# Coaltec Energy

# NRCS FINAL REPORT

**Conservation Innovation Grant 2006**

**October 30, 2009**

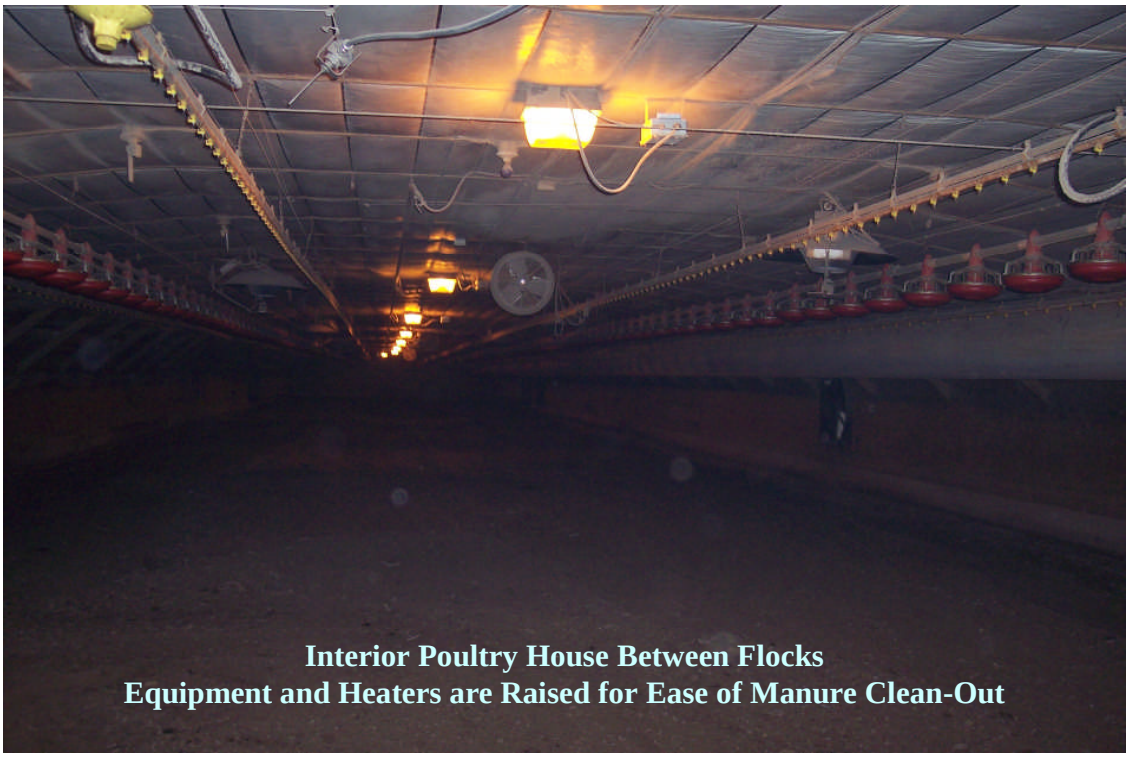
## Executive Summary

This project was funded to provide, install, and operate a gasification system on a poultry farm. There were a variety of deliverables associated with this effort, but the main focus was the determination of the viability of the gasification technology. The main goal of the project was accomplished and the operation of the gasification system has been very successful. But, as in many cases with new technologies, or new applications, the direction of the project and the deliverables which are necessary to make the project successful seem to change as the project progresses. The initial concept remained with little change; however, the importance of several factors changed dramatically and there were new discoveries made that radically changed the outcome of the project. There were many lessons learned and changes made, but overall the project was very successful and is transferable to many other potential sites – based on the work from this project, other systems are currently in various stages of development.

## Project Description

Frye Poultry is a small family owned broiler operation that supplies broilers to Pilgrims Farms. The farm consists of 3 houses, each with 20,000 feet of floor space and housing approximately 32,000 chickens per flock. The growing cycle consists of approximately 38 days from baby chicks to 4-pound broilers, with a gap typically of 2-weeks to prepare the houses for the next flock. The supply of the chicks, the collection of the broilers, the quality of the feed ration, and the pay scale for the grower are all

managed by Pilgrims. The grower is responsible for managing the environment for the birds and providing the optimum environment to maximize growth rate and provide healthy birds. This involves temperature control, relative humidity control, control of ammonia levels in the atmosphere in the houses, and a variety of other components that contribute to a healthy environment for the chickens. To accomplish this goal, each house contains multiple propane heaters, ventilation fans, and a network of pulleys, louvers, and environmental sensors to both monitor the environment and control it.



