Appendix A

Technical Performance: Global Re-Fuel Poultry Litter Furnace

A summary of preliminary technical performance findings funded by the Farm Manure-to-Energy Initiative

January 2016

Contents

1. The Technology

The Global Re-Fuel poultry litter furnace (PLF-500), manufactured by Wayne Combustion Systems in Fort Wayne, Indiana, is designed to burn poultry litter on-site as a heat source for poultry housing (Figure 1). According to Wayne Combustion, the Global Re-Fuel system has a maximum feed rate of 180 pounds of poultry litter per hour, and the system is rated to generate 500,000 Btu/hour of heat.

The design of the Global Re-Fuel unit is unique. It is a two-stage, air-to-air combustion system that can be described as “a box within a box”:

1. The combustion chamber is the inner chamber. It is a rectangular box comprised of mild steel that sits inside the outer chamber.
2. The outer chamber is the heat exchanger. A large HVAC fan (8,000-9,000 CFM) blows air around the outside of the combustion chamber where the heat from combustion transfers its energy to the air. The air is directed around the combustion chamber via baffles and ultimately exits through ductwork to the poultry house. The return air comes from the poultry house, creating a system that does not pressurize nor pull a vacuum on the poultry house.

The material handling system is comprised of a large bulk hopper that uses a drag chain to move the litter into a horizontal transfer auger. The bulk hopper has a series of “beaters” that are used to de-lump the litter before it exits the hopper and enters the transfer auger. The transfer auger takes the litter from the bulk hopper onto an inclined belt conveyor that is mostly enclosed. The belt conveyor moves the litter to a cone-shaped surge hopper located on top of the combustion unit. Another de-lumper is located between the belt conveyor and the surge hopper. The surge hopper has a material sensing switch that controls all prior material handling components in an on/off fashion. When the surge hopper is empty, the material handling components are energized and stay energized, enabling the flow of material until the surge hopper is full, thereby stopping material flow.

The surge hopper has a rotating assembly inside to keep the litter from bridging. An auger is mounted vertically in the surge hopper and is used to meter litter from the surge hopper onto the top distribution plate inside the combustion chamber. The surge hopper acts as an airlock as long as litter is inside. The top distribution plate has a sweep arm that rotates on top of the distribution plate. The top plate has holes in it so that the litter will only pass through the plate once the litter is small enough to go through the holes. This allows time for the litter to be dried and for some pyrolysis to take place before the litter falls on the combustion grate.

Another sweep arm is used to keep the litter moving on the bottom combustion grate. The concept is for the litter to combust quickly as it falls from the top plate to the bottom plate with little residence time on the bottom plate. The bottom plate acts as an air distribution grate and ash removal system. The bottom combustion grates consist of two plates that have identical slots. The bottom of the two plates remains stationary while an air cylinder is used to “shake” or rotate the top bottom grate a few degrees in a clockwiseto-counterclockwise motion to shake the ash through the holes in the grates and allow the ash to fall through the grates into an “ash pan” below. The ash pan also has a shake mechanism to keep the ash moving. The ash pan has two 3-inch flexible augers that are perpendicular to each other. They are used to remove the ash from the system. The combustion air is delivered via a blower through the bottom combustion grate slots. The combustion air blows vertically upwards through the grate, where it comes into contact with the litter and encounters volatile off-gassing from the litter, which is subsequently oxidized via combustion. On one side of the combustion chamber is a vertical steel wall that separates the combustion zone from the flue stack, located at the top on one side of the chamber.

The control system uses a programmable logic controller (PLC) to control the entire system. Turning the system on simply requires the operator to press the “GO” button. The system has safety features designed to prevent overheating and to detect problems in the system. If problems are detected, the system is designed to shut down to prevent damage.

By design, the only other things the farmer needs to do are load the large hopper and empty the ash barrel. In these case studies, it typically took 30-45 minutes to heat up with propane before the system started using litter as the fuel. It took another 30-60 minutes to reach full temperature.

This system operates in tandem with the poultry house’s existing propane heating system. The house controllers are then used to manage the propane-fueled unit heaters to provide supplemental heat for the houses. The two systems operate independently of each other; the Global Re-Fuel system operates continuously because the unit is not able to modulate to meet a varying thermal load. The propane burners can be set to turn on at any set temperature. This arrangement allows the systems to operate together but on separate controls. If the Global Re-Fuel system is not working, then the propane burners will heat the houses. When the Global Re-Fuel unit returns to operation, it will generate heat; the propane burners will only turn on when more heat is needed than what the Global Re-Fuel unit can provide.

The Global Re-Fuel furnace has an adjustable fuel feed rate. If the houses need less heat, then the Global Re-Fuel unit can be set to a lower feed rate with a press of a button. Currently, there is no mechanism to automatically reduce the temperature of hot air delivered to houses.

