Farm Manure-to-Energy Initiative Final Report

Using Excess Manure to Generate Farm Income in the Chesapeake Bay Region's Phosphorus Hotspots

January 2016

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Written and produced by the Farm Manure-to-Energy Initiative.

Copies are available in Adobe Acrobat format (.pdf) at www.sustainablechesapeake.org and from the eXtension website at www.extension.org/68455 (under "Additional Resources").

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Steering Committee

National Fish and Wildlife Foundation in partnership with the Chesapeake Bay Commission, Farm Pilot Project Coordination, Inc., International Biochar Initiative , Lancaster County Conservation District, Sustainable Chesapeake, University of Maryland Center for Environmental Science, University of Maryland Environmental Finance Center, Virginia Cooperative Extension, Virginia Tech Eastern Shore Agricultural Research and Extension Center, and members of the Chesapeake Bay Funders Network (including the Campbell Foundation and the Foundation for Pennsylvania Watersheds).

Farm Partners

Technology demonstrations were hosted by the Flintrock Farm of Lititz, PA; Mark Rohrer Farm of Strasburg, PA; Mike Weaver Farm of Fort Seybert, WV; Riverhill Farm of Port Republic, VA, and Windview Farm of Port Trevorton, PA. Additional support provided by the Earl Ray Zimmerman Farm of Ephrata, PA; Frye Poultry of Wardensville, WV; North Carolina State University Animal & Poultry Waste Management Center; Old Mill Farms of Melfa, VA; Robert, Brad, and J.B. Murphy of Rhodesdale, MD; Riverbank Farm of Dayton, VA; and Terra Blue Hen Farm of Delmar, DE.

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On the cover: The view from Windview Farm, Port Trevorton, PA.

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Executive Summary

The Farm Manure-to-Energy Initiative was launched in 2012 to demonstrate and objectively evaluate manure-based energy systems operating on several private farms in the Chesapeake Bay region. As a collaborative multi-state effort, the Initiative included farmers in Pennsylvania, Virginia, West Virginia, and Maryland, with project management and support from foundations, nonprofit organizations, academic institutions, government agencies, and private businesses. Over the course of four years, thermal manure-based energy systems were developed and installed on five farms, and each was assessed for its technical, environmental, and financial performance.

Livestock manure contains valuable nutrients and organic matter that can improve soil fertility and promote healthy crop production when used as a fertilizer. For most animal operations, on-farm or local use of manure as a fertilizer is a standard practice and considered appropriately protective of water quality when manure is applied according to nutrient management plan recommendations.

However, managing manure to protect water quality can be challenging in areas where animal production is concentrated. In these areas, long-term application of manure to fields has resulted in high levels of soil phosphorus and increased risk of transport to surface waters through stormwater runoff. Because manure is bulky and costly to transport long distances, opportunities to sell excess manure for use on nutrient-deficient fields outside of high-density production areas are limited.

Demonstrations and Evaluation Strategy

The Farm Manure-to-Energy Initiative focused on farm-scale thermochemical (thermal) systems. Thermal systems generate energy while producing nutrient rich co-products (ash and biochar) that could be more easily transported out of nutrient-dense areas and sold elsewhere as fertilizer. Four thermal technologies were selected for demonstration on five farms in the Chesapeake region:

- Ecoremedy ® gasifier (designed and installed by Enginuity Energy, with continuing support from Ecoremedy Energy) on Flintrock Farm in Lititz, PA
- Global Re-Fuel (designed and installed by Wayne Combustion Systems) on the Mark Rohrer Farm in Strasburg, PA, and on the Mike Weaver Farm in Fort Seybert, WV
- Bio-Burner 500 (by LEI Products) at Riverhill Farm in Port Republic, VA

- Blue Flame Boiler (designed and installed by Total Energy Solutions) on Windview Farm in Port Trevorton, PA

Additionally, Farm Manure-to-Energy Initiative partners helped to develop and secure funding for a demonstration of the Biomass Heating Solutions Ltd. (Bhsl) technology on a farm in Rhodesdale, MD. Construction for this project is anticipated in the spring of 2016. Partners have also supported AHPharma Inc. efforts to demonstrate a pyrolysis thermal manure-to-energy system at their research farm in Tyaskin, MD.

Before installation, project partners worked closely with EPA Region 3 and state permitting agencies to determine permitting requirements for farm-scale systems in each of the Bay states. These conversations informed air emissions testing methodology and laid the foundation for the demonstration projects.

Each of the systems was evaluated for technical performance, environmental performance, and financial performance. Technical factors included the reliability of the system, how well the system integrated with the farm's existing heat delivery systems, and how well the technology succeeded in maintaining target temperature and relative humidity goals. To monitor environmental performance, project partners collected data on air emissions and documented the fate of nutrients as poultry litter moved through the system. Partners also evaluated the market potential of the ash and biochar co-product and compared its fertilizer value to raw poultry litter and traditional commercial fertilizers. Financial performance factors included the costs to install, operate, and maintain the system, and any reduced costs for propane or electricity.

Findings

Technical Performance

Performance varied considerably between the technologies. On one hand, the Global Re-Fuel technology failed to perform reliably and will need additional research and development before additional on-farm deployments. Alternatively, the Blue Flame boiler and Biomass Heating Solutions Ltd. technologies have been used successfully on poultry farms in the Chesapeake Bay region and Europe for up to 5 years. The Bio-Burner 500 and Ecoremedy gasifier are still in early phases of deployment. Additional data is needed on their performance before further deployments are recommended.

All of the technologies successfully integrated with existing propane heating systems and provided heat to poultry houses. However, the amount of heat produced (and propane offset) varied by the technology and the fuel quality of the poultry litter. The two technologies that have the longest track record for successful on-farm use (the Blue Flame boiler and BHSL system) are deployed on farms that completely clean out poultry houses between every flock. Most farms in the Chesapeake Bay region limit whole-house cleanouts and instead remove the top layer of poultry litter from the house at the end of each flock. Two farms that converted to organic production during this project period experienced an increase in litter moisture after the conversion. In one case, litter moisture was too high for the Global Re-Fuel system to use as a fuel. While the Ecoremedy gasifier successfully used higher moisture litter as a fuel, the heat output was reduced.

For AHPharma, Inc.'s demonstration project in Tyaskin, MD, partners were not successful in locating a commercially available pyrolysis technology that was designed to integrate with a poultry house heating system that met the project's cost criteria.

Environmental Performance

Air emissions for the demonstration technologies were evaluated using a certified, third-party air emissions testing company to inform nutrient mass balance and permitting. For a pyrolysis technology developed by North Carolina State University (NCSU) proposed for demonstration in Maryland, partners conducted preliminary emissions testing for nitrous oxide and particulate matter to determine if the technology could meet Maryland emissions requirements. The technologies demonstrated a range of air emissions. Because of the high potassium content of poultry litter, most vendors will need to control particulate matter emissions. Particulate matter proved challenging for several of the vendors who were not able to demonstrate that the technologies would be feasible for installation in Bay states with low thresholds for particulate matter emissions. Two technologies (BHSL and the NCSU pyrolysis technology) demonstrated the potential to meet all Bay state permitting requirements. Four of the technologies (Global Re-Fuel, Blue Flame boiler, Bio-Burner 500, and Ecoremedy gasifier) require additional controls for particulate matter to meet permitting thresholds in Maryland. Three of the technologies (Global Re-Fuel, Blue Flame boiler, and Bio-Burner 500) require additional reductions in nitrous oxides (NOx). System tuning for NOx emissions was recommended as the next step prior to consideration of NOx emissions controls. Three of the vendors demonstrated that, despite the nitrogen content of poultry litter, farm-scale thermal systems can be designed as low NOx emissions technologies.

The nutrient balance assessment suggests that much of the reactive nitrogen in poultry litter (primarily organic nitrogen and ammonia) is converted into non-reactive nitrogen in the thermal process. Reactive nitrogen in air emissions from thermal manure-to-energy systems was compared with reactive nitrogen (ammonia) lost from land application via various strategies (injection, shallow disking, and surface application without incorporation). Findings suggest that technologies with the lowest reactive nitrogen emissions will result in less reduced reactive nitrogen loss to the atmosphere than recommended practices for reducing nitrogen loss through land application (injection and immediate incorporation with a shallow disk). The technology with the highest nitrogen concentration in air emissions still reduced reactive nitrogen loss compared to surface application without incorporation.

The nutrient balance for phosphorus suggests that almost all of the phosphorus in poultry litter is sequestered in the ash (both bottom ash and fly ash from emission control systems). However, there was some loss of phosphorus in the emissions associated with particulate matter.