**Interior Poultry House Between Flocks**
**Equipment and Heaters are Raised for Ease of Manure Clean-Out**

Also, as a part of the production cycle, after each flock is removed from the house a layer of manure is removed from the floor and then removed from the site. This process is called “crusting” and removes the top few inches of material. On a less frequent basis, usually once each year, the manure on the floor is removed completely and a bed of wood shavings is put down and the process begins again.

The disposal of the manure once it is removed from the houses is a significant issue. For many years, the manure from poultry operations has been land applied as a source of nutrients for crops. As such, it has a value for the farmers and has been a source of revenue for them. This value fluctuates wildly depending on the density of the farms, the distance from the growers to croplands, and lately it has been impacted by the nutrient levels of the land where it is applied. Frye Poultry is in the Chesapeake Bay Watershed, which has been greatly been impacted by nutrient loading on the land from

agricultural operations. Frye currently is still able to sell his manure and receive revenue from it, but due to issues in the watershed, this situation is changing.

A combination of all of the previous factors places the growers in a position where they are struggling to remain profitable and therefore are looking for alternatives. The addition of the gasification process to the operating system on the farm has the ability to change the existing situation.

The concept of the project was to design, install, and operate a gasification system using the manure removed from the poultry houses as the fuel. The energy produced from the system would be drawn through an air-to-air heat exchanger and produce a clean hot air product that could be blown into the chicken house under positive pressure to ventilate the house. The primary initial concept of the project was to reduce or eliminate the cost of propane to heat the house. However, in order to develop an economically sustainable project, there must be alternative value provided by the gasification system. Various potential benefits that can be derived from the system are:

- Cost reduction due to replacement of propane.
- Improved animal health and growth rates due to reduced use of propane; thus the relative humidity in the houses is reduced which improved the environment. This also lowers the ammonia content as the humidity in the air reacts with nitrogen in the manure to form ammonia.
- Reduced mortalities; and reduced cost of disposal of mortalities by using them as fuel for the gasifier.
- Ash product from the gasifier as a fertilizer additive – this has created the greatest surprise in the project and the most opportunity. The ability to produce a biochar product from the gasifier, which contains a carbon char element in the ash, has greatly increased the value of the material as a fertilizer additive and has also

provided opportunities for marketing biochar as a water filtration medium, a litter amendment, and a feed supplement.

- Reduction in labor and time involved to maintain the houses as well as prepare the houses between flocks for the next chicks. This has dual benefits; 1) it reduces the labor cost and 2) a shorter turn around time between flocks could actually allow for an additional flock per year, thus providing more revenue for the same infrastructure.
- Improved animal health due to ventilation system – positive pressure in the house eliminates the surge of cold air when vents are opened in response to exhaust fans running to remove ammonia from the air.

The actual gasification system begins with the feed system. Manure that has previously been removed from the floor of the poultry houses is loaded into a storage hopper. This is a 10-ton capacity hopper that discharges manure from one end through the use of a chain driven flighted conveyor. The hopper discharges onto an inclined belt conveyor that discharges into the feed bin of the gasifier. The feed bin is a small hopper that moves material via a walking floor. The material is "walked" to the discharge end of the floor where it drops into a chute. This chute is 6 inches high and 36 inches wide; thus any acceptable material sized smaller than 6 inches can be used as fuel. The material dropped into the chute is pushed into the gasifier through the use of a hydraulic plunger.

The material is pushed into the primary unit of the gasifier. This is a 4-foot by 9-foot refractory lined enclosure that has another "walking floor" system as the floor of the unit has air pipes to distribute outside air throughout the unit. Inside of the unit, air and temperature combine to gasify the fuel. The system is controlled to limit the volume of air introduced to assure the process is gasification rather than combustion. The fuel is reacted to produce a carbon-rich syngas, predominately Carbon Monoxide, which is then pulled by an external fan out of the gasifier into the oxidizer. As the gas enters the oxidizer, there are 3 air ducts where additional outside air enters the system. This additional air provides enough Oxygen to support combustion and the Carbon Monoxide

is converted to Carbon Dioxide, also producing tremendous heat. The temperature of the gas in the oxidizer is typically in the 1800 $^{o}$- 2000$^{o}$ F. range.

