested feedstocks, the analysis also reveals how prior anaerobic treatment influences nutrient retention and the quality of the resulting biochar.

Key Benefits of Pyrolysis

Nutrient Stabilization and Densification: Pyrolysis substantially increased nutrient concentrations in the solid fraction. As shown in Table 1, P levels in biochar were 7.3 times higher for undigested manure and 7.9 times higher for digested manure, compared to the dairy manure solids following the prototype hydronic dryer. The higher P increase in digested manure is due to the farm's use of an iron-based chemical treatment in the digester to reduce the production of hydrogen sulfide (H₂S) in the biogas. Since this material contains iron, it also binds with P as a flocculant, allowing more P to be removed during waste separation. The effect of increased P levels typically dissipates after approximately 30 days, potentially providing the benefit of a slow-release P fertilizer (Sanford et al. 2022). Additionally, the evaluation of this effect emphasizes the importance of understanding the entire manure management system, rather than individual processes. K concentrations also rose markedly, confirming the strong thermal densification effect of the process. Most of the ammonia (NH₃) was lost through volatilization. A portion of other nitrogen components were also released to the atmosphere, but due to the lower operating temperatures of the pyrolysis process and no oxygen, it was emitted as N₂ gas. These findings illustrate the system's ability to retain and stabilize nutrients, reducing the risk of runoff or leaching that often accompanies the land application of liquid or raw manure.

Carbon (C) Retention and Soil Health Improvement: C composition increased progressively through each treatment stage, reaching 50%–55% by weight in the final biochar (Table 1). The C content of the undigested manure solids was higher than the digested material. This likely resulted because a large portion of C from the digested solids was utilized with the production of biogas (methane). This

result carried through to the C content in the biochar. This stable C fraction contributes to long-term soil organic matter and durable C sequestration. When applied to agricultural soils, biochar improves cation exchange capacity and water retention, increasing fertility and resilience, particularly during drought periods. Similar research indicates that such amendments can raise soil water holding capacity by 15%–30% and enhance nutrient-use efficiency by up to 20%. The use of biochar as a valuable soil amendment can reduce the reliance on commercial fertilizers, presenting cost savings to the farm.

Odor, Pathogen, and GHG Reduction: At operating temperatures above 400°C, the pyrolysis process effectively destroyed odor-causing volatile compounds and eliminated pathogens present in raw manure. This conversion also prevented CH₄ and nitrous oxide (N₂O) emissions normally produced during manure storage or surface application. When considered alongside the nutrient retention data in Table 1 and the compositional differences between digested and undigested samples (Figure 3), these reductions demonstrate the system's potential for substantial GHG mitigation while producing a clean, pathogen-free end product.

Operational Efficiency and Energy Integration: The system's integrated design allowed partial recovery of waste heat from the pyrolysis chamber. The prototype hydronic dryer reused this captured heat to lower feedstock moisture prior to processing, directly supporting the 35%–40% moisture window associated with optimal operation (Figure 3). Maintaining this range produced uniform, high-quality biochar and reduced external energy demand. With additional heat-exchange optimization and potential integration of digester biogas as supplemental fuel, near-energy-neutral operation is achievable.

Reduced Volume and Transportation Cost: The pyrolysis process reduced the total solids volume by approximately 70%–80%, transforming wet, bulky waste into a lightweight biochar, easing transportation. This volume reduction lowers hauling costs and allows for the redistribution of stabilized nutrients beyond the immediate farm gate. The resulting biochar product is drier, more stable, and easier to manage for long-term storage and application logistics.

Economic and Market Opportunities: Although markets for biochar are emerging and regionally available, the nutrient-dense, carbon-rich biochar documented in Table 1 and Figure 3 presents emerging market potential as both a soil amendment and a carbon credit commodity. Using conservative carbon offset values (\$50–\$60 per ton CO₂e)

and observed nutrient densification ratios, a large-scale dairy operating a comparable system could generate more than \$30,000 per year in carbon credit revenue, alongside additional income from biochar sales for agricultural, landscaping, or other commercial uses.

TABLE 1: THE PERCENTAGE OF MOISTURE AND ORGANIC CARBON, TOTAL NITROGEN, AMMONIUM NITROGEN, POTASSIUM AND PHOSPHORUS IN A. DIGESTED AND B. UNDIGESTED SAMPLES.

Values in parentheses represent the standard error of the mean. For each column, like letters indicate that the samples are not significantly different while unlike letters indicate that Tukey pairwise comparisons show differences at the P<0.05 level or better.