The nutrient balance also illustrated challenges with quantifying the fate of nutrients in farm-scale systems. Two of the analyses suggest that there is more phosphorus in the ash and air emissions than in the poultry litter used as a fuel. Since there is no known mechanism for creating phosphorus in on-farm thermal manure-to-energy systems, it is likely that variability in the fuel feed rate, ash production rates, and nutrient content of the poultry litter contributed to the variability of the results.

Financial Assessment

The financial assessment process was limited by the length of the performance period. However a simple analysis, considering just capital costs and energy savings, suggest that farm-scale systems can have a positive return on investment (ROI), even when they are not performing well. For example, despite technical problems, the Global Re-Fuel system has the potential to generate a 34% ROI over a 15-year period (or 26% over a 10-year period). The Blue Flame System would generate a 49% ROI over 15 years (or 38% over ten years). This analysis did not take into account operations and maintenance costs, cost-share program contributions, or allowances provided by the integrator for propane or electricity purchases. These allowances, which are common for organic or antibiotic-free integrators, can have a considerable impact on the ROI.

Although the available data, which was limited by the duration of the performance monitoring period, did not quantify the generated heat in a way that statistically correlates the technology with reduced propane use, farmers repeatedly observed and reported the trend toward reduced propane use while the systems were running. This saved energy and money for the growers and reduced their carbon footprint.

Fertilizer Value of Ash and Biochar Co-Products

Field row crop trials and laboratory analysis were used to evaluate the fertilizer value of ash and biochar co-products produced from a range of thermal systems, including combustion, gasification, and pyrolysis technologies. The fertility value of thermal co-products was compared with commonly used commercial phosphorus and potash fertilizers (triple super phosphate and muriate of potash), as well as untreated poultry litter.

Results suggest that, although not as concentrated, poultry litter co-products are feasible as a substitute for commercial fertilizer products for row crop production. Trace mineral content of the bottom ash also met state requirements for fertilizers.

Nutrient densification varied between pyrolysis, gasification, and combustion systems: phosphorus was concentrated between 4-12 times its original density, potassium was concentrated between 3-13 times its original density, and sulfur was concentrated between 2-5 times its original density. Thermal technologies that operate at higher temperatures densified nutrients more than lower temperature technologies (such as pyrolysis).

The nutrient densification and value of this material as a fertilizer indicates that cost-effective transport out of high-density production regions of the Chesapeake Bay is feasible and that this material could provide a new source of revenue for poultry growers. Although additional work is needed to establish markets, ash co-products have the potential to provide new sources of revenue for poultry growers through the sale of excess farm nutrients. One transaction that occurred during this project demonstrated this potential through the sale of poultry litter ash – at market prices for the phosphorus and potassium content – to soybean growers in Missouri.

Lessons Learned

This four-year project generated many important insights on the potential of these thermal systems and the remaining challenges for more widespread success. Some of the key lessons learned are:

1) On-farm thermal systems are not a good match for every farm. They require considerably more management than propane heating systems and, depending on the farm, they may not be cost effective. On-farm thermal systems also require more time to operate, especially because the technologies are still in the early phases of commercial deployment.
2) The success of a particular technology on one farm does not mean that it will succeed on another farm. The characteristics of poultry litter vary significantly between farms, requiring farm-specific adjustments to the system. Success requires collaboration between the vendor and the farmer.
3) Poultry litter ash and biochar are valuable plant nutrients. Depending on the process, poultry litter ash contains in the range of 14 to 18% phosphorus fertilizer and 13 to 24% potash fertilizer. Plant availability of the nutrients also varies by process but is in the range of 80 to 100%.
4) To support regulatory compliance, vendors should be prepared to supply data on air emissions. In states with strict particulate matter emissions thresholds, advanced air emissions controls may be needed to trap and remove fine particulate matter when poultry litter is used as a fuel.
5) State rules vary significantly with respect to on-farm thermal poultry litter-to-energy technologies. Only two technologies identified through this initiative have the potential to meet permitting requirements for all the Bay states.
6) Initial capital expenditures for installing systems to heat poultry houses currently range from $87,000 to over $300,000 per house to install. As these technologies mature, prices will likely come down over time.
7) Costs vary significantly, but a face-value comparison may not be the best way to determine value. A comparison that normalizes the cost may be a better way to evaluate different technologies. For example, a unit such as dollars-per-BTU-

delivered is worth considering in addition to the total cost of the system. On-going operation and maintenance costs should also be considered.

8) Farm-scale thermal systems can improve cold weather ventilation and reduce relative humidity in poultry houses resulting in better in-house air quality and improved bird health. These potential production benefits warrant further investigation.

9) Organic poultry farms may offer the best opportunity for deploying farm-scale thermal systems. In the Chesapeake region, organic production requires 3 to 5 times more propane than conventionally produced poultry. If a thermal, manure-based system can reduce propane use and improve bird health and feed conversion, organic integrators may especially stand to benefit.

Next Steps

The Farm Manure-to-Energy Initiative identified both opportunities and challenges associated with these emerging technologies. Recommended next steps are as follows:

- Continue to support technology vendor efforts to improve emissions controls for deployment in all the Bay states. The project team is working with air emissions experts to recommend next steps for emissions control design and installation.
- Build on fertility trials to develop markets for poultry litter co-products that connect growers with ash or biochar to end users willing to pay a fair price for the nutrients.
- Continue to communicate results: partners will work with farm partners to host field day events when avian influenza risk is lower.

For More Information

- Visit the project website hosted by eXtension at www.extension.org/68455.
- View the video at www.extension.org/68455 (available in January 2016).
- Contact Kristen Hughes of Sustainable Chesapeake at kristen@susches.org.

1. Background and Objectives: Manure-Based Energy in the Chesapeake Region

Thermal, manure-based energy systems are drawing increasing interest from farmers, scientists, business owners, environmentalists, and policymakers. In the Chesapeake Bay region, manure-based energy technologies have been highlighted as a potential strategy for meeting multiple goals: improving farm productivity, reducing nutrient pollution in waterways, and diversifying sources of energy production. A 2012 report by the Chesapeake Bay Commission and its partners described how progressive farmers and their technology partners had begun to demonstrate these "triple benefits" and concluded that their success "should not be limited to the pioneering few."[1]

To further investigate this potential, the Farm Manure-to-Energy Initiative was launched in 2012 to demonstrate and objectively evaluate manure-based energy systems operating on several private farms in the Chesapeake Bay region. As a collaborative multi-state effort, the Initiative included farmers in Pennsylvania, Virginia, West Virginia, and Maryland, with project management and support from foundations, nonprofit organizations, academic institutions, government agencies, and private businesses. Over the course of four years, thermal manure-based energy systems were developed and installed on five farms, and each was assessed for its technical, environmental, and financial performance.

Steering Committee

National Fish and Wildlife Foundation
Chesapeake Bay Commission
Chesapeake Bay Funders Network
Farm Pilot Project Coordination, Inc.
International Biochar Initiative
Lancaster County Conservation District
Sustainable Chesapeake
University of Maryland Center for Environmental Science
University of Maryland Environmental Finance Center
Virginia Cooperative Extension
Virginia Tech Eastern Shore Agriculture Research & Extension Center
USDA Conservation Innovation Grant
U.S. EPA Innovative Nutrient and Sediment Reduction Program

Project Funders

Chesapeake Bay Funders Network
National Fish and Wildlife Foundation

Participating Farms and Technology Vendors

Flintrock Farm, Lititz, Lancaster County, PA; system by Enginuity Energy
Riverhill Farms, Port Republic, Rockingham County, VA; system by LEI Products
Rohrer Farm, Strasburg, Lancaster County, PA; system by Wayne Combustion
Weaver Farm, Fort Sybert, Pendleton County, WV; system by Wayne Combustion
Wind View Farm, Port Trevorton, Snyder County, PA; system by Total Energy
North Carolina State Animal and Poultry Waste Management Center

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[1] *Manure to Energy: Sustainable Solutions for the Chesapeake Bay Region*. Chesapeake Bay Commission, Chesapeake Bay Foundation, Maryland Technology Development Corporation, and Farm Pilot Project Coordination, Inc. (January 2012)

1.1. Nutrient Imbalance in the Chesapeake Region

Livestock manure contains valuable nutrients and organic matter that can improve soil fertility and promote healthy crop production when used as a fertilizer. For most animal operations, on-farm or local use of manure as a fertilizer is a standard practice and considered appropriately protective of water quality when manure is applied according to nutrient management plan recommendations.