The combusted gas is pulled through an air-to-air heat exchanger. The heat exchanger has a series of tubes which pass through the hot air produced in the oxidizer. It contains another fan which takes clean outside air and pushes it through those tubes, which heats up that air. This air then passed through ducting and a perforated nylon sock to distribute this hot air throughout the chicken house. This entire process utilizes a series of thermocouples and dampers to regulate the temperature delivered to the chicken house. All of the fans are Variable Frequency Drives, which means the speed of the fans can be infinitely controlled.

This entire system is controlled by an Allen Bradley Programmable Logic Controller. It is designed with a significant amount of automation to allow the system to operate unattended. With the exception of filling the storage hopper twice each day of operation, the system can operate unattended. The system can be monitored and operated remotely through the use of a web-based, remote access system. In fact, it has been operated from several places in the United States and from Canada.

## Historical Background

The gasification system was installed in March, 2007. The initial installation did include the feed system, but started with the feed bin on the gasifier and ended with the heat exchanger. The feed system and air distribution systems were added later.

The initial installation took two days to set up the equipment and connect the electrical equipment. One the third day, the gasifier was heated to cure the refractory lining and by the fourth day the system was gasifying chicken manure. The system operated for 2 days on manure that was brought fresh out of the chicken houses as well as some mortalities that were included in the feed.

**Following are Photos Taken on the First Day of Installation of the Gasification System at Frye Poultry.**

Approximately a month later the ducting to the chicken house and the perforated ventilation sock were added and the system was operated again for a few days. The house was ventilated under positive pressure and the controls were adjusted to determine the best method of regulating the temperature in the house. While ventilating under positive pressure was one of the issues of concern raised by almost every expert when the project began, it worked very well from the beginning.

The next step was the addition of the feed system. The storage hopper and conveyor belt were added and the controls were automated to start the belt and hopper to refill the bin automatically when the feed bin on the gasifier became low on fuel. The electrical supply was changed then also. Frye Poultry, like most poultry operations, only has 110-volt power available. The electrical system for the gasifier includes a roto-phase, which simply is a series of capacitors and a 20-horsepower motor that produce a third phase, and the system then operates on 230-volt, 3-phase power. The initial installation was connected to the power supply in one of the chicken houses, but a 200-amp service was then installed at the gasifier site to provide a better source.

The system was operated intermittently over the next 2 years, under a variety of conditions. The system was operated while the house was empty to preheat the house for the initiation of the baby chicks; it was operated for 7 days while the birds were small to measure the impact during that period; it was operated when the chickens were larger and producing a significant quantity of heat themselves; and the system was operated during different periods of the year and thus during different outside temperatures – ranging from 20 degrees up to 90 degrees.

There were a multitude of lessons learned, issues discovered and resolved, and changes made during these trial runs. The feed chute was modified to handle the poultry manure, which is denser than most biomass fuels. The stack was changed to handle the heat that was bypassed when the needs of the chicken house changed. The controls and the automation were changed many times to provide a system that automatically addressed the needs of the farm.

The most significant change that was made was in the fuel quality. The target quality for the gasifier is a fuel with 4,000 BTU/pound of energy. The manure under good conditions coming directly out of the chicken house barely contains that amount of energy. The handling and storage of the manure outside of the house created issues as the moisture content was increased and the energy level became lower than the target level. The solution was to construct a litter shed to store the manure. This was a portion of the initial project plan, but it was delayed due to funding delays and the EQIP process. The higher moisture content fuel was capable of gasification, but created issues in the ability to operate the system automatically and produce consistent heat for the chicken house.