While the system is automated, the farmer needs to adjust the system from time to time. As previously mentioned, the system provides heat to the houses regardless of house temperature. If the houses do not need heat or if they need minimal heat, the system either has to be either turned off or the feed rate reduced. Other things that were not automated and needed periodic adjustment include:

- The combustion air, which is manually adjusted.
- The ash system is timed using the feed rate to set the time interval and could not be changed without PLC programming changes.

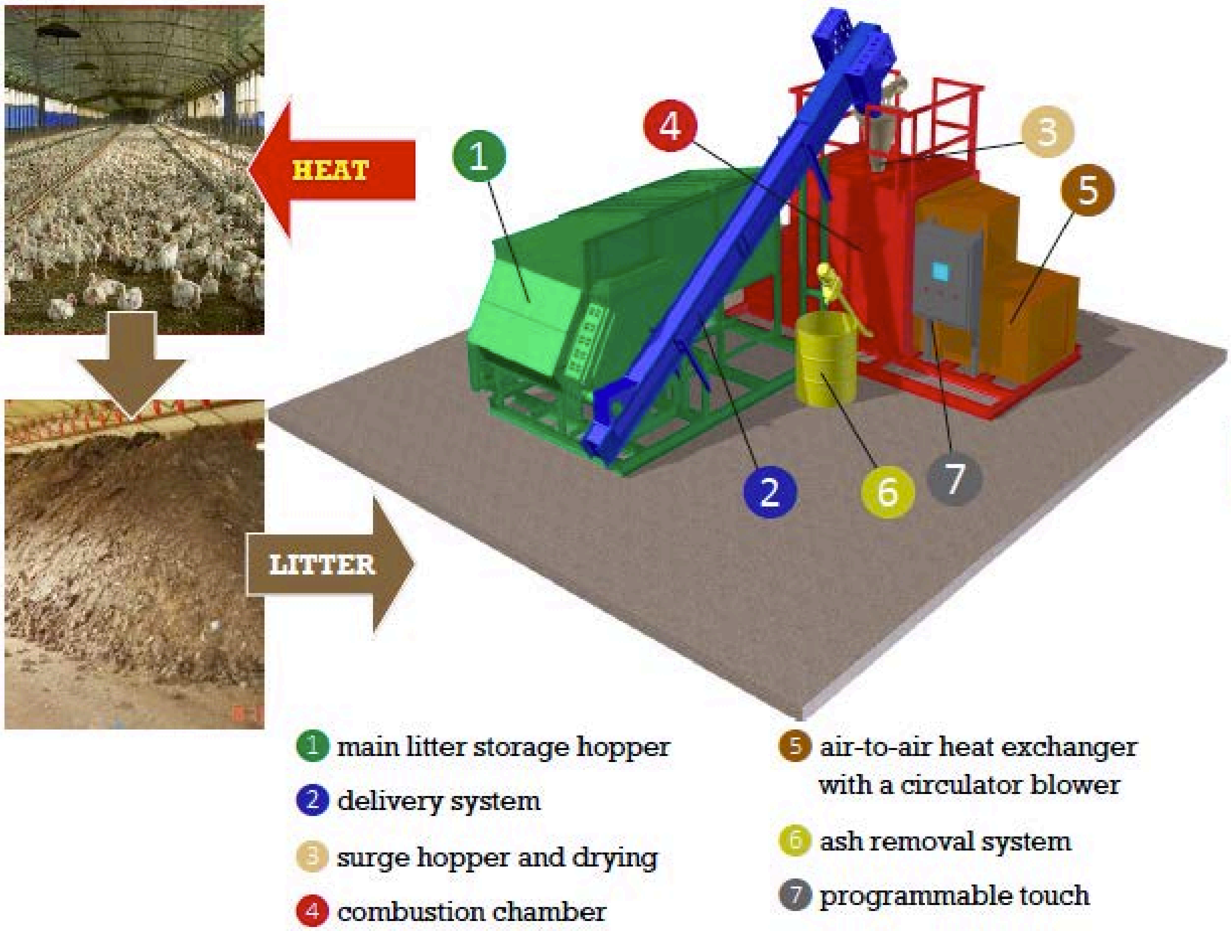


Figure 1. Configuration of the Global Re-Fuel poultry litter furnace, manufactured by Wayne Combustion.

Because hot air cannot be delivered long distances without sacrificing temperature, the Global Re-Fuel system must be located in close proximity to the load. It can be installed between two poultry houses (Figure 2) or alongside one house with duct work installed underground to heat two houses, maintaining vehicle access between the houses if necessary (Figure 3).

Figure 2. The Global Re-Fuel system at the Rohrer farm is located between two poultry houses to reduce length of ductwork.