However, managing manure to protect water quality can be challenging in areas where animal production is concentrated. In these areas, long-term application of manure to fields has resulted in high levels of soil phosphorus in excess of crop fertilizer requirements. Nutrient management plans limit manure application of manure to fields with excessive soil phosphorus levels because high phosphorus levels increase the risk that manure phosphorus will be transported to surface waters through stormwater runoff. Today, areas in the Chesapeake Bay watershed that have the highest rates of phosphorus loading in their waterways correspond to areas where animal production is concentrated: Lancaster County, Pennsylvania; the Delmarva Peninsula; Virginia's Shenandoah Valley; and the eastern panhandle of West Virginia (see Figure 1).

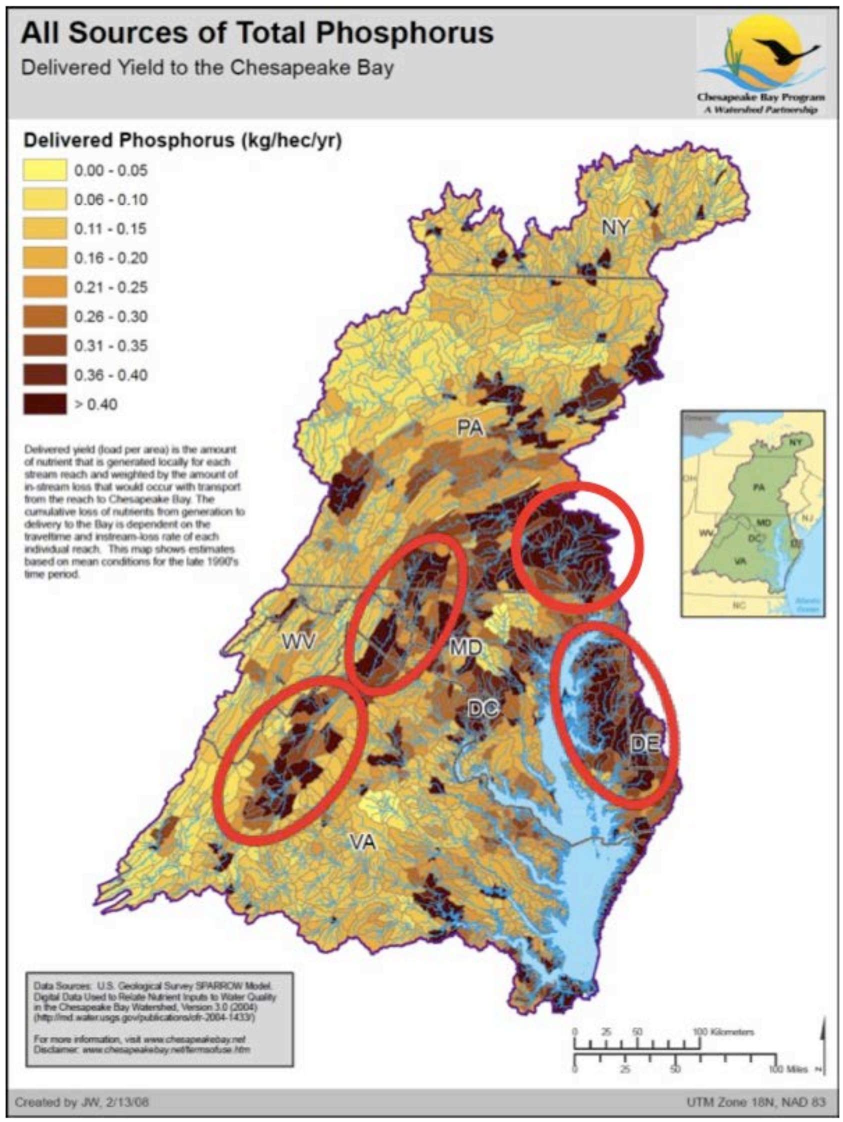

Figure 1. Nutrient "hotspots" in the Chesapeake Bay watershed.

In surface waters, the same nutrients that make manure a good fertilizer fuel the growth of algae in aquatic systems; noxious algal blooms caused by an overabundance of nutrients — nitrogen and phosphorus — are the primary cause of poor water quality in the Chesapeake Bay. Agriculture is the largest source of nitrogen and phosphorus pollution in the

Bay, and manure nutrients contribute about half of the nutrient load that originates from agriculture.

Because manure is bulky and costly to transport long distances, opportunities to sell excess manure for use on nutrient-deficient fields outside of high-density production areas are limited. In these high-density animal production areas, the market for manure nutrient is saturated, and farmers typically sell manure at a far lower price than they would receive in regions without concentrated animal production.

The goal of this project was to evaluate the feasibility of using manure-to-energy technologies to increase revenue farmers receive from manure nutrients and to generate on-farm energy, offsetting the use of non-renewable fuels.

1.2. The Technologies

Manure-to-energy systems fall into two categories: thermal systems, which use heat to convert biomass to energy, and anaerobic digestion systems, which use bacteria to convert organic carbon in manure to methane gas. A variety of techniques exist under both categories, using different types of manure.

Gasification is one type of a thermal system, shown here at Flintrock Farm in Pennsylvania.

Anaerobic digestion has been used successfully on larger farms for decades, using wet manure from cows or swine as feedstock. During the digestion process, microbes convert some of the organic nitrogen and phosphorus in the manure to an inorganic form that can be used as fertilizer. However, the total concentration of nitrogen and phosphorus is not changed in a digester. The process can reduce the volume of manure, but typically not enough for cost-effective transport over long distances. For drier manure like poultry litter, the digestion process – which requires the addition of water – may make transport of nutrients over long distances more expensive. Although some vendors are working on post-digestion treatment technologies that could facilitate transport of excess nutrients, anaerobic digesters are typically not used to address regional nutrient imbalance. [2]

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[2] However, there are advanced solid-liquid separation technologies in the pilot phase of development that could facilitate concentration of phosphorus from liquid manures (including anaerobically digested manure). Several of the Farm Manure-to-Energy Initiative partners are engaged in or supporting evaluation of these technologies on dairy farms in the Chesapeake Bay watershed. The National Fish and Wildlife Foundation Chesapeake Bay Stewardship Fund program is sponsoring demonstration and evaluation of two advanced

Because of the Chesapeake region's emphasis on water quality and nutrients, the Farm Manure-to-Energy Initiative focused on technologies that had potential to expand the markets for excess manure nutrients by facilitating transport over long distances. To meet both energy and water quality goals, the project focused on thermal systems. Types of thermal systems include combustion, gasification, and pyrolysis; each of these systems captures energy from manure and, at the same time, concentrates excess nutrients in an ash or biochar. These co-products can be cost-effectively transported long distances and sold to farmers in nutrient-deficient regions. In addition, thermal processes destroy any pathogens associated with raw manure. The resulting ash or biochar can be used as a replacement for inorganic phosphorus and potash fertilizers for crops such as fruits and vegetables, where raw manures are typically not used as fertilizer (see Appendix F).

1.3. Goals and Objectives

The overarching goals of the Farm Manure-to-Energy Initiative are to:

1) Reduce the land application of manure in the Chesapeake region's nutrient hotspots
2) Displace imported fertilizer products with products derived from locally grown manure
3) Reduce phosphorus and nitrogen runoff to the Chesapeake Bay and its tributaries
4) Increase the viability of sustainable agriculture by transforming a manure liability into a farm asset
5) Increase private financing of manure-to-energy technologies in the region

To meet these goals, the steering committee focused on the following objectives:

1) Demonstrate manure-to-energy technologies on four working farms in phosphorus hotspots in the Chesapeake region and evaluate their technical, environmental, and economic performance.
2) Create a network of local, independent, manure-to-energy experts, as well as a web-based clearinghouse of data and resources, to help farmers and service providers compare differing technologies.
3) Expand local and regional markets for co-products that generate revenue for farmers.

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solid liquid separators used with liquid dairy manure. Pennsylvania State University is working with the USDA Agricultural Research Service on one demonstration project in the Lancaster County, Pennsylvania. These technologies are still in development and not ready for widespread adoption.

4) Improve access to both public and private financing options by developing state-specific financing templates that identify existing funding options and innovative approaches for private financing.

