Advantages of Wood Heat for Commercial Poultry Production

Agricultural Growth, Research and Innovation

FINAL REPORT

Prepared for: Minnesota Department of Agriculture, Agricultural Marketing & Development Division

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ACKNOWLEDGEMENTS

This project was supported by a grant from the Minnesota Department of Agriculture, Agricultural Growth, Research and Innovation (AGRI) Program, through Minnesota taxpayers.

The authors acknowledge the following individuals for their financial, in-kind or other contributions to the project: Viking Company owner Bill Koenig, the host and operator of the technology; Jim Eiynck, owner of EvenTemp Biomass and installer of the technology; GNP Companies, including Sustainability Manager Paul Helgeson and Production Manager Alex Bronder; the staff of the Agricultural Utilization Research Institute; and staff of the Chicken and Egg Association of Minnesota.

Executive Summary

This demonstration project, "Advantages of Wood Heat for Commercial Poultry Production," field tested a 1.65 million Btu (British Thermal Unit) wood chip furnace in a live commercial poultry operation. The project, generously funded by the Minnesota Department of Agriculture's Agricultural Growth, Research and Innovation Program (AGRI), spanned 23 months and 12 flock rotations. Viking Company of Albany, Minnesota, an experienced poultry growing operation, hosted and operated the wood furnace in its two-story broiler chicken barn as a test. An identical barn heated with liquid propane immediately adjacent to the test barn served as an experimental control to observe differences in operability, fuel costs, and flock production.

The wood furnace demonstrated considerable fuel cost savings against historically low liquid propane prices from fall 2015 through summer 2017. As expected, fuel cost savings from using woody biomass were highest in the colder months when thermal demand is greatest. The fuel cost savings from this project averaged $8,029 per year with liquid propane prices fluctuating from $0.99 to $1.29 per gallon.

Viking Company and its processor, GNP Companies (now Pilgrim's Pride), observed flock production benefits beyond the estimated wood fuel cost savings, indicating the wood furnace may contribute to reduced production losses for the integrator. Though not within the scope of this project, the observed production benefits point to the need for a veterinary study to examine flock health differences from the use of a wood furnace.

This project provided detailed insight into the use of wood heat to meet the thermal needs of poultry production. The data collected demonstrates woody biomass is a viable, cost-effective fuel for producers looking for alternatives to liquid propane.

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Introduction

The Agricultural Growth, Research and Innovation Program (AGRI) awards grants and other forms of financial assistance to create agricultural jobs and profitable businesses. Investments are focused on livestock development, value-added business and market development, farm to school, research, and renewable energy.

Pursuant to the recommendations of the NextGen Energy Board, this project, "Advantages of Wood Heat for Commercial Poultry Production," was awarded funding in the summer of 2015 to fulfill several objectives:

- Support the deployment and performance evaluation of existing commercial biothermal technology.
- Address the critical barrier of financing switch-over projects from propane heating to biomass alternatives.
- Provide woody biomass heat to a poultry growing facility.
- Support wood energy market development across the supply chain from fuel, to heating equipment, to installation capacity.
- Produce thermal energy from untreated wood fuels.
- Increase the use of Minnesota's bioenergy resources, encourage energy self-reliance and security, and promote sustainability.

Minnesota leads the nation in turkey production[1] and has a thriving chicken and egg industry. The majority of Minnesota poultry facilities rely on liquid propane as their thermal source because of the prohibitive economics of routing natural gas lines to rural poultry operations.

In large part, this project grew out of a fuel shortage during the 2013-2014 winter. A wet harvest season followed by a long, extremely cold winter (atypical even for Minnesota) in 2013 created a significant propane shortage and caused a large price spike, which hurt many agribusinesses. Minnesota turkey and chicken growers alone suffered significant input cost increases estimated at $25 million due the propane shortage.[2] Additionally, Kinder-Morgan reduced the flow of propane in the Cochin pipeline, and ultimately reversed the flow direction of the pipeline later in 2014 to carry light petroleum condensate instead of propane. The pipeline used to carry approximately 40% of Minnesota's propane supply.[3] Despite other private measures taken, such as adding propane-handling train terminals and storage capacity, propane accessibility and supply remains an agribusiness vulnerability. [4]

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[1] U.S.D.A. Economic Research Service, Turkey Sector: Background and Statistics, Nov. 14, 2016 (indicating Minnesota produced 41 million turkeys). *Available at* https://www.ers.usda.gov/topics/in-the-news/turkey-sector-background-statistics/

[2] Winter Propane Shortages Hearing Before the Committee on Energy and Natural Resources, Senate, 113th Cong. 29 (2014) (Testimony of John Zimmerman).

[3] Belden, Doug "Solution to future propane problems eluding Minnesota lawmakers", *Saint Paul Pioneer Press*, March 29, 2014. *Available at* http://www.twincities.com/2014/03/29/solution-to-future-propane-problems-eluding-minnesota-lawmakers/

[4] Shaffer, David "Propane industry scrambles to replace supply from major pipeline", *Minneapolis Star Tribune*, December 7, 2013. *Available at http://www.startribune.com/propane-industry-scrambles-to-replace-supply-from-major-pipeline/234815871/*

Minnesota is home to several wood furnace and wood boiler manufacturers who serve residential and small commercial interests. Yet, none of these manufacturers has tapped into an agricultural market heavily dependent on liquid propane for thermal needs. This project demonstrates livestock production is a potential market opportunity for wood furnace manufacturers. It also demonstrates thermal biomass technology, as a standalone furnace or hybridized with conventional propane furnaces, is a valuable hedge against fuel price volatility for agribusiness. This project stands as proof that thermal biomass technology applications in agriculture present viable and cost-effective alternatives to traditional fuels.

The Project Team

Viking Company, a broiler chicken growing operation in Albany, MN. It is a limited partnership family farm, owned and operated by managing partner William Koenig and his family. Mr. Koenig has been raising broiler chickens for over 36 years, primarily as a contract grower for Gold'n Plump, then GNP Companies, and now Pilgrim's Pride Corporation.

Advanced Bio Heat d.b.a. EvenTemp Biomass, a local thermal technology and installation vendor in Becker, MN, which is owned and operated by Jim and Louise Eincyk. Mr. Eincyk has been vending and installing heating technologies for over 35 years.