While the majority of the changes and operating testing has been done to provide a valuable product to the chicken house, a significant component of the project is the quality of the ash product. The ability to produce a biochar product from the manure became evident shortly after testing began. Since this potentially is as valuable as any of the other revenue streams, a great deal of effort was done to determine the best method of operation, and the best product. The ash floor of the gasifier was modified to produce a more consistent product. The operating conditions were also changed multiple times to produce a biochar product with different characteristics. The testing is ongoing and may take a few more years of research, but there has been enough production of biochar, and enough testing on that product, to demonstrate that this product can be produced consistently, and it has a tremendous value in several different applications. This one component has the greatest economic impact on the project and clearly makes the project economically viable.

## Results

The desired results from the project were to first prove that the technology would effectively operate at a poultry operation, and then produce data that would quantify a variety of impacts on the operation that would determine the economic feasibility of the process. Additionally, by obtaining this data, the project should identify the potential of the technology in the industry and the limits, if any, of the application to different style and size operations.

Before the project began, the technology had been tested utilizing poultry manure as the fuel. The gasifier had also been used in other applications to provide heat as an energy source, so both of these processes were not the subject of the project; but the

ability to integrate this into the operation of the poultry facility and provide an economic payback was the center of the project.

The first step of the process was to install and operate the system to the point where the results were consistent and repeatable. The next phase was to operate under those conditions and collect the data to demonstrate the benefits of the system. The system was able to consistently operate and produce more than enough energy to supply the house with heat. It also was able to maintain temperature control better than the existing system in the houses. While there were some barriers to overcome, the results actually exceeded the expectations. The bonus from all of the operation was in the production of a biochar product from the ash. While the ash value was an important feature in the project from the beginning, the addition of biochar had a significant impact on the economics and alone could make the project worthwhile. As with many projects, there are surprises and disappointments that impact the direction the project will take, but the development of the biochar product made a huge difference in the project and the potential transferability to other growers.

## Operational Issues Identified and Corrective Actions

During the past 2 years of operation, there have been numerous issues identified and changes made. Some of these changes were made directly to the unit at Frye Poultry, and other changes have been made to the design of the gasifier for future projects. The list of the issues identified and the actions taken are as follows:

1. Feed chute – the design of the gasifier is such that the plunger leaves a 36-inch "plug" of material in the chute when it pushes fuel into the gasifier. This is done to provide a seal and prevent any air from traveling out of the gasifier chamber and entering the feed bin. This is to prevent any burn back when the feed is stopped and eliminate the risk of any fire hazard. This depth of plug provided too much resistance on the hydraulic ram and the distance was reduced to 18 inches. This resolved the issue and further testing with more porous fuels demonstrated that 18 inches was sufficient to produce an adequate seal.
2. Quality of fuel – it was known before the project started that the fuel was very borderline and needed to be monitored. The ash component of the actual poultry manure is very consistent when analyzed, so the moisture content is the critical component. The optimum moisture content was identified as being in the 20 to 25% range. The typical moisture content of the manure was around 30%, which is still a useable fuel. However, on many occasions the moisture content was up to 40%, which made consistent operation more difficult. For small projects like this, it is not feasible to include a dryer, so alternatives were sought. The installation of the litter shed resolved 90% of the problem as it removed the problems created when the fuel was stored on the ground and the moisture content increased. However, there were still occasions where the manure was too wet – this was usually a result of

Pilgrims making surprise feed changes which resulted in variations in quality of the manure. When these occasions occur, a small amount of wood chips is simply added to the feed mix to provide additional energy.

3. Heat Exchanger – the hot gas from the oxidizer is pulled directly into the heat exchanger. One of the issues created when the moisture content of the fuel increases is the plugging of the heat exchanger. When the moisture content is high, some of the calcium in the manure remains soluble when it is heated and instead of remaining in the ash, it is carried out with the gas. This creates both a plugging issue after 5 to 7 days of continuous operation, and also creates a visible plume from the exhaust stack.
4. Ash removal – the ash removal system is critical to the operation for two reasons. First, for extended periods of operations, the ash bed needs to remain relatively level and consistent. Also, in order to produce a consistent biochar, the retention time of material in the gasifier must be controlled, and the depth of material inside of the gasifier also must remain consistent. The walking floor system that removes the ash from the gasifier was modified. The length of the stroke was extended and the number of flights were increased to ensure that an equivalent amount of material was moved forward from all areas of the floor.