1.4. The Project Steering Committee

Given the regional nature and ambitious goals of the Farm Manure-to-Energy Initiative, the National Fish and Wildlife Foundation (NFWF) established a steering committee to oversee the project. Members were recruited to provide direct assistance in project implementation (the project team) as well as members who worked collaboratively to make key decisions and share project findings with stakeholders. The steering committee met at least quarterly throughout the four-year project. Individual participants who served on the steering committee, along with a brief summary of their roles, are presented below:

- Jake Reilly, Elizabeth Nellums, Amanda Bassow, Mandy Chestnutt, and Mark Melino of NFWF provided overall project coordination, including contracting with project partners and coordinating funding. The NFWF team served as the lead applicant on the USDA Conservation Innovation Grant that provided critical support for this project, and brought additional funding via private and U.S. EPA funds to the project.
- Kristen Hughes Evans with Sustainable Chesapeake provided overall project management, including coordination among project partners and the steering committee, budget management, and sharing results with funders and stakeholders.
- Bob Monley, Preston Burnette, and Jane Corson-Lassiter (on detail from the USDA Natural Resources Conservation Service) with the Farm Pilot Project Coordination took the lead on contracting with technologies and farm partners, overseeing technology installation, and evaluating technical performance.
- Jill Jefferson, Naomi Young, and Sean Jefferson of the University of Maryland Environmental Finance Center (EFC) evaluated the financial feasibility of the projects. Dr. Dan Kugler, Allie Santacreu, and Michelle Arthur developed a financing inventory that identified funding resources for projects in the Chesapeake region. The EFC team also evaluated program-related investments, an innovative approach to private philanthropic support for these emerging technologies.
- Dr. Mark Reiter of the Virginia Tech Eastern Shore Agriculture Research & Extension Center led efforts to evaluate the fertilizer value of the ash and biochar co-products and track the fate of nutrients in the poultry litter as they moved through the system.

- Connie Musgrove of the University of Maryland's Center for Environmental Science headed up efforts to develop a clearinghouse website to share information.
- John Ignosh of the Virginia Cooperative Extension and Virginia Tech Biological Systems Engineering provided support for monitoring, air emissions testing, and performance evaluation.

Amanda Bassow and Preston Burnett, both members of the Steering Committee, view the thermal system installed at Riverhill Farm in Virginia.

- Don McNutt of the Lancaster County PA Conservation District helped connect the project's farm partners and facilitated project implementation in Pennsylvania.
- Bevin Buchheister of the Chesapeake Bay Commission helped to communicate lessons learned to policy makers in the Chesapeake region.
- Pat Stuntz of the Campbell Foundation lead outreach efforts with Maryland stakeholders and provided project financial support.
- John Dawes of the Foundation for Pennsylvania provided guidance and financial support for project implementation in Pennsylvania.
- Debbie Reed and Stefan Jirka of the International Biochar Initiative supported the project team in evaluating the potential of pyrolysis technologies.

2. Process: Getting Projects on the Ground

2.1. Selecting Farmers

The Farm Manure-to-Energy Initiative released a request for farm partners and relied on local conservation professionals for introductions to farmers who were interested in installing a manure-based energy system on their farm. The team looked for farms of various sizes that were a good fit for the technology and whose owners were committed to supporting the system both during the study period and beyond. The steering committee also sought to partner with farmers who would support efforts to share the project findings. Five farms were selected to demonstrate technologies funded by the Farm Manure-to-Energy Initiative. The project team also worked with a sixth farm (Double Trouble, Rhodesdale, MD) to secure funding for a technology demonstration (this project is still in the permitting and construction phase).

Farmers across the Chesapeake region worked with the Farm Manure-to-Energy Initiative to explore the potential of thermal technologies, including Mark Rohrer of Strasburg, PA.

2.2. Selecting Vendors

The project team solicited technology vendors through a request for information (RFI), which was distributed widely. Vendors were asked to provide information on technologies that not only convert manure to energy but also facilitate transport of nutrients out of high-density animal production regions. They were encouraged to provide information on costs (installation, operation, and maintenance), their experience using manure as a feedstock, and data that demonstrated environmental performance. Vendors were also asked to describe any financial and technical resources they were willing to contribute to a demonstration project.

Four vendors were selected as partners in the demonstration projects: Enginuity Energy LLC, Total Energy Solutions LLC, LEI Products, and Wayne Combustion Systems. All had experience using poultry litter as a feedstock and financial resources they could contribute to developing the projects. Two of the vendors provided data on air emissions data available to facilitate permitting.

2.3. Pairing Technologies with Farm Partners

Four thermal technologies were selected for demonstration on five farms. The project team also worked with a sixth farm to secure funding for a fifth technology demonstration and with APHarma Inc. to pilot a poultry litter-to-energy system used with a radiant floor heating system. Demonstrations funded by the Farm Manure-to-Energy Initiative that have been installed on farms in the Chesapeake Bay region include:

- Ecoremedy ® gasifier (designed and installed by Enginuity Energy, with continuing support from Ecoremedy Energy) on Flintrock Farm in Lititz, PA
- Global Re-Fuel (designed and installed by Wayne Combustion Systems) on the Mark Rohrer Farm in Strasburg, PA, and on the Mike Weaver Farm in Fort Seybert, WV
- Bio-Burner 500 (by LEI Products) on Riverhill Farm in Port Republic, VA
- Blue Flame Boiler (designed and installed by Total Energy Solutions) on Windview Farm in Port Trevorton, PA

Demonstration projects in development with support from the Farm Manure-to-Energy Initiative:

- AHPharma, Inc. is working to demonstrate a farm-scale pyrolysis manure-to-energy technology used in conjunction with a radiant floor heating system at a poultry research farm in Tyaskin, MD. Initiative partners conducted preliminary air emissions testing and fertilizer value of biochar for a pyrolysis technology located at North Carolina State University (NCSU) to support this effort.
- Biomass Heating Solutions Ltd. (Bhsl) is working with the Murphy's to demonstrate a farm-scale fluidized bed combustion manure-to-energy system in Rhodesdale, MD.

2.4. Permitting

Before installation, project partners worked closely with EPA Region 3 and state permitting agencies to determine permitting requirements for farm-scale systems in each of the Bay states. These conversations informed air emissions testing methodology and laid the foundation for the demonstration projects.

In general, all but one of the technologies demonstrated fell under the purview of federal rules for Industrial, Commercial, and Institutional Boilers. One was not currently covered under a federal permit program because it was an air-to-air heat system rather than a boiler. In all cases, poultry litter used as a fuel met EPA fuel-legitimacy requirements, a critical test to satisfy criteria of Section 112 of the Clean Air Act. If these criteria had not been met, the systems would have been covered by Section 129 of the Clean Air Act, which applies to incineration regulations with associated permitting requirements that would not be feasible for a farm-scale project. However, all of the technologies fell below the size threshold that would require registration under the federal rules for boilers.

For these projects in which the only fuel was poultry litter produced on the farm, compliance with the federal Clean Air Act permitting requirements was relatively straightforward.[3] The project team was able to work closely with both the EPA the U.S. Department of Agriculture to help ensure that future farmers using these technologies understand the federal fuel legitimacy requirements. As a result, the team produced a federal permitting checklist for farmers interested in installing manure-based energy systems, available at www.extension.org/68455.

At the state level, the rules varied significantly. In the interim, both Virginia and West Virginia approved permits for running the systems as research projects. Air emissions testing results from this project will help to facilitate future permitting in these states. While exploring the potential for a demonstration project in Maryland, the project team supported efforts by the Maryland Department of the Environment to update its rules; the team learned that Maryland and Delaware have the strictest related emissions rules, with respect to nitrous oxides (NOx) and total particulate matter in the Chesapeake region. The project team challenged the technology vendors participating in this initiative to meet the permit requirements for all Bay states, including Maryland and Delaware, regardless of the state where the demonstration was installed.

3. Performance Evaluation

Each of the five systems installed through this initiative were evaluated for technical performance, environmental performance, and financial performance.

Technical performance was based on several factors, including the reliability of the system, how well the system integrated with the farm's existing heat delivery systems, and how well the technology succeeded in maintaining target temperature and relative humidity goals.

To monitor environmental performance, project partners collected data on air emissions and documented the fate of nutrients as poultry litter moved through the system. In addition, partners evaluated the market potential of the resulting ash, conducting laboratory

Certified emissions testing, shown here on Windview Farm in Pennsylvania, was conducted at three demonstration locations.

[3] The process is more complex for larger systems that import poultry litter from multiple farms.

analysis and field trials to determine the value of the fertilizer as compared to raw poultry litter and traditional commercial fertilizers. Air emissions data was collected by a third-party, certified testing company using EPA methodology. This data was used in conjunction with EPA-approved risk screening tools to determine whether emissions from on-farm manure-to-energy systems pose a threat to the health of farm families and surrounding communities.

Financial performance factors included the costs to install, operate, and maintain the system and the reduced costs of propane or electricity. The Environmental Finance Center also completed a review of financing options for on-farm manure-based systems in the Chesapeake region (http://efc.umd.edu/manuretoenergyinitiative.html#.Vngu32SDGko), as well as an evaluation of financing opportunities through program-related investments as a means of providing support for future technology deployment in the region.