Agricultural Utilization Research Institute, a Minnesota-based nonprofit organization providing applied research services and product development assistance to create new ag-based products, process refinements and assistance to move them to market. Its mission is to foster long-term economic benefit for Minnesota through value-added agricultural products.

The Minnesota Project (later integrated into the University of Minnesota Extension - **Clean Energy Resource Teams**).

The project team brought forward a 1.65 million Btu forced air, wood chip furnace for testing under live poultry barn conditions.

The Viking Company farm site served as an ideal host for testing and comparing the wood furnace to a conventionally heated liquid propane barn. The farm site consists of two identical two-story broiler chicken barns positioned in parallel, north-south orientation and 200 feet apart (see *Methodology* below).

The 1.65 Million Btu Wood Chip Forced Air Furnace and Components

Imported by EvenTemp Distributing in Waco, Nebraska[5], and distributed locally by EvenTemp Biomass in the Upper Midwest, the 1.65 MMBtu biomass furnace and smaller models are manufactured by Mabre, S.R.L.[6] in Terracina, Italy.

The wood furnace was custom-built to meet 100% of the estimated Btu requirement of the Viking Company two-story broiler barn. This customization came at a higher financial cost relative to other industrial biomass furnaces. EvenTemp Biomass of Becker did not breakdown the costs of components out of concern for business privacy and competition.

EvenTemp Biomass had the wood furnace and the majority of its components delivered by semi-truck directly to Viking Company in Albany. EvenTemp Biomass personnel installed the wood furnace, chimney, ductwork, and dampers throughout the month of July and early August 2015.

The test barn required structural modifications to the control room in order to house the wood furnace. Modifications included concrete slab flooring, a firewall sealed with fireproof caulking between the control room and the barn extending to the roof steel, and a fire door between the control room and entryway to the service room. Table 1 below lists the supplier, components, and costs:

[5] "Even Temp – Distributing", http://eventempdistributing.com/index.php/about
[6] "Mabre: Biomass – Air", last modified 2014, http://www.mabre.it/eng/bio_eng.htm.

Table 1. Viking Company Equipment and Construction Cost Detail

Supplier	Item	Description	Cost
Mabre S.R.L. (imported by EvenTemp Distributing)	BMF 1650 WC	1.65 MMBtu Wood chip biomass forced air furnace with 80% efficiency	**$71,000**
	Touch Screen	Program Logic Control 10" screen – internet ready	
	Flue Exhauster	1.0 HP motor – inverter driven	
	Blower	15.0 HP motor – inverter driven	
	Feed System Auger	1.5 HP motor – inverter driven	
	Hopper Auger	1.0 HP motor – inverter driven	
	Combustion Blower	0.25 HP motor – inverter driven	
	Stirrer	0.33 HP motor – inverter driven	
	Wood Chip Hopper	512 ft^3 – extra large	
EvenTemp Biomass (Parts and Installation Labor)	Class A Chimney	16 ft. with threshold temp. of 2100°	**$22,775**
		Square support and flue extension	
		Anchor plate	
		Roof flashing, storm collar, rain cap	
		Roof bracing	
	Damper	16 in. by 16 in. - motorized[7]	
	Polymax Tubing	800 ft. 24" – 20" diameter flame-retardant stabilized polyethylene with air holes	
		Chain, hooks, and grommets	
	Metal Spiral Duct	20 in. diameter with fittings to upper and lower barn levels; spiral "T" attached to Polymax tubing	
	36 in. x 36 in. Fire damper	With metal grate and serving return air through the fire wall	
	Two 24 in. x 24 in. Fire Dampers	With metal grate and serving return air through the fire wall	
Shingobee Construction	16 ft. 9 in x 35 ft. 6 in. Utility Building	Single-slope, framed utility building including earthwork, site preparation, slab-on-grade concrete, insulation, interior and exterior metal liner paneling, overhead door and basic electrical service	**$28,380**
Viking Company	Storage Bunker Re-purposing	Post-frame modification with cement work to contain wood chips	**$7,800**
Hardware and Infrastructure Total			**$129,955**

[7] Viking Company altered the 16 in. by 16 in. motorized damper to remain open and screened to maintain barometric conditions in the barn.

Figure 1: Side view of the newly constructed lean-to housing the 1.65 MMBtu wood furnace (furnace chimney not yet installed). Photo looks east.

Figure 2: The wood furnace following recent delivery and pre-installation. Photo looks south.

Figure 3: Interior view of the new lean-to construction with the hopper and wood furnace fully installed. Photo looks south.

Figure 4: Structural modifications and re-purposing of the storage bunker to house wood chip fuel. Photo looks southwest.

Methodology

This test project was a macro-level examination of biomass thermal technology and fuel use between two similarly situated broiler chicken production barns. Its purpose was to determine the operability and fuel economy values of a 1.65 MMBtu biomass furnace in a live poultry production environment in Minnesota.

Equipment

In addition to the 1.65 MMBtu biomass furnace described above, the farm site and equipment included two identical, two-story broiler chicken barns positioned in a parallel, north-south orientation, set 200 feet apart (see Figure 5 below). Both barns measure 41 feet wide by 460 feet long by 20 feet high. Each barn contains twelve L.B. White Guardian Ag Animal Confinement Building propane heaters for zone heating use with a reduced throttle setting of 160,000 Btus per heater with a single-barn maximum thermal production capacity of 1,920,000 Btus per hour. The West Barn and its flocks served as an experiment control and the East Barn hosted the wood furnace as the experiment to compare wood fuel consumption to liquid propane consumption, assess operability, and examine flock performance.