A. DIGESTED

	MOISTURE	CARBON	NITROGEN	AMMONIUM	POTASSIUM	PHOSPHORUS
INFLOW	94.978 (0.096) A	2.208 (0.054) A	0.296 (0.003) A	0.158 (0.001) A	0.235 (0.006) A	0.041 (0.001) A
OUTFLOW	96.216 (0.066) A	1.467 (0.032) A	0.282 (0.002) A	0.155 (0.002) A	0.273 (0.003) A	0.04 (0.0001) A
WET SOLIDS	65.387 (0.745) B	18.314 (0.38) B	0.591 (0.013) B	0.151 (0.006) A	0.257 (0.004) A	0.109 (0.003) AB
DRY SOLIDS	45.173 (2.694) C	28.992 (1.393) C	0.786 (0.029) C	0.105 (0.007) B	0.408 (0.021) A	0.168 (0.009) B
BIOCHAR	0.955 (0.166) D	31.339 (1.941) C	0.829 (0.056) C	0.002 (0.001) C	2.777 (0.173) B	1.328 (0.052) C

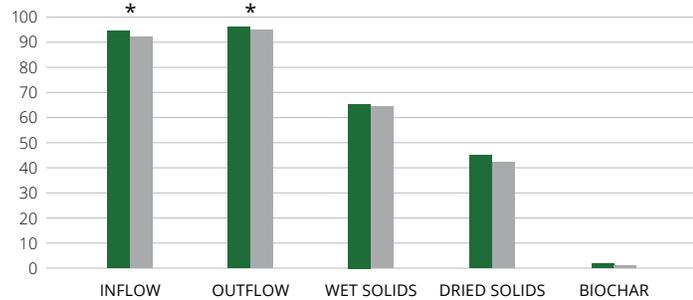
B. UNDIGESTED

	MOISTURE	CARBON	NITROGEN	AMMONIUM	POTASSIUM	PHOSPHORUS
INFLOW	92.508 (0.177) A	3.507 (0.075) A	0.282 (0.005) A	0.101 (0.002) A	0.217 (0.006) A	0.038 (0.001) A
OUTFLOW	95.722 (0.052) A	1.773 (0.021) A	0.25 (0.003) A	0.107 (0.003) A	0.212 (0.004) A	0.036 (0.001) A
WET SOLIDS	65.146 (0.788) B	17.603 (0.333) B	0.426 (0.021) B	0.068 (0.01) B	0.222 (0.004) A	0.052 (0.001) A
DRY SOLIDS	42.514 (1.753) C	29.472 (1.053) C	0.607 (0.019) C	0.07 (0.005) B	0.359 (0.009) A	0.084 (0.003) A
BIOCHAR	0.731 (0.145) D	37.042 (0.957) D	0.925 (0.047) D	0.007 (0.004) C	2.051 (0.113) B	0.61 (0.05) B

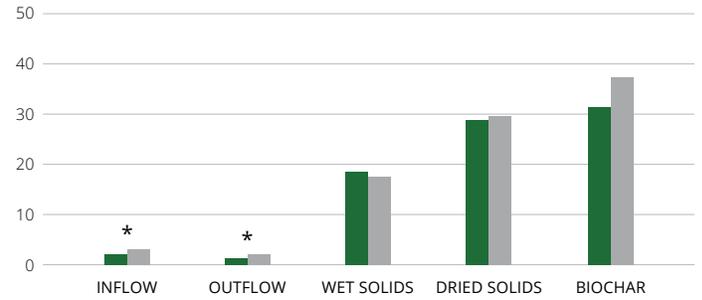
FIGURE 3: DIFFERENCES BETWEEN UNDIGESTED AND DIGESTED SAMPLES FOR EACH OF THE EXAMINED NUTRIENTS.

Asterisks indicate a significant difference at the P<0.001 level (Möller & Müller 2012). ■ DIGESTED ■ UNDIGESTED