4. Summary of Results

4.1. Technology Performance

Ecoremedy Gasifier

- *Technical*: The Ecoremedy gasifier is a chain-grate, air-blown gasification system designed to deliver between 0.8 and 1.2 MBtu/hr of heat via hot water to four poultry houses. Installed on Flintrock Farm, the system uses poultry litter removed from the top surface of the bedding and is still in the early phases of commercial development. While the system is integrating well with the farm's existing propane heating system and controllers, Ecoremedy Energy is working to address several technical issues that have impacted system reliability. This system is capable of using "crust out" and wetter litter as fuels. However, the conversion from conventional to organic production during this project period resulted in high litter moisture and reduced heat output from the system. Flintrock Farm has implemented a number of strategies to improve fuel quality and has successfully reduced moisture and large rocks in the poultry litter used as a fuel for this system. Given that this technology is still in the

The Ecoremedy gasifier shown here was installed on Flintrock Farm in Pennsylvania to provide heat to four poultry houses.

early deployment phase, successful operation at Flintrock Farm is warranted prior to additional installations.

- *Environmental*: While this system meets NOx emissions thresholds for permitting in states with the strictest NOx permit requirements, additional particulate matter emissions controls will be needed for installation throughout the Chesapeake Bay region. A SCREEN3 analysis was used to predict maximum concentrations of pollutants from this system, and all pollutants evaluated were below established thresholds designed to protect public health. Nutrient balance suggests that most of the phosphorus is concentrated in the ash. Measured total reactive nitrogen in air emissions from the Ecoremedy gasifier are lower than best practices for land application of the same amount of poultry litter (e.g., lower than injection or immediate incorporation by shallow disking).

  This project has also demonstrated the potential for this technology to facilitate transport of manure phosphorus produced in excess of the farm's needs out of the Chesapeake Bay region. Enginuity Energy brokered a sale of the ash co-product to soybean growers in Missouri. The soybean grower was willing to pay market price for the phosphorus and potash content of the ash, based on previous experience using the product.

- *Financial*: The Ecoremedy system was the most expensive system to install. While it offers flexibility in terms of moisture content of poultry litter that other systems do not have, the higher moisture content of the poultry litter after the farm converted to organic production has resulted in reduced heat output and propane savings. A simple ROI analysis (looking at capital costs and propane savings) and current performance suggests that, based on energy savings alone, this system does not have a positive ROI over a 10- or 15-year period. Recent and planned improvements for the system may improve heat delivery and performance and thus financial feasibility.

  The sale of ash from this system at market prices to famers located outside of the Chesapeake Bay region demonstrates the potential for these technologies to increase the value of excess nutrients produced on farms in high-density animal production areas. Even considering transportation costs, the purchase price for the ash exceeded the locally available market price for untreated poultry litter.

Global Re-Fuel Poultry Litter Furnace (PLF-500) by Wayne Combustion Systems

- *Technical*: The Global Re-Fuel PLF-500 is combustion technology that delivers heat via hot air to poultry housing. It was installed on two farms in the region (the Mark Rohrer Farm in Strasburg, PA and the Mike Weaver Farm in Ft. Seybert, WV). One system was also installed on a farm in Port Republic, VA, with funding from the Eastern Shore of Virginia Resource Conservation & Development Council. Previously, the system had also been installed and operated on a poultry farm in Indiana.

  

  The Global Re-Fuel system was installed on two farms, shown here on the Mike Weaver Farm in West Virginia.

  Despite the previous on-farm history, the Global Re-Fuel furnace did not perform well on farms in the Chesapeake Bay region. Both systems experienced multiple technical failures that compromised system reliability and required considerable time for repairs. Located in Indiana, Wayne Combustion Systems did not have local technicians and instead relied on the farmers to make almost all of the repairs.

  Currently, none of the Global Re-Fuel systems installed in the Chesapeake Bay are operational. In addition to technical problems that negate continuous operation, one farm converted to organic poultry production and now produces poultry litter with a moisture value too high for use as a fuel in the Global Re-Fuel Furnace. Both farmers participating in the Farm Manure-to-Energy Initiative have received funding to support decommissioning.

  However, when the system was working, it did successfully integrate with existing propane heating systems and house controllers. Despite the poor performance, the projects demonstrated the potential for a simple, direct air-to-air heating system to reduce propane use.

  Given the technical performance issues, this technology will need additional research and development before installation on farms. To support this effort, the project team developed step-by-step recommendations for improved performance on the existing units. Florida A&M University has secured funding to explore options for improving technical performance.

- *Environmental:* Wayne Combustion Systems was not able to meet air permitting requirements for the strictest Bay states because of high particulate matter. Opacity was also a concern. Improvements to the combustion chamber design are recommended as the first step in reducing emissions of particulate matter. Additional particulate matter emissions controls are also recommended. However, technical performance issues are the primary concern with this technology and should be addressed before additional investments in emissions controls.
- *Financial:* Even with performance that did not meet the design criteria, the Global Re-Fuel System realized propane savings and demonstrated that a low-cost, simple heat delivery system can have a positive ROI. A simple ROI analysis that considered only infrastructure and energy savings for the Mark Rohrer Farm demonstrated an ROI of 26% after 10 years and 34% after 15 years. An ROI for the Mike Weaver Farm, where propane use is lower than average because of energy conservation measures, yielded a lower ROI of 4% over 10 years and 5% over 15 years. This difference illustrates the importance of looking at all options for reducing energy use prior to investing in a farm-scale technology. Farm energy audits are designed to identify the most cost-effective strategies for reducing propane and electricity use and should be taken into consideration when evaluating the cost-effectiveness of on-farm manure-to-energy systems.

Blue Flame Boiler by Total Energy

- *Technical:* The Blue Flame boiler is designed to deliver 1.5 to 2.0 MBtu/hr of heat to poultry housing via hot water. This technology has the longest track record for using poultry litter as a fuel in the Chesapeake Bay region. The start of the 2015 cold weather season is the sixth year of use at Windview Farm in Port Trevorton, PA, and the fourth year in operation at the Earl Ray Zimmerman Farm in Ephrata, PA. After a fire in an electrical panel damaged the installation at Windview Farm, a new Blue Flame boiler was installed in the summer of 2015 with support from the Farm Manure-to-Energy Initiative. The new system improved the hot water distribution system and has to date been used successfully to heat one flock. Previous experience at both Windview Farm and the

The start of the 2015 cold weather season launched the sixth year of use for this Blue Flame Boiler at Windview Farm in Pennsylvania.

Earl Ray Zimmerman Farm suggests that, after an initial learning curve, the system performs as designed, integrated with existing propane heating systems and house temperature controllers, and results in significant propane savings.

An important consideration is that both farms using this technology remove all poultry litter from the houses between every flock. Most poultry growers in the region remove only the top crust from the poultry litter between flocks, as replacement bedding is expensive. Windview Farm grows antibiotic-free chickens and is required by their integrator to replace bedding between flocks, while the Earl Ray Zimmerman Farm adopted this approach to improve fuel quality and system performance.

- *Environmental*: Total Energy Solutions will need to reduce both NOx and particulate matter emissions from the Blue Flame boiler to meet all Bay state permitting requirements. Tuning of this system to improve NOx emissions is recommended as the first approach. Improved cyclones installed between the first and second round of emissions tests reduced particulate matter emissions by 31%, but emissions are still too high for installation in Maryland and Delaware. However, improvements to the cyclones reduced the maximum concentration of particulate matter as predicted by SCREEN3 to levels below thresholds established to protect public health.
- *Financial*: A simple ROI analysis focusing on capital costs and energy savings demonstrates a positive ROI for this technology on Windview Farm (38% ROI at 10 years and 49% ROI at 15 years). Although the ROI did not take this into consideration, both Windview Farm and the Earl Ray Zimmerman Farm receive a propane subsidy, which considerably improves the ROI for this system.

Bio-Burner 500 by LEI Products

The Bio-Burner 500 at Riverhill Farm in Virginia was modified to accept poultry litter as a fuel.

- *Technical*: The Bio-Burner 500 is a biomass combustion system that comes with a boiler. Use of hot water generated by the system is up to the end user (LEI does not design heat delivery systems). At Riverhill farm, funding from the Farm Manure-to-Energy Initiative was used in the summer of 2015 to modify an existing system previously fueled by woodchips to accept poultry litter. These modifications included the addition of a wet scrubber to control particulate matter emissions and poultry litter and ash handling. This unit is permitted with a biomass research permit, and the Farm Manure-to-Energy partners are currently working with the Virginia Department of Environmental Quality to finalize permitting so that this unit can be operated using poultry litter as a fuel on a regular basis. Currently, biomass research permits facilitate data collection only. Hence, long-term technical performance of this unit using poultry litter as a fuel is currently not available.