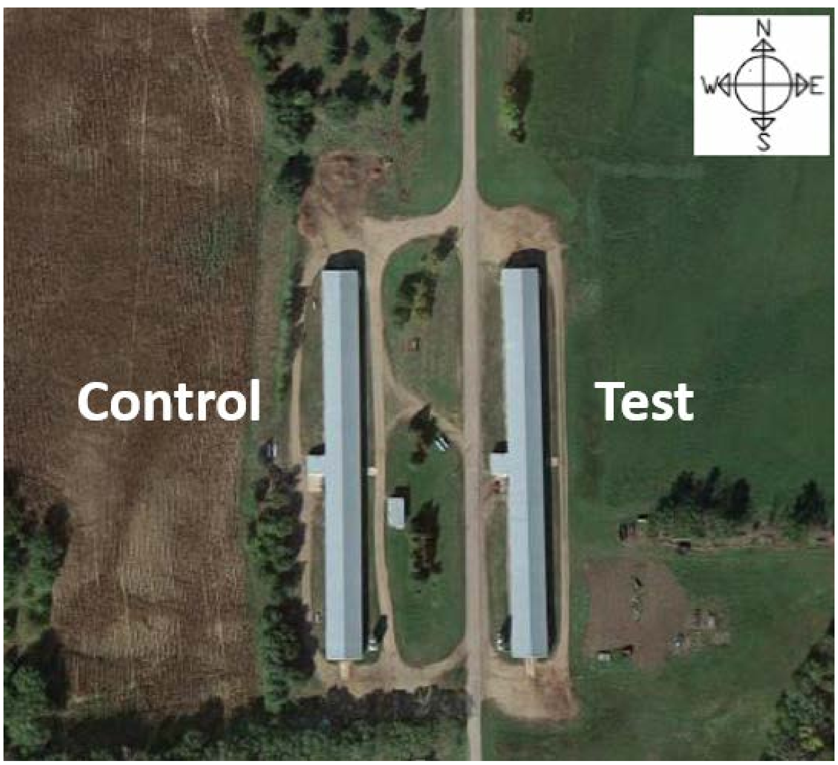

Figure 5: Aerial photo of the Viking Company host site in Albany, MN before the furnace room was added to the "Test" barn.

The Project Team assumed thermal energy consumption was nearly identical between the Control and Test Barn. The Team agreed this was a fair assumption because both barns had near identical liquid propane consumption historically. Additionally, flocks entered and exited the Control and Test barns on identical or nearly identical schedules. During the sixth flock from June 4 through July 29, 2016, both barns relied exclusively on liquid propane while a maintenance problem was resolved. This coincidence assisted in partially determining whether a correlation exits between the wood furnace use and flock health.

Measurements

Throughout the project, the GNP Companies measured liquid propane fuel use by metering consumption in gallons from the liquid propane tanks on both the Control and Test barns. Viking Company measured wood chip consumption by estimating volumetric weight according to the two-ton volume of the Extra Large Furnace hopper and by tracking the number of loads required to fill the two-ton (U.S.) hopper with a skid loader. Specifically, one skid load weight averaged 275.24 pounds (lbs) with an average volume of 15.8 cubic feet (ft^3). Viking Company tallied the number of loads delivered to the hopper and multiplied the total number of loads by the 275.24 pound-load factor to estimate the total tonnage consumed in a flock rotation. The estimated wood chip tonnage consumption was corroborated by comparing it to the truck weight tonnage of wood chips purchased and delivered to Viking Company from area suppliers.

Viking Company collected air bag samples on April 1, 2016 and May 1, 2016. Air samples included an open-air control sample and test samples from inside the Control barn and the Test barn (three samples total) while flocks were present. PACE Analytical, a third party laboratory, analyzed the air samples for ammonia (NH_3), carbon monoxide (CO), and oxygen (O_2). The Team examined ammonia levels to identify differences between the Test and control barns for ammonia presence and potential impact on flock growth. The Team also examined carbon monoxide and oxygen levels to identify heat source efficiency and building ventilation differences. These air elements can have a direct effect on bird health and flock performance.

Operability

Viking Company used the first several flocks in late summer and fall of 2015 to optimize the wood furnace and identify the best wood chip fuel mixes. As expected, the wood furnace and components required some adjustments to ensure smooth operation. By the second year, Viking Company had worked out nearly all challenges and had optimized use of the wood furnace for its poultry operation.

Initial Firing

Viking Company and EvenTemp Biomass first fired the wood furnace on August 26, 2015 with Mabre engineers from Terracina, Italy present. Ground elm with a 22% moisture content was the initial fuel source and proved challenging. The wood furnace ran for 20 minutes before shutting down automatically when its sensors identified excessive smoke. Viking Company was forced to heat the barn with LP for several days until it located a second wood chip fuel type, finely chipped kiln-dried furniture waste wood with an 8% moisture content. Viking Company was able to blend the ground elm and furniture waste wood to manage smoke emissions and some of the bridging problems associated with the ground elm through the first flock.

Static Pressure

Viking Company also discovered challenges involving static pressure and wood furnace convection. Leaving doors open to the furnace room caused a backdraft in the wood furnace and chimney. This pressure reduction caused backfiring through the feed auger, which triggered emergency sensors to shut down the furnace and close the air space. Viking Company learned that keeping doors closed and sealed correctly effectively managed the static pressure caused by the convection up the chimney. The addition of a chimney section also increased convective pressure. Ultimately, the backdraft difficulties were only resolved by directing the furnace's software settings to idle the exhaust continuously.

Hopper - Fuel Flow and Corrosion Issues

Wet wood fuel also proved problematic for Viking Company. The ground elm used throughout Flock 1 did not flow down to the feed auger consistently. The ground elm bridged over the feed auger chute and fused to the top of hopper table feeder, causing a gap in fuel supply and challenges in operating the wood furnace. Viking Company experienced corrosion on the underside of the cone agitator from wood fuel types with high moisture content. The moisture caused the cone agitator to rust and fuse to the bottom of hopper, thus preventing consistent fuel feeding to the wood furnace again. Viking Company resolved this problem by coating the cone agitator with a graphite-based paint and relying on wood chip fuels with lower moisture content and consistent size.

Figure 6: Hopper with the table feeder following graphite paint coating. Hopper contains low moisture furniture wood waste.

Program Controls

At initial set up, Mabre, S.R.L. configured the Human-Machine Interface (HMI) program controls in order to receive all fire, smoke, and malfunction alarm signals in Terracina, Italy. In the instance of an alarm or error message, Mabre S.R.L. would contact EvenTemp Biomass, who would then telephone Viking Company. Viking Company lacked the ability to change internal software parameters without contacting Mabre, S.R.L. via the internet. Understandably, this proved to be an operational hazard. Although Viking Company received the manual HMI program controls, at the time of this writing it awaited receipt from EvenTemp Biomass of the interface codes to control the wood furnace remotely. It warrants noting that full program control at the user-end is essential to effectively managing and monitoring system controls for optimum function from setup to installation completion.

