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On-Farm Resources and Renewable Energy in Broiler Chicken Production: Brinson Farms Case Study

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Abstract: Agriculture faces sustainable intensification to meet escalating food demands in an environmentally friendly way while still allowing farmers to compete economically. Relative to meat consumption, chicken is the most popular choice in the United States. This manuscript describes a commercial broiler farm that implemented renewable energy strategies to utilize litter and community wastes while reducing the environmental impact of the operation. Brinson Farms integrated broiler production, an anaerobic digester and a composting facility to create energy on the farm as well as a complete litter utilization strategy. Value-added products from the digester include an organic liquid fertilizer and undigested solids that become part of the compost substrate. This is the first farm-scale anaerobic digester converting broiler litter to methane (CH_4) in the United States. Beyond that, the comprehensive strategy for local resource utilization is unparalleled. Producers can learn from this example to improve the sustainability of their own broiler operations.

Key words: Anaerobic digester, broiler, compost, litter, renewable energy

INTRODUCTION

Sustainable intensification has engulfed all of agriculture with the goal of producing greater quantities of food without detriment to the environment. Mounting competition for land and water resources results from the need to feed 9 billion people by 2050. With this, food production demands a 70% increase over current levels (equating to 1 billion tons more cereals and 200 million additional tons of meat; FAO, 2011). Currently, more broiler meat is consumed in the U.S. than beef or pork. In 2010, U.S. consumption of broiler meat was 13,463,000 metric tons, approximately 12% more than beef and 56% more than pork (U.S. Census Bureau, 2012). As a preferred and primary protein source, it is logical to invest in the sustainable production of broilers. Compared to other livestock systems, broiler production is reasonably efficient per unit output, but like all of agriculture, there is potential to reduce its environmental impacts (Leinonen *et al*., 2012; Johnson *et al*., 2007).

The three major categories of environmental concern at broiler farms are energy, emissions and manure management. Energy, a significant production expense, is directly used when feeding, ventilating, lighting and heating (Baughman and Parkhurst, 1977; Rajaniemi and Ahokas, 2012). Escalating energy costs at present and in the coming years will have a profound effect on farm economies, but it is impossible to predict the magnitude of the effect (Clark, 2007). Increasing cost and possible scarcity of fuel have been a primary concern of the poultry industry for almost four decades (Baughman and Parkhurst, 1977). Thus, renewable energy generated on the farm, using local wastes and resources, will make energy prices more predictable and reduce the dependency on outside sources. Curtailing transport of the local wastes/resources away from the farm and community reduces the environmental footprint of the operation (by reducing energy consumed and eliminating emissions from hauling). This impact is further reduced as the on-farm generation of energy can be eco-friendly.

Direct emissions from broiler operations come from litter in the houses, but also from manure storage and land application (Moore *et al*., 2011). The emissions include greenhouse gases, ammonia (NH_3) and particulate emissions. Greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are associated with global warming, but the potency of each is different. For the 100 year time horizon, the global warming potential of CH_4 and N_2O are 25 and 298 times greater than CO_2, respectively (Forster *et al*., 2007). Ammonia is a known irritant that can negatively impact bird health and production (Anderson *et al*., 1964; Miles *et al*., 2004); also, NH_3 contributes to eutrophic surface waters (Hutchinson and Viets, 1969), soil acidification (Van Breemen *et al*., 1982) and fine particulates in the atmosphere (McCubbin *et al*., 2002). Mitigation of emissions must be targeted at the source (Miles *et al*., 2014).

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Beyond the potential for emissions, broiler litter management can be a significant environmental challenge where production is concentrated; those farmers at times have more litter to utilize than the land base can support (for use as fertilizer) and transportation out of the vicinity is costly. State regulations govern the application of litter to prevent nutrient runoff. For these reasons, litter-to-energy alternatives are gaining popularity. Combustion, gasification, cofiring and pyrolysis were briefly discussed by Singh *et al*. (2010). A novel approach is anaerobic digestion, using litter to create CH_4 for fuel and nutrient rich coproducts (Miles and Brooks, 2010).