## Benefits and Associated Value

Probably the most important aspect of this project is the economic evaluation. Simply providing a system that eliminates the manure is not a solution – there needs to be an economic justification for installing and operating a system. When the project began, this was the area where there was the greatest opportunity, as well as the most unknowns. The key to making the system economical for the farmer is to develop multiple revenues, or multiple benefits. The goal of the project was to first identify the benefits, then quantify the value, and then attempt to produce those benefits for Frye Poultry. The individual benefits and their value were:

1. Energy value – the most straight forward benefit to identify. The gasifier can produce up to 3 MMBTU/hr. of energy when using the normal quality of manure seen on the farm. This is equal to the total output of all of the propane heaters combined in all 3 houses at Frye Poultry. Therefore, the gasifier can easily replace all of the propane needed to heat the houses. The only real question when quantifying the benefits is the cost per gallon of propane. Those costs changed by a factor of 3 during the term of the grant. The annual potential savings range from a low of $20,000 to a high of $60,000 per year. Realistically, the savings would most likely be between $40,000 and $50,000 per year.
2. Mortality disposal – another simple value to show. The energy content per pound of a chicken carcass is very close to the content of manure. There is some difference in how they react in the gasifier, but when mortalities were

mixed into the fuel, the performance of the gasifier was not changed dramatically. Frye Poultry is managed well and has a mortality rate of approximately 3%. This equates to over 20,000 mortalities per year. The value of this service varies from farm to farm as they have different methods to handle this. One of the intangibles is that it completely eliminates any risk of the spread of disease.

3. Animal health – lower mortalities, increased growth, improved feed rate conversion. In addition to the cost of using propane, there are some environmental issues inside of the chicken house that are created by the propane heaters. For every gallon of propane burner, there is 0.8 gallons of water exhausted into the air. The hydrogen molecule in the water combines with the nitrogen in the manure to form ammonia. The higher ammonia level is detrimental to the health of the chickens. The ventilation is set up to exhaust the ammonia-rich air to keep the birds healthy. When the fans are turned on to exhaust the air, the louvers are automatically opened to allow for fresh air to enter the house. When the weather is cold, this introduces very cold air which travels to the center of the house before the air is warmed with the heaters. So there is layering of temperature in the air in the house. All of these issues combine to provide an atmosphere that impacts the animal growth and health. Ideally, a relative humidity level close to 50% is ideal. The relative humidity is constantly monitored in every house at Frye Poultry. The house being heated with the gasifier consistently maintained a relative humidity of approximately 20% lower than the houses heated with propane. When the gasifier was used to preheat the house prior to the arrival of baby chicks, the variation was 45% - 55% with the gasifier and 90% with propane heaters. The improvement of the environment is easy to quantify. The question is how this impacts the actual performance of the flock. The environmental performance was consistent over many operating periods. The growth performance also demonstrated good results, but there was not enough data to be statistically relevant. The data that was collected illustrated a reduced mortality rate and a growth rate that was an 8% improvement. However, collecting meaningful data was sometimes difficult. Twice a good controlled set of data was collected only to discover that Pilgrims was unable to correctly count the number of birds placed in each house and had an error of 3000 birds on 2 different occasions. The additional benefit to lower humidity is the elimination of wet spots on the floor. These wet spots produce blisters on the birds which result in price reductions for the grower. While this is an obvious advantage, there was no definitive evidence to support this benefit. The financial benefit for the grower exceeds the 8% of extra weight gain. Since the growers are paid on a formula derived by the integrator that includes several performance factors, their pay is based on relative performance versus other growers – so better performance is magnified in the pay structure.