Engineering Review

The Mabre furnace is not an Underwriter Laboratories listed product. In order to address risk, Elmdale Mutual Insurance Company requested Viking Company and EvenTemp Biomass have the 1.65 MMBtu unit undergo an engineering review. EvenTemp Biomass contracted with a local electrical and engineering inspector, Power System Engineering of Blaine, Minnesota, who certified all of the electrical components to satisfy the requirements of Elmdale Mutual Insurance Company. All electrical components in the wood furnace checked out as suitable for field installation and operation.

Air Recirculation Benefit

Unlike conventional barns using liquid propane zone heating, Viking Company learned it could warm the barn to optimal temperature in the summer months and use the blower fan to recirculate the warm air. This was possible because Viking Company determined the wood heat provided a cleaner air environment and required less exhaust ventilation. The air recirculation afforded Viking Company a small wood chip-fuel-savings benefit and maintained a better temperature zone uniformity, albeit in the summer months during lower thermal need.

Learned Maintenance Practices

Like all heating equipment, the wood furnace requires regular cleaning and maintenance to avoid ash build-up, reductions in wood chip fuel efficiency, and fire hazards. Viking Company developed a maintenance checklist and schedule throughout the project to address issues as they arose.

Hot Pot Ash Trays

On an as-needed basis, Viking Company cleaned the ash trays located at the bottom of the wood furnace around the "hot pot". The ash tray cleaning process is straightforward: Pull the ash trays out with a large metal hook, dump the ash into a metal bucket, and then drag a scraper through the bottom of the wood furnace several times to pull out any remaining ash. A single flock fills approximately 8 to 10 trays of ash, depending on the fuel type. Because the ash does not pile evenly around the hot pot, sifting the ash around is required for removal from the wood furnace. Typically, ash blows around in the wind, soiling the person cleaning the unit.

Figure 7: Wood furnace Hot Pot with some accumulated ash in the surrounding ash trays.

Poly Max Tubes – Barn Interior

The Poly Max tubes accumulate dust during a flock due to hot air blown through the approximately 800 feet of tubes. Periodically, and during the turnaround period between flocks, Viking Company unties the ends the Poly Max tubes and manually bats them to clear out accumulated dust, a technique learned by necessity.

Heat Exchanger Tubes and Cabinet – Interior

Fly ash accumulates in the bottoms of the 69 heat exchanger tubes as heat rises through the wood furnace. Every two weeks during a flock rotation, Viking Company personnel clean fly ash out of the interior of the tubes with a snug-fitting scraper and/or an air hose to pull and blow out the ash out of the heat exchanger tubes. Accumulation of fly ash depends on the fuel source: coarser wood fuels have less fly ash than finely chipped wood fuel combinations. A higher rate airflow also pulls more ash through the wood furnace and out the chimney. Viking Company observed an estimated 50% reduction in heat exchange efficiency between the stack temperature and output temperature when the interiors of the heat exchange tubes had accumulated ash; however, lost heat exchange efficiency was regained following clean out. Cleaning the heat exchangers without removing the turbulators takes 20 minutes per instance, or less than one hour per flock.

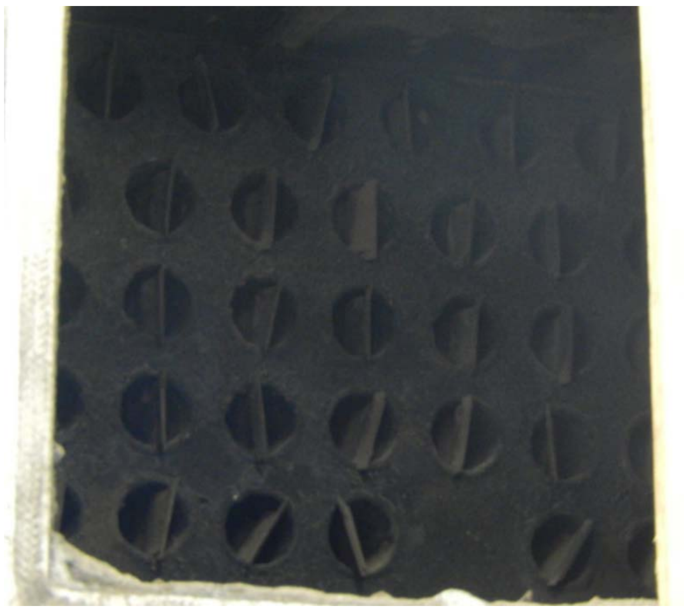

Figure 8: Heat exchange tubes with turbulators and cabinet opening.

Condensate and Heat Exchanger – Exterior

During Flocks 4 and 5, Viking Company observed holes half to three-quarters of the way down end of the Poly Max tubes in the barns. Initially thought to be rodent chew holes, Viking Company identified them as burn holes. Viking Company discovered condensate and charcoal-like detritus had accumulated in stalactite formations on the outside of the heat exchanger tubes after three and half flocks (without blowing clean up the chimney) and was breaking off in chunks blowing into the barn and down the Poly Max tubes as red-hot particles where it melted through to the barn floor. Rather than risk a fire loss, Viking Company immediately shut down the wood furnace and notified Elmdale Mutual Insurance Company and EvenTemp Biomass. As Viking Company and EvenTemp Biomass considered the problem and potential resolution, Viking Company relied solely on liquid propane heat during Flock 6 and limited wood fuel use in Flock 7. Viking Company discovered the condensate buildup occurred mostly when it used the wood furnace for air recirculation only. At an 80-degree barn temperature, detritus would build up on the outside of the heat exchanger. Much of the detritus would burn off and blow out the chimney when the wood furnace was re-fired. Over time, however, the condensate accumulated into the dangerous stalactite charcoal formations.