Commercial interest in anaerobic digestion on livestock farms has boomed since 2000, as evidenced by the number of digesters installed at commercial dairy operations (U.S. EPA, 2014). As of January 2014, AgSTAR reported 239 anaerobic digesters operating on commercial livestock farms across the country (U.S. EPA, 2014). The number of digesters for each type of fecal matter treated was: 193 dairy, 4 beef, 8 mixed, 5 poultry and 29 swine. Only 8 of the 193 digesters at dairy operations were operational prior to 2000. The first poultry digester using broiler litter came online in 2005 and is the subsequent subject of this paper. Benefits of anaerobic digestion on the farm include the production of readily usable biogas and the reduction of odor potential from manure (Safley *et al*., 1987). The biogas consists primarily of CH_4 and CO_2 as 2:1 with smaller amounts of other gases such as hydrogen sulfide (H_2S) (Kukic *et al*., 2010). Generating electricity using biogas reduces the need to purchase power. In a cogeneration system, the biogas is used to generate electricity as well as steam to maintain the optimal temperature for microbial conversion of wastes in the digester. The steam can also be used to provide heat to broiler houses. Another major benefit of biogas production is to offset climate change. Fuels produced from biomass are carbon neutral because the CO_2 released was recently fixed (in the biomass) and does not shift the carbon cycle (Johnson *et al*., 2007), unlike fossil fuels where the carbon has been stored for millions of years. At Brinson Farms, the purpose of adding anaerobic digestion, solar power, biomass boilers and a composting facility to the farm infrastructure was to implement a sustainable solution and system for managing broiler litter and other organic wastes from the community while attaining long-term energy independence. The benefits of this approach are numerous; some of these include (1) creating green energy/rural jobs, (2) removing organic materials from landfills, (3) protecting surface waters from nutrient runoff, (4) producing a high quality liquid fertilizer, (5) reducing greenhouse gas emissions, (6) producing a renewable fuel for heat and electricity, (7) eliminating the problems of manure disposal and (8) conserving water, land and air resources. The system is briefly described below.

MATERIALS AND METHODS

Broiler production and litter management: Brinson Farms LLC., located in Prentiss, Mississippi, USA, operates 12 commercial broiler houses growing a population of approximately 360,000 birds/flock with each flock lasting 56 d. The tunnel-ventilated houses were built in stages as the farm expanded and are of varying size. Three of the houses measure 13 x 122 m (44 x 400 ft), five measure 12 x 122 m (40 x 400 ft), two measure 13 x 152 m (42 x 500 ft) and two are recently constructed mega-houses that measure 20 x 183 m (66 x 600 ft). Air enters each house through evaporative cooling pads on the brood end of the house. There are 12 to 20 tunnel ventilation fans per house located in the non-brood end of each house. The houses are equipped with automatic feeder lines and nipple waterer lines, have solid sidewalls and insulated drop ceilings. Between flocks, litter is decaked (i.e. the upper encrusted layer of litter is removed). This litter is then moved to the storage shed and becomes the feedstock for the digester. The storage time allows for any remaining original bedding (pine wood chips) to further decompose. Total clean out of the houses occurs approximately once every two years. Prior to 2001 (approximately a year before the litter was characterized for digestion), the addition of new bedding material between flocks was suspended. The integrator implemented windrowing between flocks to reduce the litter bacterial load. Top dressing (adding a thin layer of fresh shavings once the litter was re-spread) was only used if the litter became too thin. It is believed the lack of additional bedding material changed the litter composition compared to previous flocks. In order to assess the potential of litter to produce biogas, the litter was analyzed for moisture content, ash, N, P, K, pH, thermal value and protein at the Mississippi State Chemical Laboratory. Also, scientists at Mississippi State University performed laboratory scale digester tests to determine the viability of broiler litter CH_4 production. They found a particular microorganism worked best within a thermal range of 51.7-54.4°C (125-130°F). Brinson Farms then worked with scientists at West Virginia State University for two years to isolate the bacteria.