4. Lower maintenance of ventilation system – the existing ventilation system in every house includes many exhaust fans and multiple pulleys and louvers to allow fresh air to enter the house, ammonia-rich air to be exhausted, and also to close up the house to maintain the heat inside of the house. All of these moving components are inside of the house and are subject to the very corrosive environment that exists inside of the house. The ammonia, chlorine, and chicken feathers and manure that are airborne all combine to attack the infrastructure inside of the house. With the gasification system, there is one fan that is outside of the house, and it pushes clean hot air into the house. The positive pressure eliminates the need for the numerous exhaust fans, as well as the pulleys and louvers. When the gasifier ventilation system pushes air into the house, it simply forces open the hinged doors in front of the existing exhaust fans and pushes out the equivalent amount of air from the house. This not only reduces the amount of equipment to maintain, but provides a complete controlled air exchange at a managed rate. The need to clean fans, repair pulleys, louvers, etc, is eliminated by eliminating the need for all of this equipment. Since much of the labor needed on the farm is to handle the maintenance between flocks, this directly reduces the need for that labor.
5. Quicker turn around time between flocks – the goal of the project is to be able to demonstrate that the system can provide benefits that will improve the farmer's bottom line. Frye Poultry currently raises broilers to approximately 4 pounds, with a growing cycle of 38 days. Typically there are 14 days in between flocks, making a maximum of 7 flocks possible annually. The farmer maintains and pays for the farm infrastructure regardless of how many flocks are available. Since the integrators provide the birds and feed, the farmer's incremental expenses are minimal. By reducing the amount of work to prepare the houses for the next flock, and with the option of "baking" the house with the energy from the gasifier, the farmer can accelerate the process between flocks and gain one flock per year. This is a potential 15% increase in revenue annually, which is a significant gain in income.
6. Credits – the opportunity to generate revenues through various credit programs has been virtually meaningless in the past. However, the value of those credits continue to increase and more and more programs are being initiated that provide funding for different improvements. No credits have been applied for on this project, but it has become a significant portion of other Coaltec projects and credits will be applied for in the upcoming year for Frye Poultry.
7. Manure disposal costs – on this project, this was not a revenue generating situation. Frye Poultry is still able to sell raw manure and received a small value for it. This situation is likely to disappear in the near future, and in the case of many growers, they are already forced to pay a transportation cost that exceeds the value of the manure. This item is listed in the report simply because it is a potential benefit that could be realized depending on the specific situation of the host farm.

8. Infrastructure costs – this topic does not apply to Frye Poultry as the houses are already built and operational. But, in the case of a new farm, or an expanding one, there is a significant cost savings in the design of poultry houses if they are going to incorporate the gasifier. The basic benefits are;
    a. Fewer houses due to the ability to design larger individual houses since controlled heating is easier.
    b. Lower cost of construction due to fewer vents, fan openings, pulleys, etc.
    c. Lower component costs – fewer fans, electrical equipment.
9. Ash/Biochar value – the key to economics that bring value to the farmer is having multiple revenue streams and the ability to add value in many areas. While this is all true and this project has shown those benefits, the value of the ash/biochar has the ability to make a project viable as a standalone value. The revenues from all of the above benefits are subject to many variables, but if the system was used to heat all of the houses at Frye Poultry, the benefit of all of the above would be between $125,000 and $175,000 per year. In many cases, this would be a worthwhile capital investment, but the payback period would still be 6 to 8 years, which is borderline for many companies. However, the value of the biochar changes the economics dramatically. During the term of the grant, Frye Poultry was able to sell raw manure for $5 to $10 per ton. The biochar product is approximately 30% of the weight of the raw manure, so any value of biochar above $30 per ton is increased revenue. The system will produce 3 tons per day of biochar if operating at capacity. If the value of the biochar is only $200 per ton above the value of the manure, it will generate $200,000 per year if the system operates at 90% availability. This can make the economics viable alone, but when added to the other benefits, makes the project a 2 to 3-year payback. Therefore, it is very easy to understand why Coaltec spent a significant amount of time testing, evaluating, and researching the value and opportunities of biochar. Biochar contains a portion of the carbon found in the manure that is retained in the ash in the form of a carbon char. This compound has been researched extensively and has been linked to some amazing crop growth enhancements. The characteristics of the biochar also make it valuable as a water filtration medium and a litter amendment. The other elements found in the ash product also present the potential to use the ash as a feed supplement for the chickens to replace dicalcium-phosphate. This usage has been successfully tested in trials at Auburn University and is supported by poultry specialists in several areas. The ability to market the ash product in 4 potential applications provides huge potential. Biochar is becoming a highly recognized, valuable commodity. Sequestering the carbon during gasification turns this project into a carbon-negative rather than a carbon-neutral project. Studies of the growth potential of crops using biochar have shown incredible results. Increase of growth rates of 2 to 8 times have been demonstrated in well-documented research. The two leading authorities on biochar in the world have visited the