As a resolution, EvenTemp Biomass was able to cut a hinged door into the heat exchanger cabinet, which allowed Viking Company to knock down and scrape out accumulated condensate in the heat exchanger cabinet. Viking Company is able to clean out the cabinet and accumulated condensate in 40 minutes between flocks.

Figure 9: View of "stalactite" condensate buildup that was breaking off and being blown into the barn as red-hot particles.

Figure 10: The door cut into the heat exchanger allowing Viking Company to clean out the condensate char.

Wood Fuel Type and Heating Economics

The Project Team began this venture with a clear understanding that wood fuel quality and type have a direct impact on the economics of using wood fuel though it was unknown what the wood furnace could burn properly. Viking Company experimented with several wood fuel types at different costs from local vendors to identify fuel mixes most compatible with the wood furnace.

As a general rule, the wood furnace operated best with wood chips sized 3 inches or less, screened to remove tops and rounds, and with a moisture content of 15% or less. Table 3 details the range of wood chip fuels Viking Company fired in the wood furnace over the course of the project. Every flock employed a different blend of two or three of the fuel types listed.

Table 3: Wood Chip Fuel Types

Type	Moist. Content	Chip Size	$/Ton	Result
Ground Elm	22%	N/A (ground, not chipped)	$48	Problematic: Bridging, hopper corrosion
Furniture Waste Material (kiln-dried, chipped maple and hard wood mix)	7%	≤1 inch	$48-$50	Fast “matchstick” burn, easy fuel flow, excellent for blending
White Oak	15%	2-3 inch	$90-$95	Consistent, high temperature burn; easy fuel flow
Carpenter Trim/Molding Waste (various wood types, self-chipped)	10%	3/8 - 1 inch	$38-$40	Consistent, high temp burn; easy fuel flow
Recycled Construction Wood (Ash, Box Elder, Cottonwood)	20%	2 inch	$70	Consistent burn; easy fuel flow
Construction/Demolition Waste (Douglas Fir)	15%	2-3 inch	$70	Consistent, high temp burn; easy fuel flow

Cost Recovery

With the varying wood fuel costs and liquid propane prices specific to this project, the 1.65 MMBtu saved an estimated $16,057 in fuel costs over 12 flocks and 22 months, or $8,029 per year (six flocks in a year) with liquid propane prices fluctuating from $0.99 to $1.29 per gallon.

This represents a simple fuel savings cost recovery of **16.2 years**[8] from the total $129,955 investments in the wood furnace, barn addition, and wood chip bunker modifications. The simple cost recovery *excludes* any price variations in liquid propane pricing, wood chip fuel pricing, equipment depreciation, the federal renewable energy business investment tax credit, impacts on livestock production, and the amount of liquid propane displaced with wood fuel during production.

Including $2,095 per flock in estimated “effective cost” reduction from flock improvements (see Flock Production and Effective Cost section below) by six flocks, in addition to the $8,029 annual fuel savings, the cost recovery drops to **6.3 years**.[9]

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[8] $129,955 total cost ÷ $8,029 annual fuel savings = 16.2 year cost recovery

[9] $129,955 total cost / [(6 flocks x $2,095 effective cost savings) + $8,029 annual fuel savings)] = 6.3 year cost recovery

In a "best case" scenario, including the $2,095 effective cost reduction, and the optimized fuel cost savings of $12,061 in the second year, the cost recovery becomes a rapid **5.3 years**.[10]

Additionally, Viking Company has determined that a much less costly and smaller sized furnace would provide most, if not all, of the same benefits at a lower capital cost.

Fuel Cost Savings

As expected, the wood furnace demonstrated greater fuel savings in the winter months during greater thermal demand. The warmer months provided marginal fuel cost savings, indicating the technology might provide a competitive advantage to poultry growers in the Upper Midwest over growers in the Southern States.

With the exception of Flock 6, which used all propane, and Flock 8, which relied on all wood heat, Viking Company used a combination of majority wood heat and minority liquid propane heat to meet the thermal demands of flocks in the Test Barn. This hybridization technique was necessary to maintain consistent temperature during troubleshooting phases of the project and during turnaround periods of low heat demand when running the wood furnace did not make operational sense. Table 4 summarizes the heating economics on a per flock basis.

Table 4: Summary of the Test Barn's Fuel Cost Savings Per Flock

Flock	Dates	Wood Tons	LP Offset	$/gal LP	$/ton wood	Fuel Cost Savings
1	08/25/15 - 10/03/15	9.56	61%	$ 1.29	$ 48.60	$ 244.88
2	10/04/15 -12/08/15	22.29	74%	$ 1.29	$ 76.67	$ 1,283.89
3	12/09/15 - 02/08/16	43.45	68%	$ 1.06	$ 76.67	$ 1,269.10
4	02/09/16 - 04/06/16	33.14	67%	$ 1.00	$ 62.35	$ 269.83
5	04/07/16 - 06/03/16	2	77%	$ 1.01	$ 73.33	$ 1,586.51
6	06/04/16 - 07/29/16	0	0	$ 0.99	$ -	$ (658.35)
7	07/30/16 - 09/27/16	3.9	75%	$ 0.99	$ 81.25	$ (19.88)
8	09/28/16 - 11/29/16	22.56	93%	$ 0.99	$ 59.78	$ 721.58
9	11/30/16 - 01/24/17	47.44	100%	$ 1.00	$ 49.39	$ 2,426.80
10	01/25/17 - 03/22/17	24	82%	$ 1.19	$ 59.00	$ 5,317.00
11	04/03/17 - 05/14/17	22.78	72%	$ 1.24	$ 59.00	$ 2,139.14
12	05/29/17 - 07/20/17	8.6	89%	$ 1.24	$ 59.00	$ 1,476.60

Detailed economic performance, fuel costs, and fuel types for each flock are available in Appendix 1. Estimated Btu outputs are available in Appendix 2. Notably, Viking Company relied more on wood heat and saved $12,061 in fuel costs in the second year of the project after optimizing wood furnace operation.

Ash Analyses

Viking Company and the Agricultural Utilization Research Institute (AURI) collected an ash sample from the wood furnace and submitted it to Twin Ports Testing, Inc. of Superior, Wisconsin on March 13, 2017

[10] $129,955 total cost / [(6 flocks x $2,095 effective cost savings) + $12,061 annual fuel savings)] = 5.3 year cost recovery

for mineral oxide and proximate analyses. The mineral oxide analysis served to determine the commercial value of the ash byproduct as a field amendment.