Energy production via the anaerobic digester, solar arrays and biomass boilers: Figure 1 shows a simplified schematic of the Brinson biorefinery and broiler operation. Figure 2 is a photo of the biorefinery. After developing a functional prototype digester, construction of the full-scale anaerobic digester began in 2004. The digester tank is 946 m^3 (250,000 gal) with an installed capacity of 75 kJ/s (75 kW) to produce biogas with end use for cogeneration and boiler/furnace fuel; it is characterized as complete mix (U.S. EPA, 2014) and was designed by Brinson Farms, LLC (John W. Logan, patent August 31, 2010, US 7,785,467 B2). A 1,700 m^3 (450,000 gal) liquid fertilizer tank works in

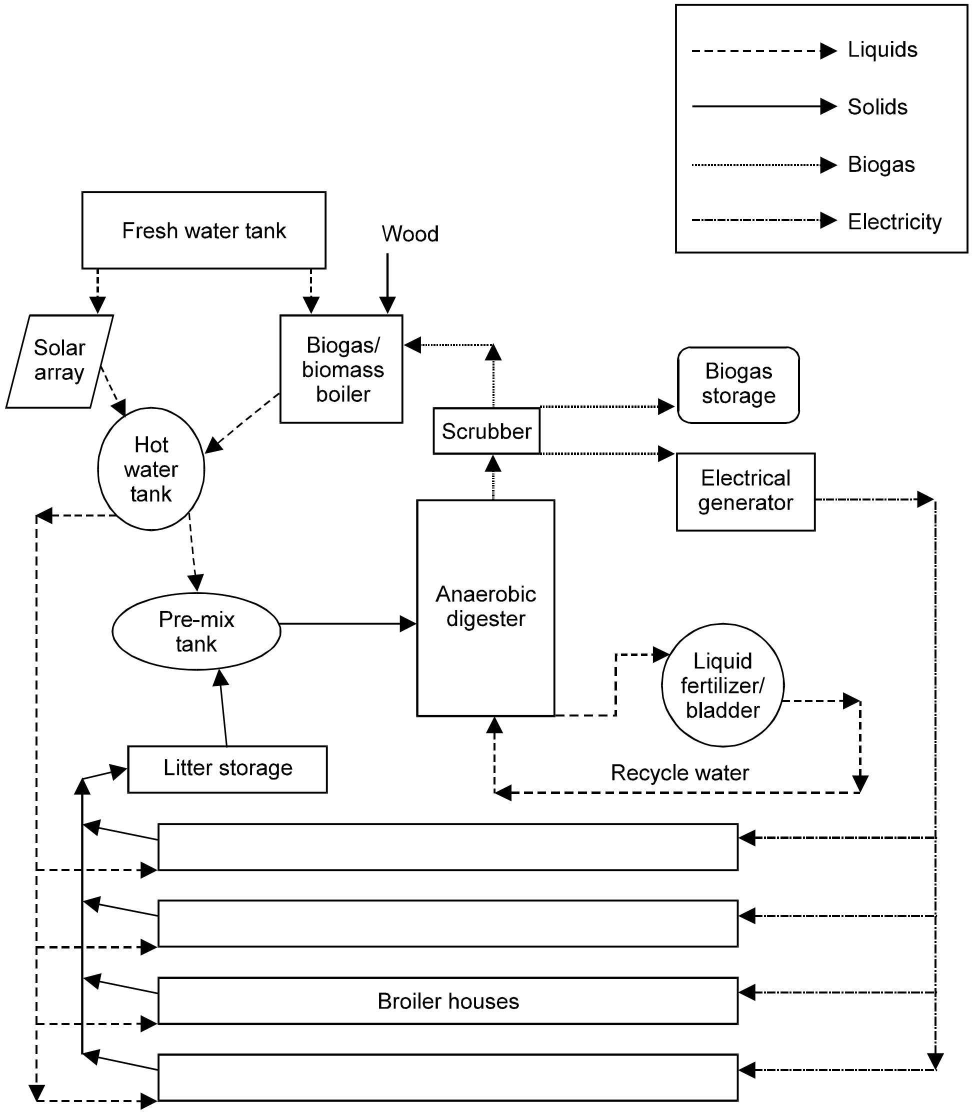

Fig. 1: Simplified schematic of Brinson biorefinery and broiler operation

conjunction with the digester, receiving liquid effluent from the digester and supplying recycled water to the digester tank as needed. A 670 m^2 (7,200 ft^2) bladder has been added to supplement the function of the liquid fertilizer tank. It contains coils with water heated by a solar thermal array (described below). It also provides biogas storage. The anaerobic digester system has been approved for mortality disposal by the MS State Board of Animal Health and the State Veterinarian.

Approximately 95% of the process water is recycled. Two 190 m^3 (50,000 gal) tanks provide makeup fresh water to the digester operation and a backup water source for the broiler houses. They are fed by 3 solar pumps from a freshwater reservoir located on the farm. These water tanks gravity feed to the digester area. In a third insulated tank, the fresh water to the system is preheated using a solar thermal array consisting of 4 rows with 18 panels each for a total power rating of 123 kJ/s (123 kW or 420,000 BTU/h, to heat 9.5 m^3/d or 2500 gal/d). When the water reaches 60°C (140°F), it transfers to the digester hot water tank (76 m^3 or 20,000 gal). The hot water tank is heated by a dual-fired boiler (Classic Pallet Burner, Central Boiler, Greenbush, MN) and exhaust from the generator. The dual-fired boiler is loaded with biomass twice daily and CH_4 from the digester is burned as needed to attain a water temperature of 93°C (200°F). The biomass feeding the boiler comes from municipal yard trimmings, roadside debris and wood cut on the farm.

A chopper mixing facility for input of solids, liquid and mortalities feeds the digester. It can also be thought of as a pre-mix or litter slurry tank. Litter (1.81 metric tons or