Frye Poultry project and have even referred to this project as an example of a commercial system producing biochar. The biochar from Frye Poultry has been supplied to the USDA lab in New Orleans where water filtration studies have been done. One sample produced a 90% capture of copper ions; outperforming some of the commercial filtration products which are selling for 65 cents per pound. Finally, as an almost bottom end value, the biochar was tested as a litter amendment. Due to its ability to capture nitrogen from the atmosphere in the house, an experiment was conducted to replace the existing litter amendment with biochar and monitor the results. Further testing will be done with monitoring instrumentation and the data will be recorded; but initial testing resulted in an obvious reduction of airborne ammonia in the house. The biochar was used in approximately the same quantity as the commercial litter amendment. There are different brands of amendment, but all sell for between $500 and $600 per ton. So even if used as a simple litter amendment, the biochar will provide a cost savings equivalent to over $500 per ton.

## Environmental Impact

One of the key components of the project was the environmental impact of the system. The gasification process must be able to operate in compliance with air standards, but the real interest in the benefits of the project is focused on the impact it can have on land and water quality due to the elimination of land application of raw manure. At least this was the view of the project as it was initially developed. The air quality issue has changed from the start of the project. The emissions from the gasifier have been tested periodically by calibrated emissions monitoring equipment. Some of the harmful compounds – CO, SOx, VOCs have never really been a concern with the gasifier and the results from testing demonstrated that they are not an issue. The main concerns from the beginning were particulate matter and NOx. Previous testing has shown that both of these were in a range below the need to permit, but the method of operation of the gasifier could impact these results. During the various operating periods, it was discovered that the NOx levels could very easily be controlled by managing the air volumes and introduction locations, as well as temperature control. The particulate levels were the same. Air controls, more specifically velocity, could impact the volume of particulate, and lower velocities inside of the gasifier prevented the particulate carryover that led to exhausting them out of the stack. One other issue became evident that is unique to poultry manure. Calcium is found in a higher concentration in poultry manure than any other fuel that Coaltec has tested. When the moisture content of the fuel is high, some of this calcium has a tendency to remain soluble and is exhausted from the stack and exhibits a visible plume. If the moisture content of the fuel is lower, this does not occur. Also, if the temperature in the oxidizer remains about a certain temperature, the plume disappears. The operating system was modified to simply turn on the oxidizer burner when the temperatures dropped below a specific set point and maintain the temperature at a level that eliminates the plume.

A surprise benefit became evident that could possibly impact the air quality in a much different fashion. Based on the research from some of the Chesapeake Bay groups, it has been found that airborne ammonia, specifically the nitrogen component, creates as much if not more of a problem as the nitrogen that is carried by rivers into the Bay. The drier air supplied into the house by the gasifier reduces the amount of ammonia generated, and therefore, the amount of ammonia exhausted from the house. The use of biochar as a litter amendment may even further capture the nitrogen in the manure; and since when it is fed into the gasifier, the majority of the nitrogen is transformed into harmless N2, the amount of harmful emissions is greatly reduced. The quantification of this benefit will take some time and effort. There is very little baseline data in this area as it is very sensitive to the industry. But the information can be gathered and measured to demonstrate the benefits.

The improvements in the water and land quality are much easier to show. The gasification of the manure eliminates 100% of the raw manure being land applied and therefore eliminates the issue of it creating nutrient loading and runoff situations. Since there are no liquids produced by the system, the only potential issue is the ash product. The biochar has multiple ways to provide beneficial results; but in the event that there are those that don't see this value, it is a dry, pathogen-free, concentrated product that can be easily transported and applied where nutrients are needed. The above section on biochar illustrates the multiple uses for this product and the many ways it has transformed from an environmental issue to a significant asset.

## Lessons Learned

There were many problems encountered, mistakes made, and new revelations that were totally unexpected during the course of the development of the project. The operational issues were discussed in the earlier sections of the report; however, there were some alternatives found to some of the original choices made. Some of the most important lessons learned were:

1. Heat exchanger – the system was designed and installed with an air-to-air heat exchanger. The concept of making a simple heat transfer and avoiding using hot oil or water was more cost effective and was felt to have fewer risks; especially since the entire concept was new and unproven. However, now that the concept is proven to work and work well, both hot water and hot oil are better alternatives. They are both easier to control, allow for a longer distance separation of the gasifier from the poultry operation, and allow for much easier heat transportation. For projects delivering heating to multiple houses or over longer distances, it would not be cost effective to use air-to-air systems.
2. Fuel storage – the manure needs to maintain over 4000 BTU/pound of energy. Proper storage in a litter shed, and/or the availability to add a little wood when the manure is too wet makes the project much more manageable.