As expected, laboratory analysis indicated the ash was primarily 36.28% calcium oxide (CaO) and 21.61% silicon dioxide (SiO_2). Other compounds included 12.5% sodium oxide (NaO), 11.5% potassium oxide (K_2O), 5.93% magnesium oxide, 2.83% phosphorus pentoxide (P_2O_5), and the remainder were different trace minerals or undetermined.

The ash sample's 11.5% potassium oxide content is valuable as a macronutrient for crop production. The 2.83% phosphorus pentoxide is also valuable as a soil amendment, and the 0.595% sulfur is valuable as a micronutrient for crops when obtained in sufficient volumes. Nonetheless, the ash sample also revealed high levels of sodium oxide, a form of salt. Consequently, the sodium content limits use of the ash as a soil amendment depending on the targeted crop application. The small amount of ash produced by the wood furnace also makes it a challenge to benefit from field application or sale.

The Proximate analysis served to evaluate the combustion efficiency of the wood furnace. The laboratory analysis showed the remaining energy content in the ash was less than 1 Btu/lb. This is indicative of highly efficient wood combustion. The full ash analyses are available in the Appendix.

Figure 11: The remaining ash of several tons of combusted wood chips at the Viking Company Facility

Air Quality and Flock Performance

AURI and Viking Company gathered several air bag samples to identify air quality differences between the liquid propane-heated Control Barn and wood chip-heated Test Barn. Samples were collected on April 1, 2016 and May 1, 2016 and submitted to third-party laboratory PACE Analytical. The samples were analyzed for ammonia (NH_3), oxygen (O_2), and carbon monoxide (CO) content. The Project Team focused on ammonia to determine the presence and quantity in each barn since ammonia impacts flock production. Oxygen and carbon monoxide were evaluated to identify heat source efficiency (combustion) and ventilation. The three air compounds have a direct impact on flock growth and overall production. Table 5 summarizes the air sample analyses.

Table 5: Air Quality Analysis

Analysis	Ammonia (NH_3) Avg. PPMv	Carbon Monoxide (CO) %	Oxygen (O_2) %
Test 1 – Control Sample 4/1/16	**0.254**	**0.4**	**21.0**
Test 2 – Propane Barn 5/1/16	**0.246**	**0.4**	**20.7**
Test 3 – Biomass Barn 5/1/16	**0.272**	**0.4**	**20.4**

The single air quality sampling showed a slight reduction in ammonia content in the Control Barn. Essentially, the barns were the same based on the low and single-instance ammonia readings. The Control and Test Barns showed a slight reduction in atmospheric oxygen compared to the control sample. The Test Barn showed a greater reduction in available oxygen, though not significant. Neither barn showed a difference in carbon monoxide presence.

Though only anecdotal evidence, Viking Company also collected air quality on a daily basis for Flock 9 in the Control Barn and Test Barn. This data revealed a different result than the laboratory test and showed slightly lower carbon monoxide, ammonia, and relative humidity readings; and slightly higher oxygen readings in the Test Barn. Table 6 summarizes the daily averages of data collected throughout Flock 9.

Table 6: Viking Company air quality data collected during Flock 9 (daily averages)

Barn	Carbon Monoxide (CO) %	Ammonia (NH3) in PPMv	Oxygen (O2) %	Relative Humidity %
Control (LP)	0.86	0.283	22.3	62.9
Test (Wood)	0.19	0.227	22.7	56.6

Additionally, Viking Company notes the Test barn had higher oxygen, lower ammonia and lower humidity during critical times, such as during the first 10 days of a flock; the averages do not reflect the day-to-day advantages of employing a wood furnace with a heat exchanger.

The information collected by Viking Company from Flock 9 is included here *only to demonstrate the need for a longer scientific analysis of air quality differences between wood-heated barns and LP-heated barns.* The scope of this project was limited to studying the fuel cost and operability differences of using woody biomass as a thermal source in commercial poultry production.

Flock Production and Effective Cost

Veterinary analysis of bird health in relation to the barn's heat source was beyond the scope of this project. GNP Companies (now Pilgrim's Pride) was hesitant to make health claims based on this project in light of the many variables that determine flock health (chick genetics, weather stress, pathogen prevalence, etc.). Before a legitimate claim on health benefits from the use of wood heat, there is a need for additional research on the health impacts from the use of different heat sources in relation to barn air quality.

However, GNP Companies provided Viking Company with summaries of the 2016 flock performance, as well as three winter flocks between the Control and Test Barns. The flock performance data provides some insight into the production benefits of using wood heat as a thermal source in contrast to conventionally heated barns. Table 7 summarizes the 2016 data provided by GNP Companies. Table 8 summarizes the three cold month flocks of 2016-2017.

Table 7: 2016 Barn Position and Flock Statistics provided by GNP Companies

2016 Year	Control Barn	Test Barn
Effective Cost per Lb.	$0.3549	$0.3515
Average Weight	6.36 lbs	6.28 lbs
Feed Conversion	1.841	1.823
Field Condemns Percent (heads)	0.61	0.52
Livability	91.2%	90.93%
Litter per Bird	$0.075	$0.073
Effective Cost Ranking	124/183	72/183
Condemned Ranking	152/205	107/205

Table 8: Barn Position and Flock Statistics for Cold Months 2016-2017 Three Flock Averages (9/28/16-11/29/16, 11/30/16-01/24/17, and 1/25/17-3/22/17 Flocks) provided by GNP Companies

’16-’17 Cold Month Averages	Control Barn	Test Barn
Adjusted Feed Conversion	1.813	1.787
Adjusted Weight in Lbs.	5.699	6.422
Total Condemned Percent (weight)	0.088	0.214
Field Condemned Percent (heads)	0.266%	0.316%
Livability Percent	93.069%	87.848%
Fuel Cost (Cents/Bird)	$0.14916	$0.13717
Daily Gain (Lbs.)	0.1325	0.1487
Effective Cost per Lb.	$0.3726	$0.3539

“Effective Cost” is the cost to the integrator of growing a pound of meat. It includes, but is not limited to, feed, fuel, electricity, pharmaceuticals, water treatments, extra materials (i.e. extra litter), livability (birds that die before slaughter), and barn rent among other matters. GNP Companies did not provide the method or all factors by which it calculates effective cost.