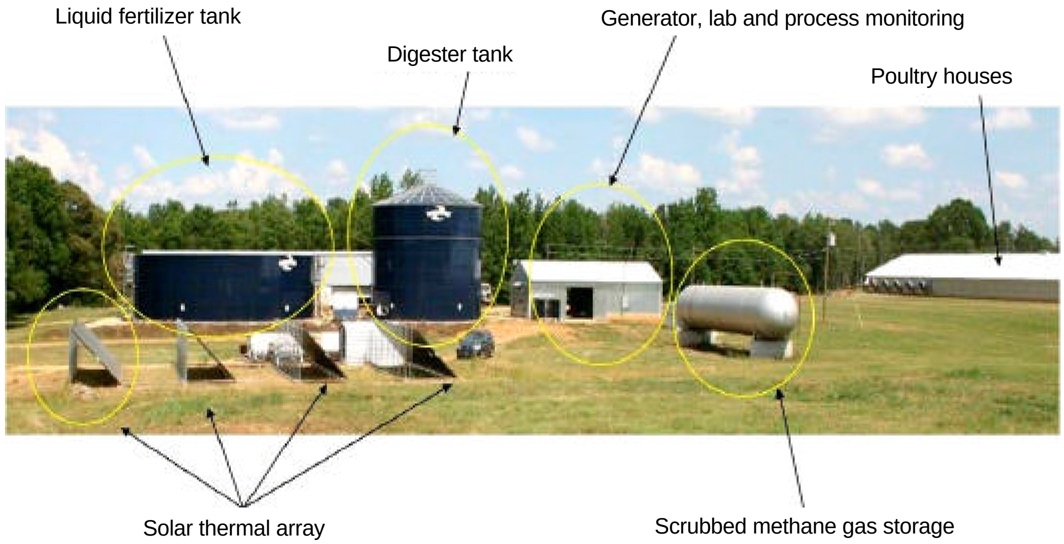

Fig. 2: Photo of Brinson biorefinery adjacent to poultry houses

2 short tons) is added to the pre-mix tank twice daily along with hot water. Litter is diluted to approximately 6% (w/w) by the addition of water. A Scumbuster® pump (Vaughn Co, Inc., Montesano, WA), the mechanical chopper in the bottom of the pre-mix tank, is used to grind the carcasses within the mixing tank and optimizes particle sizes for microbial degradation of the material. The chopper also keeps the particles suspended for optimal digestion. Within the digester, nozzles located in the bottom keep solids suspended by recirculation. Routine monitoring of the operation includes conductivity (salt concentration) and pH of the digester contents. These have to be maintained to keep the digester in the thermophilic temperature range, ideally at 50 C (123°F). At temperatures greater than 54 C (130°F), NH_3 toxicity increases. Managing NH_3 is one of the classic reasons for not using poultry manure or litter. Control of pH (at 7.3-7.5) and NH_3 concentration is accomplished by fresh water dilution. Ammonia concentration is measured from the recycle solution used to makeup each batch entering the digester from the chopper mixing facility.

For the biogas produced by the digester, a lime based, water bath gas scrubber (invented by Brinson Farms) removes most H_2S and other gas byproducts so that the CH_4 can be burned or stored. The CH_4 is either burned in the dual fired boiler mentioned above, in smaller dual-fired boilers (described below), or in generators (Caterpillar Inc., Peoria, IL; Cummins, Columbus, IN; John Deere, Moline, IL). The generator supplies electricity to the broiler houses for running ventilation fans and lighting. Storage of CH_4 includes either compression at 1136 kPa (150 psia) in a 83 m^3 (22,000 gal) tank or the CH_4 is stored in the bladder.

The broiler houses are heated in a non-traditional fashion that utilizes a portion of the on-farm renewable energy system. Rather than using traditional propane brooders or space heaters to supply heat, hot air is blown down the length of the chicken houses. An inflatable tube supplies the heated air down the length of the brood half of the houses; the tube has a 46 cm (18 in) diameter with 15 cm (6 in) holes in it. The air is heated via hot water in an air handler system comprised of a radiator and squirrel cage blower sized to achieve the desired air flow per floor area. The radiators and blowers are housed in sheet metal cabinets that were built onsite. Process water to the air handler is routed underground to the brood end of the houses; it originates from dual-fired biomass boilers (Classic Model CL7260, Central Boiler, Greenbush, MN). There are a total of six of these boilers, which are capable of 1,060,000 kJ (1,000,000 Btu) output for heating the brood area of two commercial broiler houses, each approximately 1900 m^2 (20,000 ft^2). Use of these boilers was demonstrated with the assistance of a conservation innovation grant and transferred to growers/researchers in MS during a field day program in 2012. The target water temperature exiting each boiler is 66 C (150°F). The boiler automatically fires depending on the return water temperature, usually around 49°C (120°F). Boiler fuel is either biogas from the digester or organic material. Biomass is not limited to wood and can be stored in the shelters adjacent to each boiler. A 5 kJ/s (5 kW) solar array provides for the electrical needs of the boilers and air handlers. Then, any excess enters the farm campus network. The system heat load design was based on desired production size of bird. Heating the broiler houses using hot air keeps litter drier compared to burning propane in addition to reducing ammonia and diseases associated with the litter (The Poultry Site, 2013). The air handling operation is programmed into each house's ventilation controller (Rotem, Petach-Tikva, Israel). As a backup, propane brooders are located in each house as well. They can provide 530,000 kJ (500,000 Btu) per chicken house.