Figure 3. The Global Re-Fuel system at the Weaver farm is placed on a concrete pad between two poultry houses. The farmer needed to maintain the road between the houses, so the system was installed adjacent to one house and the ductwork to the other house was buried under the road.

2. The Farms

Funding from the Farm Manure-to-Energy Initiative was used to install the Global Re-Fuel furnace on two farms in the Chesapeake Bay region: the Mike Weaver farm (Fort Seybert, West Virginia) and the Mark Rohrer farm (Strasburg, Pennsylvania). The Eastern Shore of Virginia Resource Conservation District also sponsored an installation on a turkey farm in Port Republic, Virginia. Prior to installation in the Chesapeake Bay area, the system had been previously demonstrated on a poultry farm in Indiana.

2.1 Mike Weaver Farm: Fort Seybert, West Virginia

Located in Fort Seybert, West Virginia, the Mike Weaver farm produces 585,000 broiler chickens per year for Pilgrim's Pride. Birds are grown to 4 pounds over a 36-day period in two poultry houses that measure 624 feet by 50 feet (31,200 ft^2 total area per house). In addition to poultry, the farm also produces 28 beef cattle on 60 acres of pasture. Twenty-five acres on the farm are planted in hay to produce winter forage for the cattle.

The broilers produce approximately 400 tons of poultry litter per year, which is stored under cover. Litter is "caked out" between every flock. Mr. Weaver does not use any of litter on the farm as a fertilizer. All of the farm's poultry litter is sold to farmers outside of the Chesapeake Bay watershed. Energy value and moisture content of the poultry litter produced on the farm is 4972 Btu/lb and 21%, respectively (see Appendix E for details on methods used for collection and analysis).

An energy audit was previously conducted for this farm. Based on the audit recommendations, Mr. Weaver replaced interior lighting with LED bulbs. Other energy-saving strategies in the poultry houses include attic inlets that provide solar heat to the house and high-efficiency motors for the house fans. Currently, the farm uses approximately 1,900 gallons of propane per year. At $1.30 per gallon, the total cost for propane is $2,500 per house (or $5,000 per year). Mr. Weaver pays for propane out of pocket.

The Global Re-Fuel system was intended to provide heat for both poultry houses. To maintain vehicle access between the houses, the system was installed alongside one of the poultry houses with ductwork installed under the road to deliver heat to the second house (Figure 3).

2.2 The Mark Rohrer Farm: Strasburg, Pennsylvania

Located in Strasburg, Pennsylvania, the Mark Rohrer farm began this project as a producer of conventional broiler chickens. The farm produced 296,000 broilers per year for Tysons, growing birds to 6 pounds in a 48-day period in two poultry houses measuring 48 feet by 500 feet. During the project timeframe, the Mark Rohrer farm converted to organic broiler production for Coleman Natural. Once the organic conversion took place, moisture content of the poultry litter increased beyond the specifications for the Global Re-Fuel unit. Because of higher moisture value of the poultry litter and other issues (described below) the unit has not been used since the farm converted to organic production.

The farm produces 320 tons of poultry litter per year, which is stored in a covered facility. All of the litter produced by the farm is exported for local use. Energy content of the poultry litter produced under conventional operation was 5,178 Btu/lb and 20 percent moisture (see Appendix E). After conversion to organic production, poultry litter moisture increased to 46 percent under the water lines and 38 percent elsewhere in the house.

In 2011, Mr. Rohrer installed solar panels on the poultry houses and annually generates approximately 80,000 kWhs of electricity and, via net metering, delivers 10,000 kWhs to the grid.

The Global Re-Fuel system is installed directly between the two houses (Figure 2). As vehicles can access the center lane from either side of the houses, installation in the center of two houses did not interfere with vehicle access.

3. Objectives and Methods

3.1 Overall Technical Performance Design Objectives

The objective of the performance evaluation was to determine the degree to which the Global Re-Fuel unit achieved the following design objectives:

- Use poultry litter as a fuel to reliably deliver heat to poultry houses
- Integrate seamlessly with the farm's existing propane-fired unit heaters and ventilation systems to maintain house temperature and relative humidity within industry-recommended (and grower established) targets
- Reduce propane use on the farm
- Run successfully with minimal operation and maintenance requirements (routine maintenance and daily addition of poultry litter fuel)
- Operate without negatively impacting bird production and ideally improve bird health and production by allowing for increased winter ventilation and improved air quality