Nonetheless, the data provided by GNP Companies in Tables 7 and 8 shows the Test Barn producing chickens at a lower effective cost. Lower fuel costs, heavier bird weight, reduced feed conversion rates and reduced field condemns support the lower effective cost numbers in the Test Barn, though there is reason to believe other factors are at work. In practice, reducing effective cost saves the integrator money.

By way of example, a $0.0187 effective cost savings demonstrated in the Test Barn for the 2016-2017 cold months multiplied by 240,000 pounds of meat (typical for a flock) by three flocks equals $13,464 in production cost savings for the integrator (alternatively, $4,488 per flock). This is an estimated $6,285 above the calculated fuel cost savings of from Viking Company’s use of wood chips for the same three flocks (alternatively, $2,095 additional effective cost savings beyond fuel cost savings). There are strong indicators that wood heat in poultry production provides a dual benefit of reduced fuel cost and increased production for the producer and the integrator. Regardless, a direct study of air quality, its impacts on flock health, and the resulting production benefits from using wood heat is necessary to reach a scientific conclusion.

Conclusion

The 1.65 MMBtu wood chip furnace was a successful demonstration project. It provides detailed insight into the large market potential for meeting livestock thermal demands with woody biomass—Woody biomass is a viable, cost-effective fuel source for producers dependent on liquid propane. This project stands as a case study for livestock insurance companies who question wood furnaces in a commercial operation. Though there is a need for more research to draw a scientific conclusion that wood heat provides a healthier air quality environment, the data collected includes several indicators that using a wood furnace in poultry production contributes to robust flocks and reduced costs for poultry growers and integrators. As noted earlier in the report, there is a need for further research to reach a scientific conclusion as to the impacts of air quality on flock health and the resulting production benefits from using wood heat.

Appendix 1: Fuel Economic Performance per Flock

Flock 1: 8/23/15 – 10/3/2015	Test	Control
Liquid Propane Price	$1.29	$1.29
Liq. Propane Usage (gals)	350	900
Liq. Propane Fuel Cost	$451.50	$1,161.00
Estimated Liq. Propane Avoided	61%	
Wood Type 1 and Tonnage	Ground Elm, 22% moisture content, 6.69 tons	
Wood Type 1 Price/Ton	$48	
Wood Type 2 with Tonnage	Furniture waste wood, 8% moisture content, 2.87 tons	
Wood Type 2 Price/Ton	$50	
Total Wood Tonnage	9.56	
Total Wood Cost	$ 464.62	
Total Fuel Cost (wood & LP)	$ 916.12	$1,161.00
Fuel Cost Savings Estimate	$ 244.88	

Flock 2: 10/4/2015 – 12/8/2015	Test	Control
Liquid Propane Price	$1.29	$1.29
Liq. Propane Usage (gals)	801	3121
Liq. Propane Fuel Cost	$1033.29	$4026.09
Estimated Liq. Propane Avoided	74%	
Wood Type 1 and Tonnage	White Oak, 15% moisture content, 14.86 tons	
Wood Type 1 Price/Ton	$90.00	
Wood Type 2 with Tonnage	Furniture waste wood, 8% moisture content, 7.43 tons	
Wood Type 2 Price/Ton	$50.00	
Total Wood Tonnage	22.29	
Total Wood Cost/Ton	$1708.91	
Total Fuel Cost (wood and LP)	$2742.20	$4026.09
Fuel Cost Savings Estimate	$1283.89	

Flock 3: 12/9/2015 – 2/8/2016	Test	Control
Liquid Propane Price	$1.06	$1.06
Liq. Propane Usage (gals)	2070	6410
Liq. Propane Fuel Cost	$ 2194.20	$ 6794.60
Estimated Liq. Propane Avoided	68%	
Wood Type 1 and Tonnage	White Oak, 15% moisture content, 28.97 tons	
Wood Type 1 Cost/Ton	$90	
Wood Type 2 with Tonnage	Furniture waste wood, 8% moisture content, 14.48 tons	
Wood Type 2 Cost/Ton	$50.00	
Total Wood Tonnage	43.45	
Total Wood Cost	$3331.30	
Total Fuel Cost	$5525.50	$6794.60
Fuel Cost Savings Estimate	$1269.10	

Appendix 1 cont.

Flock 4: 2/9/2016 – 4/6/2016	Test	Control
Liquid Propane Price	$1.00	$1.00
Liq. Propane Usage (gals)	1150	3486
Liq. Propane Fuel Cost	$1150.00	$3486.00
Estimated Liq. Propane Avoided	67%	N/A
Wood Type 1 and Tonnage	White Oak, 15% moisture content, 14.44 tons	
Wood Type 1 Price/Ton	$90.00	
Wood Type 2 and Tonnage	Furniture waste wood, 8% moisture content, 14.44 tons	
Wood Type 2 Price/Ton	$50.00	
Wood Type 3 and Tonnage	Waste trim and molding, 7% moisture content, 4.26 tons	
Wood Type 3 Price/Ton	$40.00	
Total Wood Tonnage	33.14 tons	
Total Wood Cost	$2089.74	
Total Fuel Cost	$3239.74	$3486.00
Fuel Cost Savings Estimate	$246.26	

Flock 5: 4/7/2016 -6/3/2016	Test	Control
Liquid Propane Price	$1.01	$1.01
Liq. Propane Usage (gals)	519	2235
Liq. Propane Fuel Cost	$524.19	$2257.35
Estimated Liq. Propane Avoided	77%	
Wood Type 1 and Tonnage	White Oak, 15% moisture content, 1.33 tons	
Wood Type 1 Price/Ton	$90.00	
Wood Type 2 and Tonnage	Waste trim and molding, 7% moisture content, 0.67 tons	
Wood Type 2 Price/Ton	$40.00	
Total Wood Tonnage	2.00	
Total Wood Cost	$146.65	
Total Fuel Cost	$670.84	$2257.35
Fuel Cost Savings Estimate	$1586.51	

Flock 6: 6/4/16 – 7/29/16	Test	Control
Liquid Propane Price	$0.99	$0.99
Liq. Propane Usage (gals)	370	295
Liq. Propane Fuel Cost	$366.30	$292.05
Estimated Liq. Propane Avoided	0	
Wood Type 1 with Tonnage		
Wood Type 1 Price/Ton		
Wood Type 2 with Tonnage		
Wood Type 2 Price/Ton		
Total Wood Tonnage		
Total Wood Cost		
Total Fuel Cost	$366.30	$292.05
Fuel Cost Savings Estimate	0	0
Note: The Control and Test Barns for Flock 6 ran on LP only during the resolution of condensate char entering the barn chamber and risking fire.		