Compost facility: Material inputs to the compost facility include litter that is not needed for the digester, undigested solids from the digester, liquid effluent from the digester and yard trimmings from local municipalities. Local municipalities and the state highway department transport yard and road wastes (limbs, trees, shrubs, etc.) to the facility which are accepted free of charge. These provide the bulk of the biomass used in the broiler farm dual-fired boilers. One employee accepts the community deliveries as well as creates and maintains the rows of compost. The primary equipment at the composting facility is a horizontal grinder (Hammerhead, Screen USA Inc., Smyrna, GA), a wheel loader (544G, Deer and Company, Moline, IL) and a hydraulic row turner with a tractor.

The facility has about 30 piles of varying ages and stages of decomposition/readiness. Any runoff is contained by berms around the perimeter of the facility. After approximately 90 to 120 days, compost rows are turned and allowed to go through a second heat. At this time, a CO_2 gauge (Bacharach, Inc., New Kensington, PA) is used to test the CO_2 content of the piles. Once the CO_2 reaches a certain level, the material is scheduled to be turned again to increase oxygen. Then the compost is screened to remove rocks and large wood particles. The compost is certified organic and is likely to be sold in bulk to commercial and landscaping users (Logan, 2012).

RESULTS AND DISCUSSION

For flocks lasting approximately 56 d, birds are grown to a weight of 3.8 kg/bird (8.5 lb/bird). The farm produces about 1814 metric tons (2000 short tons) of litter/yr. Litter properties determined for the pre-biogas phase were reported as: 23% moisture, 22% ash, 3% N, 1.2% P, 3% K, pH of 9.1, 12,560 kJ/kg (5,400 BTU/lb) and 35% protein. The most interesting result is for thermal value, which would be important in characterizing this litter as feedstock in thermal conversion systems (i.e. combustion or gasification). The thermal value at 12,560 kJ/kg (5,400 BTU/lb) is approximately 15% lower than most litters. The lack of additional cellulosic material is responsible for this difference. At these levels, the ash content and thermal value of Brinson litter made it a lower quality feedstock for thermal conversion units. The potential for litter digestion was not affected by the differences in properties compared to other litters. Lignocellulosic materials, comprising the bulk of wood products, are not degraded easily under anaerobic conditions.

Biogas is produced at a rate of 0.5 m^3/kg of chicken manure (8 ft^3/lb), of which approximately 75% is CH_4 when operating at 75% efficiency. The amount of biogas produced annually has significantly reduced the farms energy expenditure. The annual farm electric bill once reached $120,000 (for 10 houses) and has been reduced to approximately $22,000. Propane for a single winter flock reached $66,000, but now averages $12,000 maximum per year. Unlike the relatively short grow out period (34 d) for some growers, this farm grows very large broilers of 3.8 kg/bird (8.5 lb/bird) for 56 d. Other farms may grow broilers to 4.5 kg (10 lb) for 66 d. A longer grow out requires more energy. This would be especially true in cooler weather and in cooler climates. The projected emission savings as CH_4 emission reductions are 133 metric tons CO_2E/yr (U.S. EPA, 2014). Emission savings are derived by capturing and burning the CH_4 that would otherwise be emitted from the litter as well as from offset of not using fossil fuels(U.S. EPA, 2014). The approximate cost of the larger on-farm digester system is $1,200k with a payback period of 3-5 years. Smaller broiler configurations would cost approximately $480 to $850k.

Other waste streams can offer enhanced production of biogas in the anaerobic digester. At one time, vegetable wastes from nearby retailers were received at the compost facility. The local retailers paid the facility $20/ton to accept them. These tipping fees saved the retailer 33% over regular land-filling costs and paid the labor for running the composting operation. Produce like sweet potatoes and watermelon (e.g. with high carbohydrate content) worked well with the specialized bacteria and helped to balance the C:N ratio. The most advantageous volume of waste vegetables to litter was 40:60. Recently, local retailers stopped discarding the waste vegetables and began sending them for pelletizing to feed cattle. Significant amounts of fruits and vegetables are culled during production, harvest and packaging while further processing, distribution, retailers, restaurants and consumers waste even more. An estimated 52% of fruits and vegetables are lost, leaving 48% consumed collectively in the U.S., Canada, Australia and New Zealand (Plumer, 2012). Addition of the bladder allows for accepting liquid wastes such as out dated milk and ketchup factory wash down, both of which would pay the farm for disposal (approximately $900/load of 26.5 m^3 or 7000 gal). These two liquids also work well within the digester.