Previous experience at Riverhill Farm using this system with woodchips suggests that it operates reliably with less than 5% down time. At Riverhill Farm, hot water from the Bio-Burner 500 is used to heat a turkey poult house via a radiant floor heating system. The turkey brooder house, where poults spend the first five weeks, has a high heat demand compared to grow-out houses. The Bio-Burner 500 provides heat in conjunction with the house propane heating system.

- *Environmental*: The Bio-Burner 500 would need both NOx and particulate matter emissions reductions to meet all Bay state permitting requirements. The Farm Manure-to-Energy Initiative team recommends tuning this system to improve NOx as a first step. Improvements made between the first and second round of emissions testing reduced particulate matter emissions by 61%. However, SCREEN3 analysis used to predict the maximum concentration of pollutants suggests that, if all particulate matter is assumed to be fine particulate matter, the system exceeds National Ambient Air Quality Standards (NAAQS) for fine particulate matter. The short stack height and wide diameter, as configured during emissions testing, are likely contributing to this problem. Further SCREEN3 analysis with increased stack height resulted in maximum concentrations of fine particulate matter below NAAQS thresholds. Further analysis to determine the most cost-effective stack design for this system is warranted.
- *Financial*: Given the lack of performance data with poultry litter used as a fuel, an ROI analysis was not developed for this technology. However, the Bio-Burner 500 is one of the lowest cost units currently available on the market. If this technology successfully and reliably converts poultry litter to heat, it could provide a financially attractive option for smaller farms.

Biomass Heating Solutions Ltd (Bhsl) Fluidized Bed Combustion

- *Technical*: Bhsl manufactures a fluidized bed combustion system that delivers heat to poultry houses via hot water. This technology is not currently installed in the United States (the project planned for Rhodesdale, MD, is currently in development). However, several of the Farm Manure-to-Energy partners have visited Bhsl installations in the U.K. and observed that the technology works well as a source of heat for poultry housing. The Bhsl system is currently installed on three poultry farms in the U.K. with additional installations planned for 2016. The company has logged over 100,000 of operation for these units.

  The technology is available in varying sizes and, in addition to providing heating for poultry houses, also delivers electricity to the grid. Currently installations include two units that use 5 metric tons and one unit that uses 10 metric tons per day of poultry litter as a fuel.

One key difference between poultry litter management in the United States and Europe is that European poultry growers remove all poultry litter between flocks. As previously discussed, this is not a common practice in the United States. The Rhodesdale demonstration will be the first Bhsl system to use poultry litter typically of United States production systems.

- *Environmental*: Bhsl emissions for NOx and particulate matter are considerably lower than technologies demonstrated by the Farm Manure-to-Energy Initiative to date. To meet European air emissions standards, Bhsl has developed advanced emissions controls and focused on the system design to reduce NOx emissions. Third-party data collected by air emissions testing companies in Europe indicate that this technology is able to meet all Bay state permitting requirements.
- *Financial*: Bhsl offers one of the most expensive technologies for use with poultry litter, yet the company has a track record for performance and the lowest air emissions observed to date with poultry litter-fueled systems. The company is exploring strategies to reduce costs and is considering offering the technology via a managed system through which the farmer commits to purchasing energy from Bhsl, and Bhsl in turn owns, installs, and provides remote performance monitoring for the technology. While the farmer would need to provide fuel to the system, additional maintenance and repairs would be handled by Bhsl. Financial feasibility of this technology in the United States warrants further investigation and will be informed by the demonstration project planned for Rhodesdale, MD.

North Carolina State University (NCSU) Pyrolysis Technology

- *Technical:* The NCSU pyrolysis technology is a counterflow heat exchanger design that uses hot air from combustion of synthesis gas to drive the pyrolysis process. Unlike other pyrolysis systems, the synthesis gas produced through the pyrolysis process is not condensed to capture bio-oils; instead, the gases are fully combusted. Emissions exit the system where hot air could be captured for use as a source of heat. Currently, this system is operated as a batch-fed, stand-alone unit at the NCSU Animal and Poultry Waste Management Center. Additional research and development is needed to deploy this technology for use on a farm setting including integration with on-farm heating systems; continuous poultry fuel feed system and internal pyrolysis chamber temperature control.
- *Environmental*: Preliminary emissions data collected by Initiative project partners suggests that this technology has the potential to meet all Bay state permitting requirements without emissions control equipment. These results will need to be confirmed with data collected by third-party, certified emissions testing company from a unit designed for farm-scale deployment.
- *Financial*: Although estimates for farm-scale unit costs are preliminary, this unit has a simple design and has the potential to be deployed for use on farm at a reasonable cost.

4.2. Environmental Performance

4.2.1. Fate of Poultry Litter Nutrients

An analysis of the fate of poultry litter nutrients was conducted for three of the technologies: the Bio-Burner 500, Ecoremedy gasifier, and Blue Flame boiler. Data suggests that the technologies reduce reactive nitrogen in poultry litter fuel by more than 90%. This nitrogen is likely converted to non-reactive nitrogen in the thermal conversion process.

The ash co-product, rich in phosphorus, collects in the system hopper.

All technologies reduced reactive nitrogen in air emissions compared to surface application of poultry litter, a standard land application practice in the region. Total reactive nitrogen from the technologies was also similar to or less than reactive nitrogen emissions associated with immediate incorporation via shallow disk.

Phosphorus was primarily concentrated in the ash, although a small amount was identified in air emissions. Efforts to reduce particulate matter emissions should also reduce atmospheric emissions of phosphorus. If this ash is transported out of the watershed or used to replace commercial phosphorus imported into the watershed, considerable reductions in phosphorus loading would be achieved.

4.2.2. Air Emissions and Permitting

The Farm Manure-to-Energy Initiative team consulted with federal and state air permitting regulators to design an emissions testing protocol to support permitting of demonstrations and future technology deployments. Criteria and comprehensive air emissions data was collected for three of the technologies: the Bio-Burner 500, Ecoremedy gasifier, and Blue Flame boiler. Criteria pollutants from third-party, certified air emissions testing companies were also provided by Bhsl and Wayne Combustion Systems.

Analysis of poultry litter fuel characteristics to support federal permitting suggests that poultry litter contaminants are within ranges for traditional solid fuels (coal and wood). This contaminant comparison is important for determining federal regulations associated with individual technology deployments.

Air emissions data suggests that all vendors, except for Bhsl and potentially the NCSU pyrolysis technology, will need additional particulate matter emissions controls to qualify for installation in Maryland and Delaware. Additional NOx reductions are also needed for

Maryland deployment for the Bio-Burner 500 and Blue Flame boiler. The Farm Manure-to-Energy Initiative team suggests that tuning these systems is the first step in reducing NOx emissions.

With support from the USDA Air Quality and Atmospheric Change Team, the Farm Manure-to-Energy Initiative reached out to Dr. Michael Buser (Oklahoma State University), an expert in emissions controls for agricultural systems. Dr. Buser designed cyclone emissions controls for two of the demonstration projects that resulted in reduced air emissions.

Environmental scanning electron microscopy (ESEM) of particulate matter in air emissions with energy-dispersive spectroscopy to assist in both the initial chemical analysis and preliminary particle size information demonstrated that a potassium species dominated particulate matter (potassium concentration of larger and smaller particles ranged from 36 to 50%).

Potassium volatilizes in thermal manure-to-energy species and can form compounds with chlorine and sulfur. Potassium-based particulate matter is often measured at below 2.5 um and is thus categorized as fine particulate matter.

A SCREEN3 analysis for three of the technologies (Bio-Burner 500, Ecoremedy gasifier, and Blue Flame boiler) was used to determine whether air emissions posed a potential threat to public health. The SCREEN3 model predicts that maximum concentration of pollutants produced by the system, which were then compared to established thresholds for criteria pollutants and air toxics. The analysis assumed that total particulate matter was classified as both PM10 and PM2.5.

Results form the SCREEN3 analysis found that emissions from the Ecoremedy gasifier and the Blue Flame boiler (after additional particulate matter emissions controls were installed) resulted in maximum concentrations of pollutants below public health thresholds. However, assuming all particulate matter is fine particulate matter, the Bio-Burner 500 predicted maximum concentration of PM2.5 exceeds the federal air quality standard. Further analysis suggested that the low height and wide diameter of the Bio-Burner 500 is likely contributing to this problem. For example, increasing the stack height by 12 feet reduced maximum concentrations of PM2.5 to levels below federal thresholds. As such, it is likely that stack modifications should be explored for this system. Additional particulate matter emissions controls to support expanded adoption throughout the region will also result in reduced maximum concentrations for these technologies.