3.2 Technical Performance Evaluation Methods

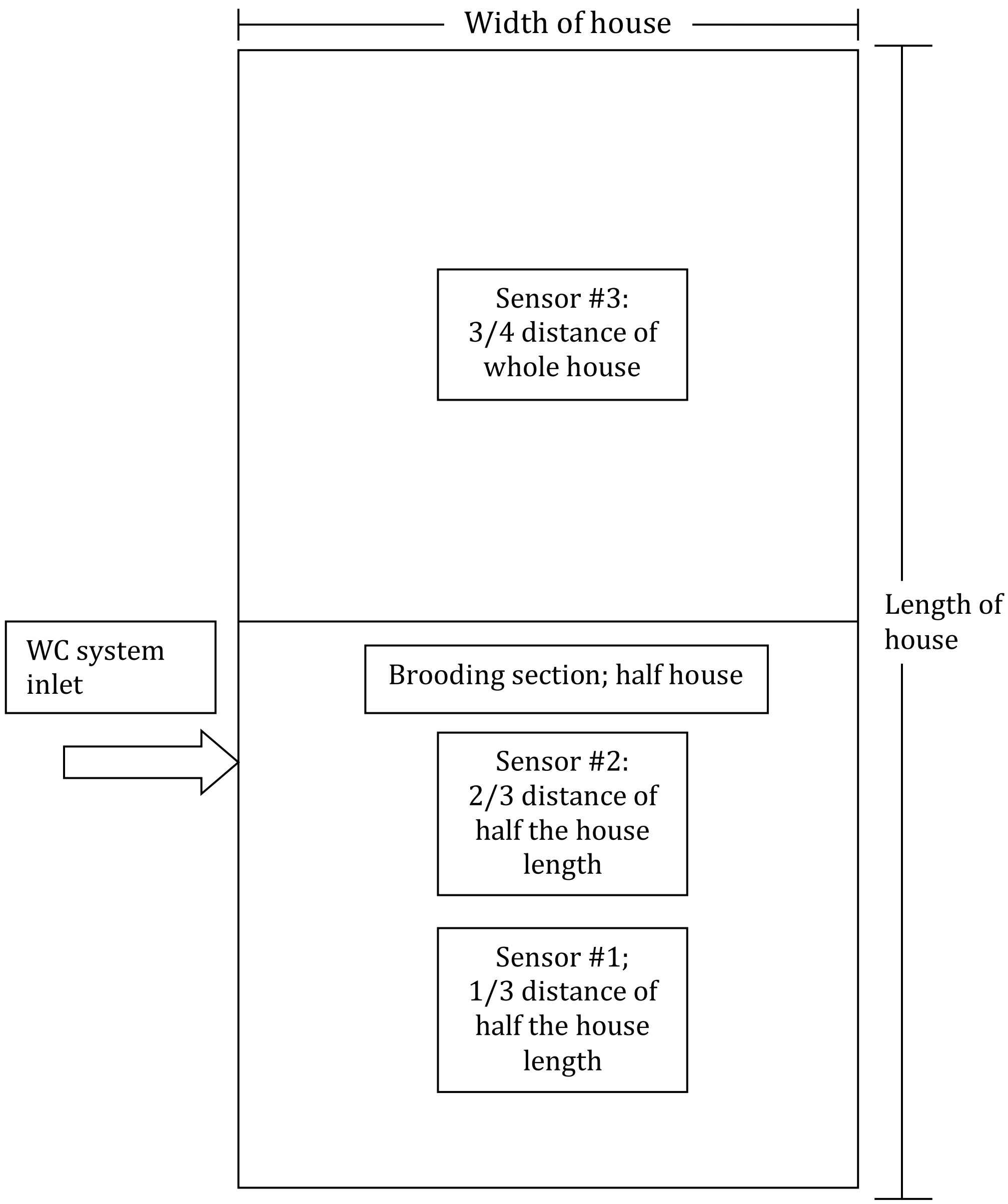
Temperature and humidity

To monitor in-house conditions, in January and September 2014, the project team installed three, 12-bit temperature/relative humidity sensors (HOBO, S-THB-MOO2) in each poultry house at the Rohrer and Weaver farms with an additional sensor installed outside of the house to monitor outdoor temperature and relative humidity. Figure 5 depicts the location of each of the sensors within the poultry houses. At the Mark Rohrer farm, temperature and humidity sensors were also installed in two similar poultry houses owned by Todd Rohrer that were located immediately adjacent to Mark Rohrer's two poultry houses. Data from the sensors was collected and stored using a HOBO data logger (U30-GSM-000-10-S100-001).

HOBO (S-THB-M002) temperature/relative humidity sensors were also installed in the inlet and outlet ducts to monitor system run time. On the Mike Weaver farm, these duct temperature sensors were installed in September 2014, while at the Mark Rohrer farm they were installed in November 2014. Whenever the inlet temperature (heat supply) was above 100 °F and there was a temperature difference of 10°F or greater between the inlet and return ductwork (with the supply ductwork having the higher temperature), the system was deemed to be "on."

In July of 2014, a smoke test was at the Mike Weaver farm to observe heat distribution in the house using the house's existing ventilation system. The propane heating system was turned off for this test.