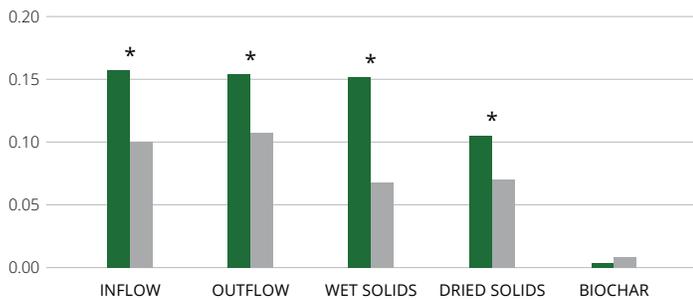
MOISTURE



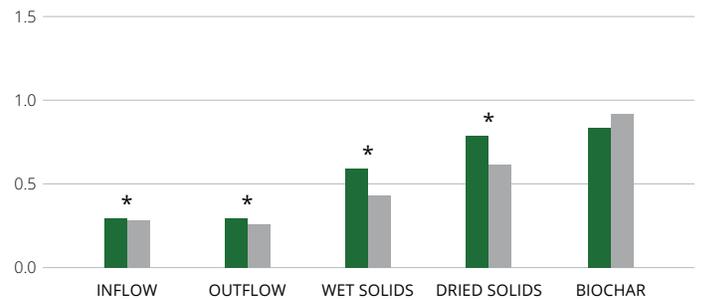
CARBON



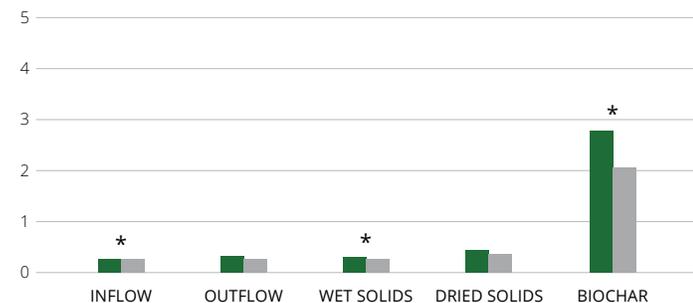
AMMONIUM



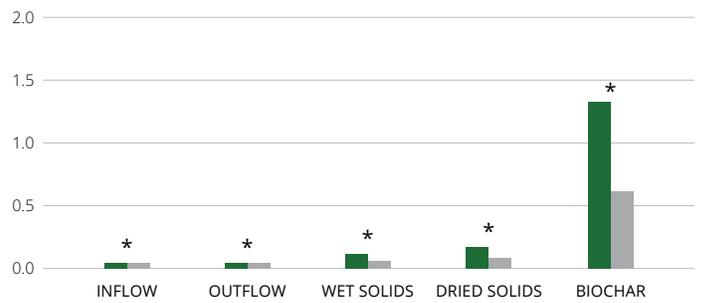
NITROGEN



POTASSIUM



PHOSPHORUS



Evaluation Key Challenges and Issues

While the Biomass Controls pyrolysis system at Spruce Haven Farm demonstrated strong potential for nutrient stabilization and C retention, several operational and technical challenges were identified during the evaluation. Addressing these limitations will be critical for improving system efficiency and enabling sustained, continuous operation at a commercial scale.

Feedstock Moisture Variability: Maintaining consistent moisture content in the feedstock was the most significant operational constraint of this evaluation. The prototype hydronic dryer typically reduced solids to about 45% moisture, but the studied system performed best between 35% and 40%. Higher moisture content in the solids impacted the pyrolysis unit in maintaining the proper operating temperature. This temperature dropped, and the efficiency of the dryer also decreased, which

resulted in increasing moisture content, impacting system performance. Variability in solids from digested versus undigested streams illustrated in Figure 3 further affected consistency. Enhancing drying capacity or incorporating inline moisture sensors could stabilize performance. Biomass Controls is evaluating other dryers for producing a more consistent and dryer feedstock to improve performance and consistent operation.

Inlet Plugging and Material Handling: Differences in moisture content, particle size, and fiber content occasionally caused bridging and compaction at the feed inlet. These blockages required temporary shutdowns for manual clearing, interrupting continuous operation. Adopting pre-conditioning steps such as grinding, pelletizing, or vibratory feeding could minimize plugging and maintain uniform flow.

FIGURE 4: OCCURRENCE OF INLET PLUGGING AND MATERIAL HANDLING.



Limited Continuous Operation: Although the system achieved reliable multi-hour batch runs, fully continuous 24-hour operation was constrained by manual feed control and moisture fluctuations. Automation of feed rate and temperature control would improve runtime stability and labor efficiency.

Heat Recovery and Energy Utilization: While waste heat was reused via the prototype hydronic dryer, it was difficult to maintain consistent temperature and moisture levels, impacting system performance and operational periods. Enhancing duct insulation, optimizing heat-exchange surface area, or integrating digester biogas as auxiliary fuel could improve thermal recovery and overall system sustainability. The use of improved commercial dryers is currently under review by Biomass Controls.

Data Collection and Sample Timing: Nutrient and C data were robust, but intermittent system downtime limited continuous logging of temperature and gas composition data. Synchronizing operational metrics with nutrient and C analyses as shown in Table 1 would allow finer resolution of process control and nutrient transformation dynamics.

System Mobility and Scalability: Because the pilot-scale system was moved multiple times during the study, setup variations affected data continuity. Ensuring modular design, stable installation, and scalable infrastructure will be critical for replication at commercial dairies. Lessons drawn from the differences between digested and undigested sample performance in Figure 3 can assist in design refinements for larger, stationary systems.

IMPLICATIONS

Results from this evaluation confirm that pyrolysis of dairy manure solids can effectively generate a stable, nutrient-dense biochar with significant potential for improving soil health and C sequestration. For dairy farms seeking to reduce waste volumes, improve nutrient management, and participate in emerging carbon markets, this technology offers a promising pathway.

The integration of pyrolysis with existing anaerobic digestion systems could create a synergistic manure management strategy—capturing CH₄ for energy, concentrating nutrients into biochar, and recycling water for reuse. Continued refinement of drying systems and feed controls will improve reliability and allow for near-continuous operation.

Spruce Haven's experience with a prototype pyrolysis system offers a practical model for other dairies seeking to enhance environmental stewardship, reduce waste, and generate additional value from manure resources. As system optimization progresses, pyrolysis could play a key role in achieving the long-term sustainability goals of the U.S. dairy industry.

For additional information on the vendor, environmental impacts, financial implications, and pyrolysis technology, visit the Biomass Controls Vendor Snapshot on the [Newtrient website](#).

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Newtrient's mission is to reduce the environmental footprint of dairy while making it economically viable to do so.

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