The project team plans to continue working with vendors to improve particulate matter emissions controls, facilitating installation on farms throughout the Chesapeake Bay region.

4.2.3. Financial Performance

The financial performance analysis for the Ecoremedy gasifier and Global Re-Fuel systems was limited to data collected over one cold-weather season. However, Windview Farm provided data for energy use and savings associated with the Blue Flame boiler for 5 years of operation.

It is important to note that even when technical issues resulted in failure of the thermal technologies in delivering heat or electricity throughout an entire flock cycle, there were periods of successful energy production that reduced the use of propane for heating the poultry houses. While the data did not quantify the generated heat in a way that statistically correlates the technology with reduced propane use, farmers repeatedly observed and reported the trend toward reduced propane use while the systems were running. This saved energy and money for the growers and reduced their carbon footprint.

A sensitivity analysis to quantify and rank different farm characteristics or their ability to influence energy outcomes was also conducted. The analysis focused on the Mark Rohrer Farm, which provided the most detailed data and a side-by-side comparison of two poultry houses with and without manure-to-energy. Findings from the sensitivity analysis include:

- **A 25% increase in R-value results in an 18.5% decrease in the amount of propane saved by the manure-to-energy facility**. Farmers starting with a better insulated poultry house, with all other factors being constant, will save less propane by switching to manure-to-energy. As a rule of thumb in nearly all sectors of the economy, energy efficiency is more cost effective than switching to renewable sources of energy.
- **A 25% increase in boiler efficiency results in a 16.5% decrease in the amount of propane saved by the manure-to-energy system**. Farms with older, inefficient heating systems (e.g., boilers and furnaces) appear to have more to gain from installing a manure-to-energy heating system than a farm with a newer, high-efficiency heating system. For farms that can rely entirely on manure-to-energy systems for their heating needs, the efficiency of the existing system becomes less important because of the complete fuel switch.
- **The switch from organic to conventional birds results in a 77% decrease in the amount of propane saved from the manure-to-energy system**. All else being equal, organic poultry operations consume more propane than conventional poultry operations because of the premium cost on organic feed and the fact that food and heat are close substitutes. A related finding is that colder climates require more heating. It would stand to reason that poultry operations in these environments have more to gain in energy savings from manure-to-energy heating systems than peer farms in warmer climates.

Given the limited availability of data, the demonstration projects illustrated a range of results for the potentials ROI. The ROI is the ratio of energy savings to capital investment; it helps describe the extent to which the energy savings can offset the equipment costs over the operating life span of the technology. The assessment was based on an “intermittent scenario” of propane and electricity usage, with the manure-to-energy technology delivering heat only 40% of the time on any given day. Obviously, in scenarios where the technology is delivering heat for longer durations, the ROI will be better.

Given a technology operation of 40% of the time, the ROI analysis yielded a range of results from 0 to 38% over 10 years, and 0 to 49% over 15 years. Windview Farm and the

Mark Rohrer Farm offer positive return on the dollar invested. With the newly installed Blue Flame boiler on Windview Farm, it is reasonable to assume that the ROI will be even more favorable in the upcoming cold months, based on the increased size (an improved match to litter generated) and improved heat delivery system.

Due to lack of data or lack of transferability to other farms, the ROI analysis did not consider several financial components that would impact system performance. For example, propane allowances that some integrators (particularly organic) provide for farms will significantly improve the ROI. Windview Farm and the Earl Ray Zimmerman Farm both receive allowances for propane from their integrator, but conventional producers typically pay a larger portion (in many cases, most of) the propane costs out of pocket. When propane costs are shared between the integrator and the farmer, the willingness of the integrator to reimburse the grower for propane savings is an important component of financial feasibility.

Additionally, the ROI analysis did not address the potential change in revenue associated with poultry litter or ash sales. Markets for ash are not well established. While some vendors have had success in brokering purchases of ash at prices reflective of the market value of the nutrient, other farmers are still giving the ash way, thus incurring revenue loss from reduced poultry litter sales.

The project team recommends that, in the future, ROI analyses focus on flock health, whole-farm operations, and the social and environmental benefits gained from implementing manure-to-energy technology. For this reason, it is important not to focus on the value of co-products (ash and biochar) alone, and instead look at what the manure-to-energy technology does for farm operations and the greater community (which affects the role of public cost-share dollars).

The project team also noted that the unique circumstances of each of these farms raise questions about the ease and potential for using their varied experiences to construct meaningful cost ranges (capital and operational) that indicate financial impacts of the technology on a farm's bottom line. At the same time, these experiences illustrate the willingness of farmers to test new technologies with the potential to generate positive environmental and economic impacts.

5. Fertility Value and Market Potential of Poultry Litter Co-Products

The environmental potential of thermal manure-to-energy technologies hinges on the

The ash co-product shows promise as a crop fertilizer and can be cost-effectively transported to fields in nutrient-deficient regions.

ability to use the ash and biochar as a fertilizer on fields in nutrient-deficient regions. Because these products are not currently produced in the Chesapeake region, end-user markets are not established. To facilitate market demand for excess phosphorus, the Virginia Tech Eastern Shore Agricultural Research and Extension Center set up field trials to evaluate the performance of ash and biochar as a replacement for commercial phosphorus for row crops (corn, soybeans, and wheat) and for fresh market fruits and vegetables (where raw manure is not used as fertilizer for health reasons). In addition, several vendors established end-user markets for ash outside of the Chesapeake Bay region. Partners are also exploring additional market opportunities for incorporation of ash into specialty fertilizers.

The research revealed that several factors impact the overall nutrient concentrations of poultry litter co-products and the degree to which the nutrients they contain (nitrogen, phosphorus, and potassium) are available for plant uptake. The thermal combustion system is one variable, which includes the temperature of combustion, fuel-to-oxygen ratio, residence time of the poultry litter feedstock, and whether or not the system has an exhaust scrubbing system to catch fly ash. Another major factor is the poultry litter: the initial concentration of nutrients, bedding material, and moisture content of the poultry litter impact the co-product.

Nutrient densification varied between systems: phosphorus was concentrated between 4-12 times its original density, potassium was concentrated between 3-13 times its original density, and sulfur was concentrated between 2-5 times its original density. Our comparisons between total nutrient digestions and water-soluble extractions found that the ash and biochar co-products were significantly less plant available than standard inorganic fertilizers. The biochar co-products had the least plant-available nutrients of the fertilizers in the study. Therefore, a greater amount of the co-products will have to be applied to achieve the same standards as traditional inorganic fertilizers or fresh poultry litter.

Still, results indicate that poultry litter co-products are feasible fertilizers. However, given the variability in nutrient content and availability, ash and biochar co-products should be individually analyzed for nutrient content before making application recommendations.

6. Summary of Lessons Learned

6.1. Technology

1) On-farm systems are not a good match for every farm. They require considerably more management than propane heating systems and, depending on the farm, they may not be cost effective. On-farm thermal systems require far more time to operate and maintain than traditional propane heating systems. Most require the addition of poultry litter to the feed hopper at least once per day. Growers can expect to spend considerable time getting a technology that is in the early phases of commercial deployment up and running properly. These technologies are only appropriate for use on farms where growers have the time and interest in maintaining them.

2) The success of a particular technology on one farm does not mean that it will succeed on another farm.
   - The characteristics of poultry litter vary significantly between farms. Moisture content, foreign material (i.e., rocks), energy value (i.e., Btu/lb), and particle size can each impact system performance. System design and adjustments should be specific to the farm.
3) Success requires collaboration between the vendor and the farmer.
4) Farmers should seek technology vendors with knowledge and real-world experience that matches their specific situation as closely as possible; this could be a challenge because few technology vendors have experience using poultry litter as a fuel.
   - Vendors should be willing to invest resources to resolve unexpected technical issues.
   - When heat delivery for animal housing (e.g., poultry houses) is proposed, vendors should have experience or work with experienced partners to support the design process. Buildings for animal housing are not comparable to other industrial buildings when it comes to the design of heating and cooling systems.
   - Industry-specific knowledge is key to ensuring that a poultry litter-to-energy technology delivers heat successfully to the poultry houses.
5) The complexity of the project will be reduced if one vendor oversees both the energy-generating technology (the thermal system) and the energy delivery system (heat or electricity to the grid).
6) To support regulatory compliance, vendors should be prepared to supply data on air emissions.
7) Some thermal manure-to-energy systems need to be sheltered from weather. NRCS standards for building construction may need to be met if the project uses federal cost-share dollars.
8) Rocks and other foreign objects (such as tools) are ubiquitous in poultry litter. Technologies that use poultry litter as a fuel need to be able to handle foreign objects without damaging the equipment, shutting down the system, or demanding unacceptable levels of operator time and attention.
9) In states with strict particulate matter emissions thresholds, advanced air emissions controls may be needed to trap and remove fine particulate matter when poultry litter is used as a fuel.
10) Growers expressed interest in both heat and electricity generation via net metering. However, poultry litter-to-energy technologies with a track record of delivering electricity to the grid are limited. Also, proximity to three-phase power as well as state net metering regulations may impact the feasibility of grid connection.