Figure 5. Temperature and humidity sensor locations at the Mark Rohrer farm, the Todd Rohrer farm, and the Mike Weaver farm. The dimensions reflect Mark and Todd Rohrer's poultry houses, but the configuration also applies to the Mike Weaver Farm.



Energy use and/or savings (propane and electricity)

The project team measured electricity load requirements for the Global Re-Fuel unit as well as propane use. On the Mark Rohrer farm and the Todd Rohrer farm, a propane meter (American Meter AL-425TCH-CF) was installed in September 2014 to measure propane consumption of both the Global Re-Fuel unit (which uses propane as a starter fuel) and propane used for poultry houses. One meter was installed for Mark Rohrer's house #3 and one meter for Todd Rohrer's house #2. Utility meters were used to monitor whole-farm electricity consumption, while a GE I-210 electricity meter was used to monitor Global Re-Fuel system electricity consumption at the Mark Rohrer farm. Electricity consumption of the Global Re-Fuel unit at the Mike Weaver farm was measured via a submeter; however, the electric meter at the Weaver farm never operated correctly.

Farmer-supplied performance data

Both Mike Weaver and Mark Rohrer used weekly log sheets to track operation and maintenance requirements, system run time and performance concerns, flock age, and their observations of in-house conditions. Metrics documented on the log included:

- Flock status (number of days from placement)
- Portion of the house occupied by the flock (partial/whole)
- Hours the system was operational (hours/week)
- Hours of farm labor needed to run the system over the week (operation and maintenance)
- Reasons the system was not run (e.g., heat not needed, maintenance problems)
- Description of any problems that occurred
- Length of system down-time due to problems
- House conditions (heat distribution, dust level, ammonia odor)
- Propane meter readings

Data on flock performance was assessed via information supplied by the integrator in the farm's "settlement sheet." Settlement sheets include data on average bird weight, feed consumption, feed conversion, and bird health relative to other producers with similar flock placement timing.

Mark Rohrer also supplied information on previous farm energy use (propane and electricity), flock performance (via settlement sheets), and poultry litter production and use (on and off the farm).

4. Performance Results

4.1 Reliability

Both Global Re-Fuel units experienced numerous mechanical problems that required significant investment in time for both farmers and Wayne Combustion. These mechanical problems interfered with the operation of the units and reduced reliability and heat delivery. As of the conclusion of the monitoring period, many of these technical problems were not yet resolved. Because of these issues (and increased moisture of the poultry litter at the Mark Rohrer farm after conversion to organic production), neither of these units are currently operational. A summary of technical issues is included in Table 1.

Table 1. Summary of mechanical problems for both Global Re-Fuel units, time required to resolve, and recommended next steps

Mechanical Issue	Farmer Time to Resolve (hrs)	Recommended Next Steps
Mike Weaver Farm		
Hopper sensor problems (multiple times)	1.5 hours	Replace sensor or replace litter handling equipment.
Ash auger jam (multiple times)	18 hours total	Replace flexible ash auger with solid shaft auger and re-do ash catch pan to eliminate the need for two separate ash augers.
Combustion grate stuck	30+ hours	Increased force to the shake grate solved problem but created a new one. Combustion grate and air delivery need to be redesigned
Incomplete ash	On-going	The combustion grate problem was solved by increasing the amount of force shaking the grate, but it shook too hard and would allow unburnt litter to fall into the ash pan.
Burner distribution plate deterioration	On-going	Replaced plate once. Plate needs to be made out of different high-temperature alloy.
Excessive dust from material handling systems	On-going	Material handling system redesigned using sealed conveyers where possible and sealing off areas under main hopper.

Mark Rohrer Farm		
Main conveyor motor overload	4+ hours	Reset overload contactor. Belt conveyor needs to be replaced with different conveying mechanism.
Ash pan broke	12 hours	The ash pan and ash augers are overheating and need to be replaced with metals that can take the corrosive and high temperature conditions. No other Global Re-Fuel system has experienced this problem. Possible cause is that draft is too low, preventing the hot gases from being adequately pulled through the stack.
Ash auger jam (multiple times)	On-going	Replace flexible ash auger with solid shaft auger and re-do ash catch pan to eliminate the need for two separate ash augers.
Combustion grate stuck	On-going	Increased force to the shake grate solved problem but created a new one. Combustion grate and air delivery need to be redesigned
Incomplete ash	On-going	The combustion grate problem was solved by increasing the amount of force shaking the grate, but it shook too hard and would allow unburnt litter to fall into the ash pan.
Litter moisture too high	On-going	The litter from the organic birds was higher in moisture (>30%) and was too high for the unit to sustain combustion.