The digester was disassembled in September 2011, after 6 years of operation and all digestate (solids) were removed via vacuum pump. There were approximately 5 truck loads (12.2 m^3 or 16 yd^3, each). These solids were air dried and mixed with compost substrate. Since this time, an upgrade to the facility includes a mechanical flushing system so that a portion of the solids can be regularly drawn off the bottom. This design improvement allows for longer operation without having to take the entire system down, so that there is no anticipated future total clean out.

The best utilization of the compost product is still in progress. An extensive marketing study (Logan, 2012) revealed that there is a market for organic fertilizer and especially for chicken manure compost because there are few producers involved in its manufacture. One possible product with N-P-K values of 10-10-10 could be sold in bulk to commercial or landscaping users at $0.09/kg or $88/metric ton ($0.04/lb or $80/short ton), but there may be more value in tailoring the nutrient contents to particular vegetation. The retail market may be considerably more as homeowners would want it for their landscape or gardening use.

Improvements to the process are continually being identified to optimize efficiency and decrease costs for new installations. Replacing the liquid fertilizer tank with bladder storage entirely can provide 29 times the capacity for storage of gas, liquids and solids while eliminating the high cost of the steel tank. The bladder also eliminates the costs associated with buying and operating compressors.

Numerous supplementary benefits make the comprehensive renewable energy system even more desirable. The farmer has observed improved bird performance, reduction in the use of fossil fuel to heat houses, reduced litter moisture, lower NH_3 with drier heat, less need for exhaust fans for air quality, better first week performance and less mortality, ability to ideally preheat houses prior to receiving birds, reduced eye irritation, less corrosion of in-house equipment (waterers, feeders and fans). The original equipment has been used in the older houses for 21 years. The owner concludes he has reduced energy consumption and, with the combination of all the technologies, has allowed the farm to remain profitable in times of rising fuel and electric costs.

Another benefit of producing energy via anaerobic digestion vs liquid biofuels is that on-farm resource utilization eliminates competition for land base to produce the commodities (e.g. corn) used in liquid biofuel production (recently cited or thought to be the cause of increasing food prices, FAO, 2011). Long term utility planning is possible because of the digester. Part of the planning process for individual growers to use in determining if the digester is a good option for their farm would include the type of birds to be grown. For example, there are different planning needs between 34 d birds and 56 d birds for obtaining feedstock (e.g. litter for the digester).

Implications are that the dry heat provided to the broiler houses minimizes NH_3 generated from the litter and produces healthier birds. Future study will need to quantify the NH_3 concentrations, litter characteristics and bird performance productivity, as well as compartmentalize each sector of the renewable energy used on the farm such that recommendations can be scaled to individual farms. Specifically, based on a farm's production (bird size and number of houses), location (climate and availability of local waste streams) and integrator requirements, recommendations for implementation of solar energy, biomass boilers and/or anaerobic digester technologies can be made. It will be important for growers to utilize the components that best fit their operation. Each has the potential to positively impact the producer's profitability and improve the environment.

Farmers must efficiently meet the challenges of greater production and minimize detriment to the environment. A novel, integrated approach to improve the sustainability of broiler production was presented. The system successfully decreased dependence on grid utilities through bio-based energy production, offered lower energy costs, utilized litter, handled mortalities, produced a quality organic liquid fertilizer, generated compost and rerouted community wood wastes away from landfills. Brinson's comprehensive local resource utilization creates environmental benefits and boosts the farm's profitability. Other farmers can employ these strategies of energy generation and local resource usage (or portions thereof) to improve the sustainability of their operations.

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