3. Energy conversion – the goal was to eliminate the propane costs and provide the ability to increase the profits of the farmer. During the work on the project, it was discovered that providing a complete heating and cooling system would be much more beneficial with a slightly higher cost.
4. Size of farm – the gasifier will supply about 3 MMBTU/hr. of output energy. While this matches the total output of all of the propane heaters in the 3 houses at Frye Poultry, it is probably more closely matched to the energy needs of 6 to even 8 houses. The Frye Poultry project was focused on proving the concept and determining issues and quantifying benefits, but future projects will look closer at matching energy loads.

## Transferability

The key indicator to any project is how well it can be transferred and possibly an even better indicator is how many follow up projects develop from the initial project and how much interest has been generated. Frye Poultry has generated a huge amount of interest. There have been multiple follow up projects that have been at least initially reviewed. The economic crisis over the past year or so has greatly reduced the capital availability, but there are projects moving forward based on the results of Frye Poultry.

The design of the project makes it a potential roadmap for almost any poultry operation. Ideally, the host site should be larger than Frye Poultry, but there are ways to make this size economical.

Up to the present, there have been initial requests for projects in 8 other states in the US, as well as more than 10 foreign countries. Josh Frye has been the subject of a Time magazine article in the European version of the magazine; the facility has been the subject of numerous articles including a feature on the International Biochar Initiative website; it was listed as a good commercial application of gasification to produce biochar in a book written by Dr. Lehmann and Dr. Joseph about biochar; and the facility has been visited by hundreds of interested people from many areas of the world.

## Conclusion

One of the measurements of the success of a project is to review the deliverables and determine if they have all been met. In this case, all of the topics were successfully addressed. Probably the biggest failure of the project has been the ability to produce enough data to make statistically supported conclusions. While there is good data to support all of the conclusions made, there needs to be more repetitions of the same data to be able to convince skeptics that the system will provide the benefits that are claimed.

Probably the most exciting conclusion is the discovery of revenues for the farmer that were unknown at the time of the project start date. This project has completely redefined how gasifier projects are viewed by those associated with the project, and the potential revenues and economic evaluation are much more positive than when the project started. The goal of grant funding should be to provide the incentive for people to try new concepts and reward them for taking the first steps. It is always more financially

advantageous to watch others take the first steps and learn, and then be second. This project has very definitely accomplished that goal.

Possibly the greatest requirement for a project to be successful is to have committed people involved. Regardless of the issues to overcome, if the team is committed, the project can be successful. Coaltec had a high degree of commitment for the project from the beginning as it was the start of a new opportunity in a business sector that had virtually no direct competition. However, at the start of the project, there is no way of knowing how committed the partners in a project will be. Josh Frye has been the most wonderful partner that could be found to develop a new application. He has devoted time and money to the project; he has opened his farm and taken his time to receive hundreds of visitors and has become a very visible subject of the development of biochar in agricultural projects. NRCS has been extremely supportive and very helpful. They have allowed the project to progress with very minimal paperwork and interference, thus allowing Coaltec to focus on the project itself. The West Virginia DEP has also been tremendous to work with. As with any new opportunity, nothing ever operates according to the initial schedule that is developed; and all of the above have been flexible enough to allow the project to fight through the learning experiences without the added pressures of deadlines and commitments that are not really necessary.

The project has been a tremendous success. Unfortunately, there is still as much work to do as there has already been done. Biochar is a very new and relatively unknown material. There has been a huge amount of research done, but there is still much to go. Since this single factor has such a big economic impact on the project, there must be follow through to quantify the sustainable value of the material. At the time of this report, testing continues to go forward. Some material has been sold, and marketing efforts are ongoing. The goal of the project was to find an economic solution to the manure issues facing the independent farmer and improve the environment at the same time – the project has shown this is possible, and the development of biochar could take the benefits to a new level.