4.2 Capacity Factor

Capacity factor as defined for this project describes the actual operation of the unit compared to the potential operational time. Each farmer had different goals for running the units (to pre-heat houses and to provide heat for chicks), and these goals changed from flock to flock. In general, Mike Weaver's operational goal was to run the unit up to three days prior to flock placement and for approximately three weeks after flock placement. Mark Rohrer's operational goal was to run the unit up to three days prior to placement and for three to four weeks after flock placement. To facilitate comparison, a timeframe of three days before flock placement and three weeks after flock placement was used as the potential operational time.

Table 2. Capacity factor performance for the Global Re-Fuel systems at the Mark Rohrer and Mike Weaver Farms

Farm Name	Flock 1 [September - November]	Flock 2 [November - January]	Flock 3 [January - March]
Mike Weaver Farm (9/26/14 – 3/5/15)	52.1%[1]	25.3%	39.3%
Mark Rohrer Farm (9/18/14 – 3/10/15	48.8%	68.2%	0[2]

[1]The percent of time the Global Re-Fuel system ran 3 days prior to flock placement, and 3 weeks after flock placement (24 days).

[2]The Global Re-Fuel unit did run prior to the third flock for Mark Rohrer; however, it only ran for a few days approximately one week prior to the flock being placed and thus that runtime was not counted.

4.3 Heat Delivery, Temperature, and Relative Humidity

Heat delivery, propane use, and electricity use are presented in Table 3. Over a three-flock period, the Globl Re-Fuel unit at the Mike Weaver farm delivered between 56.66 and 114.85 MBtu of heat to two poultry houses. During this timeframe, estimated propane heat delivery was estimated 135.5 MBtu for Flock 1 and 3 (no data on propane use for Flock 2 was available). At the Mark Rohrer farm, the Global Re-Fuel heat delivery ranged from 25.52 to 156.29 MBtu per flock over a three-flock period, while propane heat delivery ranged from 139.50 to 741.24 MBtu.

The Global Re-Fuel system consumes propane fuel to provide heat for start-up and electricity to run controllers and mechanical components. Data from both farms suggests this propane start-up fuel ranges between 0.25 and 6.78 gallons of propane/MBtu. At the Mike Weaver farm, total propane use was 0.026 MBtu propane/MBtu poultry litter heat delivered. At the Mark Rohrer farm, total propane use was 0.023 MBtu propane/MBtu poultry litter heat delivered. Over a three-flock period on the Mark Rohrer farm, the Global Re-Fuel system used 3,903 kWh of electricity to deliver a total of 291.85 MBtu of heat, or 13.37 kWh/MBtu heat.

Table 4 and Figures 6 and 7 describe the performance of the system with respect to achieving target temperature and relative humidity goals compared to operation of the poultry houses using propane fuel only. These goals were set based on the farmer's preferences. Mark Rohrer and Todd Rohrer have a goal that the temperature in the houses will be within three degrees of the house controller sensors located. Mike Weaver has a goal of only 2 degrees temperature difference between the sensors. The goal for relative humidity was to keep it under 60 percent. Performance for periods when the system was running (with Global Re-Fuel) and not running (without Global Re-Fuel) are included for comparison. Also, Table 4 includes data from two poultry houses on the Todd Roher farm that are located immediately adjacent to the Mark Rohrer farm and are included for comparison purposes.

Table 3. Operational performance data for the Global Re-Fuel unit on the Mike Weaver and Mark Rohrer farms

	Global Re-Fuel						Propane Heating System	
	Hours in Operation	Poultry Litter Feed Rate (lbs/hr)	Propane Use (gallons)	Propane Use (MBTUs)	Electricity Use (kWh)	Heat Delivered to Houses (MBTU)*	Propane Use (gallons)	Propane Use (MBTU)
Mike Weaver Farm								
Flock 1	300	100-180	14.9	1.34	n/a	114.85		135.50
Flock 2	148	100-180	29.3	2.64	n/a	56.66	1,659	
Flock 3	226	100-180	31.1	2.80	n/a	86.52	n/a	n/a
Total	674	100-180	75.3	6.78	n/a	258.04	1,659	135.50
Mark Rohrer Farm								
Flock 1	276	100-180	27.8	2.50	1395	110.04	1,550	139.50
Flock 2	392	100-180	44.5	4.01	2284	156.29	4,461	401.49
Flock 3	64	100-180	2.8	0.25	224	25.52	8,236	741.24
Total	732	100-180	75.1	6.76	3903	291.85	14,247	1,282.23

* Based on 140 lbs/hr feed rate and the Btu/lb value of the litter collected at the beginning of the project (5,178 Btu/lb for Rohrer and 4,972 Btu/lb for Weaver) times the estimated efficiency of the Global Re-Fuel unit (55%).