6.2. Environment

1) State rules vary significantly with respect to on-farm thermal poultry litter-to-energy technologies. In some Bay states, several of the technologies demonstrated through this project currently do not meet permitting thresholds for particulate matter and/or nitrous oxide. One technology supported through this process meets permitting requirements for all the Bay states.

2) Most states in the Bay region require data on air emissions to support the permitting process.

3) Design of advanced air emissions controls for use with on-farm systems in states with strict particulate matter emissions thresholds can be challenging. Off-the-shelf technologies may not be suitable without additional engineering and design modifications.

4) Good design is key to reducing air emissions. Examples of design issues that negatively impact air emissions include incomplete combustion and lack of temperature or combustion air flow through the system.

5) All vendors participating in this project except for Bhsl and potentially the NCSU pyrolysis technology will need to reduce particulate matter emissions to facilitate adoption throughout the region. NOx emissions associated with two of the technologies also exceed Maryland permitting thresholds. Only Bhsl (and potentially the NCSU pyrolysis technology) currently qualifies for installation on farms throughout the Chesapeake Bay region.

6) EPA's SCREEN3 was used to predict maximum concentrations of pollutants associated with the Bio-Burner 500, Ecoremedy gasifier, and Blue Flame boiler. Criteria and hazardous air pollutants fell below federal or state established pollutant thresholds for all pollutants except fine particulate matter associated with the Bio-Burner 500. Assuming all total particulate matter is fine particulate matter (<2.5 μm in diameter, or PM2.5), SCREEN3 predicted maximum concentrations for PM2.5 emissions would exceed federal National Ambient Air Quality Standards. Changes to the stack are recommended to partially address this problem. Additional emissions controls for particulate matter are recommended for all technologies except Bhsl.

6.3. Financial

1) Initial capital expenditures for installation can be high:
   - Systems for heating poultry houses currently range from $87,000 to over $300,000 per house to install.
   - As these technologies mature, prices will likely come down over time.
   - One vendor is proposing a "pay for service" arrangement, but most vendors sell the technology directly to the farmer.

2) Technologies vary significantly in terms of cost but face-value comparison is not always the best approach to determining value. A comparison that normalizes the cost

may be a better way to evaluate technologies with different heat delivery mechanisms and efficiencies. For example, a unit such as dollars-per-BTU-delivered is worth considering in addition to the total cost of the system. On-going operation and maintenance costs should also be considered.

3) To reduce the size of the system (and therefore its cost), the farmer should first enact an energy conservation and energy efficiency plan for the farm.

4) Lack of a technology track record for on-farm performance increases risk for cost-share programs or farmer-financed systems. For example, EQIP funding for on-farm systems requires a 10-year contract. To date, no thermal poultry litter-to-energy systems have been deployed on any farm for 10 years.

5) Consistent determinations across states are important, if and when equipment can be housed in existing NRCS cost-shared poultry storage facilities.

6) Farm-scale thermal systems can benefit bird health and production. These potential benefits from warrant further investigation.

   - These systems deliver a drier heat to poultry houses than conventional propane heaters, as the by-products of combustion are exhausted outside of the poultry house. Drier heat can reduce both air and poultry litter moisture levels, which can in turn reduce emissions of ammonia.
   - Farmers with poultry litter-fueled heating systems can ventilate in the winter to support air quality via increased fresh air exchanges due to relatively lower unit energy costs of manure-to-energy systems.
   - Better air quality could result in improved flock performance, including key indicators such as weight gain, feed conversion, and mortality, but more work is needed in these areas to characterize any bird health improvements.

7) Organic poultry farms may offer the best opportunity for deploying farm-scale thermal systems. Organic poultry growers ventilate more frequently in the winter. In the Chesapeake region, organic production requires 3 to 5 times more propane than conventionally produced poultry. If there are improvements in bird health and feed conversion, these will be particularly important for organic integrators because organic feed is far more expensive than conventional.

8) For some technologies, based on a simple ROI analysis that considered only infrastructure costs and energy savings, energy production alone will likely not be sufficient to justify their widespread adoption from a financial standpoint. It is more likely that a combination of factors, including reduced energy costs, reduced need for nutrient pollution controls, improved production, and the added income, once markets are established, from a highly concentrated lightweight ash co-product, will be what moves these technologies toward commercialization.

6.4. Marketing Co-Products

1) Poultry litter ash and biochar are valuable plant nutrients. Depending on the process, poultry litter ash contains in the range of 14 to 18 % phosphorus fertilizer and 13 to 24% potash fertilizer. Plant availability of the nutrients also varies by process but is in the range of 80 to 100%.
2) On sandy loam soils in Virginia, row crops fertilized with ash and biochar from poultry litter produced yields similar to untreated poultry litter and commercial fertilizers.
3) Ash and biochar from thermal manure-to-energy technologies contain phosphorus that is 80 to nearly 100% soluble compared to triple super phosphate. In other words, thermal treatment converts much of the organic phosphorus — which is not immediately available for plant up-take — to phosphorus that is immediately plant available.
4) Connecting ash producers with end users will be critical for achieving the project goals of generating new sources of revenue for excess manure nutrients.
    - One vendor has had success in establishing markets with Midwest soybean growers who are willing to pay market price for the phosphorus and potash components of the poultry litter ash. However, other participating farm hosts do not have established markets for ash they are currently producing.

7. Communicating Results

With support from the Livestock Poultry Environmental Learning Center, project partners developed a website to serve as a clearinghouse for information and third-party evaluations of farm-scale thermal manure-to-energy technologies. Located on the eXtension website at www.extension.org/68455, the website was designed to serve as a central repository for future Extension or Land Grant University-affiliated evaluation efforts.

In addition to the website, steering committee members have given more than 120 presentations to stakeholders (farmers, policy makers, conservation professionals, state and federal agency representatives, and environmental nonprofit organizations) throughout the Chesapeake region. The project team also supported presentations given at national Livestock, Poultry and Environmental Learning Center meetings as well as hosting a webinar available to conservation professionals around the country.

Although field day events at project demonstration sites were initially planned, concerns about avian influenza outbreaks during the fall of 2015 curtailed these important communication opportunities. As an alternative, project partners worked with The Downstream Project to create a video highlighting the farm demonstrations and results from the project. The video will be available at www.extension.org/68455 in January 2016.

8. Summary & Next Steps

In summary, the Farm Manure-to-Energy Initiative has identified both opportunities and challenges associated with these emerging technologies:

- Several of these technologies have been in operation on multiple farms for more than three years. However, others are still in the early demonstration phase. One technology that initially seemed promising proved not ready for further deployment.
- All require a greater investment of time and capital to manage and install than traditional propane heating systems.
- The technologies demonstrated reductions in reactive nitrogen and the potential to cost-effectively transport excess phosphorus to nutrient-deficient farms outside of high-density animal production areas. Most of the technologies reduced reactive nitrogen emissions to air resources compared to standard land application practices.
- All but two technologies will need additional work on air emissions (particulate matter especially) before they can be installed in the Bay states with the strictest air permitting standards. The high potash content of poultry litter facilitates production of fine particulate matter. Only Bhsl and potentially the NCSU pyrolysis technology met all criteria for installation throughout the Chesapeake Bay region.

Next steps are as follows:

- Continue to support technology vendor efforts to improve emissions controls for deployment in all the Bay states. The project team is working with air emissions experts to recommend next steps for emissions control design and installation.
- Build on fertility trials to develop markets for poultry litter ash that connect growers with ash or biochar to end users willing to pay a fair price for the nutrients.
- Continue to communicate results: partners will work with farm partners to host field day events when avian influenza risk is lower.
- Research on the impact of thermal farm manure-to-energy systems on in-house air quality and poultry health, feed conversion, and weight gain is also recommended.
- Support research and development needed to bring promising technologies to the market.