Table 4. Temperature and relative humidity performance in houses heated with the Global Re-Fuel system for the duration of the monitoring period (three flocks). Performance for periods when the system was running (with Global Re-Fuel) and not running (without Global Re-Fuel) are included for comparison. Also, data from two poultry houses on the Todd Rohrer farm that are located immediately adjacent to the Mark Rohrer farm are included for comparison purposes.

Farm Name (Monitoring Period)	Temperature Target			Relative Humidity Target		
	Achieved for the entire flock	Achieved with Global Re-Fuel	Achieved without Global Re-Fuel	Achieved for the entire flock	Achieved with Global Re-Fuel	Achieved without Global Re-Fuel
Mike Weaver Farm (9/26/14 – 3/5/15)	27%	28%	28%	4%	16%	3%
Mark Rohrer Farm (9/18/14 – 3/10/15	72%	71%	87%	10%	37%	45%
Todd Rohrer Farm (10/22/14 – 3/10/15)	75%	n/a	n/a	14%	n/a	n/a

Figure 6. Temperature as measured by inside and outside sensors, compared to target temperature during Flock 1. Periods when the Global Re-Fuel system was operational (Global Re-Fuel on) are denoted by a straight green line at bottom of the graph.

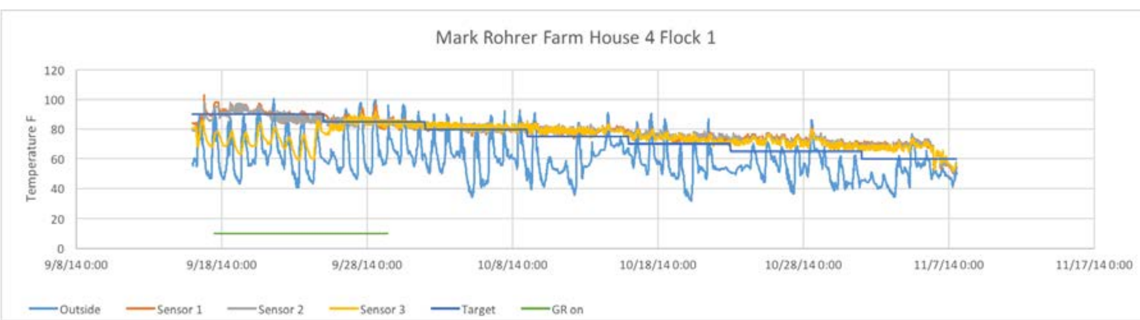
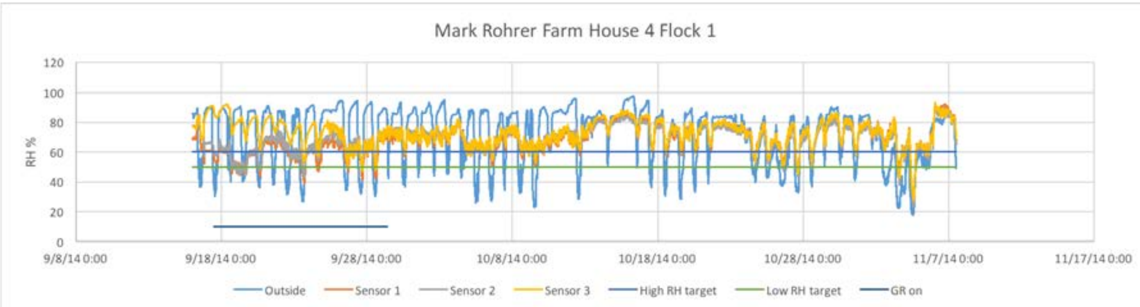


Figure 7. Relative humidity (RH) as measured by in-house and outdoor sensors at the Mark Rohrer farm for House 4 during Flock 1 compared to the target RH. The period when the Global Re-Fuel unit was operational (Global Re-Fuel on) is denoted by a straight line at the bottom of the graph.



4.4 Operation and Maintenance Requirements

Time spent by both Mr. Weaver and Mr. Rohrer for non-routine maintenance on the Global Re-Fuel unit was much higher than anticipated. For example, Mr. Weaver's time investment during one flock, primarily for maintenance, was 10% of the total run time for the unit (32 hours of labor for 304 hours of runtime). Mr. Rohrer kept detailed records of his time operating and maintaining the unit. On weeks when the system was operational, he spent 3 to 3.5 hours in routine maintenance. Overall, for the period of time when the unit operated, he spent 50 hours operating and maintaining the unit for 695 hours of operation. At 695 hours (or 4.12 weeks) of operation, routine operation should have required 13 hours.

5. Performance Discussion

5.1 Reliability and Capacity Factor

Multiple technical performance issues resulted in considerable negative impacts to the Global Re-Fuel system reliability and capacity. These technical performance problems (summarized in Table 1) will need to be addressed before the system should be deployed on additional farms. At the conclusion of this project, the units on the Mike Weaver farm and the Mark Rohrer farm are not operational. Note that the Mark Rohrer farm has since converted to organic production and now produces poultry litter with moisture content above 30%. This moisture value exceeds the design specifications for the Global Re-Fuel unit. Hence, in addition to addressing technical problems with the unit, litter moisture would also need to be addressed for successful operation on the Mark Rohrer farm. Both Mike Weaver and

Mark Rohrer have been provided with funding from the Farm Manure-to-Energy Initiative to support decommissioning of the system.

5.2 Heat Delivery, Temperature, and Relative Humidity

When the Global Re-Fuel systems were operational, initial performance suggests that it did successfully integrate with the farm's existing propane heating systems on the Mike Weaver farm. Data is less conclusive at the Mark Rohrer farm, where there is an apparent improvement in performance when the Global Re-Fuel system is off, although it is not possible to determine whether the Global Re-Fuel system is the contributing fact to the decrease in performance or whether other factors are a function (larger birds and whole house heating later in the flock, for example).

One technical problem that impacted temperature delivery on the Mike Weaver farm was observed. It was discovered that the Global Re-Fuel unit's louvers that control the air flow through the ductwork and into the poultry houses malfunctioned and were partially closed. This caused the temperature for the supply air to reach over 200^0 F with a significantly reduced airflow. This caused the sensor in the middle of the barn to be a few degrees higher when the Global Re-Fuel system operated, causing the percent time of the sensors were within 2 degrees of each other to be very low. This failure of the Global Re-Fuel system's louvers was not detected by the Global Re-Fuel controls and will need to be addressed in the future.

Farmers noted that they needed to adjust their circulation fans and house vents to adjust for the Global Re-Fuel system. This area of heat distribution can be studied in the future projects.

Relative Humidity is the amount of water vapor present in air expressed as a percentage of the amount needed for saturation at the same temperature. Zero percent relative humidity means the air is completely dry; 100% relative humidity means the air is saturated and any more water vapor added to the environment would "fall out" as rain or condensation. A target of 50-60% relative humidity is considered comfortable for humans and good for bird health.

Relative humidity for both farms fell within acceptable industry ranges for a small percent of the time (Table 4). Table 4 indicates that the Mike Weaver farm showed improved relative humidity performance when the Global Re-Fuel system was operational, while the Mark Rohrer farm had the opposite experience. Hydronic heat or air-to-air heating systems (as provided by the Global Re-Fuel system) should provide a drier heat than propane, which releases 0.8 gallons of water as moisture for every gallon of propane burned. Therefore, it is unclear why the Mark Rohrer farm experienced worse relative humidity performance without the Global Re-Fuel system, particularly since the system primarily operated in the beginning of the flock, when the birds were smaller and therefore producing less moisture in the form of manure and respiration.

5.3 Operation and Maintenance Requirements

Operation and maintenance requirements for these two units greatly exceed the amount of time that farmers anticipated. Despite the time Mr. Rohrer and Mr. Weaver invested in equipment repairs, the units did not consistently perform as designed. In addition to design issues as previously discussed, Wayne Combustion did not have technical staff available on an as-needed basis to support equipment repairs during the commissioning period. Often, technical staff would provide guidance to the farmers over the phone, and the farm partners would then implement the repairs on their own. While this was sometimes successful in the short-term, ultimately these systems needed far more technical repair and support than Wayne Combustion was able to provide, resulting in an unacceptably high labor investment required of the farm partners.

6. Recommendations and Next Steps

Given the Global Re-Fuel Furnace's technical performance issues, this technology is currently not ready for widespread adoption. Research and development investments are needed before this technology is ready for further deployment on farms. Wayne Combustion Systems, a company that specializes in gas-powered burners rather than farm equipment, has decided not to continue investments in developing and commercializing this technology.

However, given the low price-point and compelling design, project partners suggest that this technology has the potential to provide a low-cost option for on-farm poultry litter-generated heat. To support the additional research and design needed to bring this technology to market, the Farm Manure-to-Energy Initiative team has consulted with Wayne Combustion Systems and the Global Re-Fuel technology inventor to identify strategies to address these technical problems. Detailed, step-by-step recommendations have been developed to support this process including specific engineering and mechanical recommendations, the order of implementation, and an approximate budget.

With support from the Natural Resources Conservation Service, Florida A&M will begin implementing these strategies and will look at how changes in operational parameters such as combustion air, litter moisture, and draft conditions effect the performance of the system and the emissions (focusing on carbon monoxide, nitrogen oxides, and particulate matter). This project will involve members of the Farm Manure-to-Energy Initiative to implement a testing protocol to look at the changes in combustion on the Global Re-Fuel unit located near Harrisonburg, VA.