Appendix 1 cont.

Flock 7: 7/30/16 – 9/27/16	Test	Control
Liquid Propane Price	$0.99	$0.99
Liq. Propane Usage (gals)	100	400
Liq. Propane Fuel Cost	$99.00	$396.00
Estimated Liq. Propane Avoided	75%	
Wood Type 1 with Tonnage	White Oak, 15% moisture content, 2.93 tons	
Wood Type 1 Price/Ton	$95.00	
Wood Type 2 with Tonnage	Waste trim and molding, 7% moisture content, 0.96 tons	
Wood Type 2 Price/Ton	$40.00	
Total Wood Tonnage	3.90	
Total Wood Cost	$316.88	
Total Fuel Cost	$415.88	$396.00
Fuel Cost Savings Estimate	($19.88)	

Flock 8: 9/28/16 – 11/29/16	Test	Control
Liquid Propane Price	$1.09	$1.09
Liq. Propane Usage (gals)	150	2241
Liq. Propane Fuel Cost	$148.50	$2218.59
Estimated Liq. Propane Avoided	93%	
Wood Type 1 with Tonnage	White Oak, 15% moisture content, 6.19 tons	
Wood Type 1 Price/Ton	$95.00	
Wood Type 2 with Tonnage	Furniture waste wood, 8% moisture content, 10.59 tons	
Wood Type 2 Price/Ton	$50.00	
Wood Type 3 with Tonnage	Waste trim and molding, 7% moisture content, 20.35 tons	
Wood Type 3 Price/Ton	$35.00	
Total Wood Tonnage	22.56	
Total Wood Cost	$1348.51	
Total Fuel Cost	$1497.01	$2218.59
Fuel Cost Savings Estimate	$721.58	

Flock 9: 11/30/16 – 1/24/17	Test	Control
Liquid Propane Price	$1.09	
Liq. Propane Usage (gals)	979	5623
Liq. Propane Fuel Cost	$1065.15	$6117.82
Estimated Liq. Propane Avoided	83%	
Wood Type 1 with Tonnage	Recycled Construction Wood, 20% moisture content, 18.91 tons	
Wood Type 1 Price/Ton	$70.00	
Wood Type 2 with Tonnage	Furniture waste wood, 8% moisture content, 8.18 tons	
Wood Type 2 Price/Ton	$50.00	
Wood Type 3 with Tonnage	Waste trim and molding, 7% moisture content, 20.35	
Wood Type 3 Price/Ton	$30.00	
Total Wood Tonnage	47.44	
Total Wood Cost	$2343.20	
Total Fuel Cost	$3408.35	$6117.82
Fuel Cost Savings Estimate	$1361.65	

Appendix 1 cont.

Flock 10: 1/25/17 – 3/22/17	Test	Control
Liquid Propane Price	$1.19	$1.19
Liq. Propane Usage (gals)	1000	6664
Liq. Propane Fuel Cost	$1193.00	$7950.15
Estimated Liq. Propane Avoided	85%	
Wood Type 1 with Tonnage	Furniture waste wood, 8% moisture content, 12 tons	
Wood Type 1 Price/Ton	$50.00	
Wood Type 2 with Tonnage	Demolition Waste (Doug. Fir), 15% moisture content, 12 tons	
Wood Type 2 Price/Ton	$70.00	
Total Wood Tonnage	24 tons	
Total Wood Cost	$1440.00	
Total Fuel Cost	$2633.00	$7950.15
Fuel Cost Savings Estimate	$5317.15	

Flock 11: 4/3/17 – 5/14/17	Test	Control
Liquid Propane Price	$1.24	$1.24
Liq. Propane Usage (gals)	1123	3932
Liq. Propane Fuel Cost	$1392.562	$4875.68
Estimated Liq. Propane Avoided	71%	
Wood Type 1 with Tonnage	Furniture waste wood, 8% moisture content, 11.39 tons	
Wood Type 1 Price/Ton	$48.00	
Wood Type 2 with Tonnage	Demolition Waste (Doug. Fir), 15% moisture content, 11.39 tons	
Wood Type 2 Price/Ton	$70.00	
Total Wood Tonnage	22.78	
Total Wood Cost	$1344.02	
Total Fuel Cost	$2736.54	$4875.68
Fuel Cost Savings Estimate	$2139.14	

Flock 12: 5/29/17 – 7/20/17	Test	Control
Liquid Propane Price	$1.24	$1.24
Liq. Propane Usage (gals)	200	1800
Liq. Propane Fuel Cost	$248.00	$2232.00
Estimated Liq. Propane Avoided	89%	
Wood Type 1 with Tonnage	Furniture waste wood, 8% moisture content, 4.3 tons	
Wood Type 1 Price/Ton	$48.00	
Wood Type 2 with Tonnage	Demolition Waste (Doug. Fir), 15% moisture content, 4.3 tons	
Wood Type 2 Price/Ton	$70.00	
Total Wood Tonnage	8.6	
Total Wood Cost	$507.40	
Total Fuel Cost	$755.40	$2232.00
Fuel Cost Savings Estimate	$1476.60	

Appendix 2: Wood Heat MMBtu Output Estimate

Flock	Wood Type	Tonnage	Moisture Content Efficiency Factor	Gross Heating Value (Btus/ton at 0% M.C.)	Net Heating Value (Btus/ton)	Furnace Efficiency	Useable Btu Output	Useable MMBtus	Total MMBtus
1 (8/25/15 - 10/3/15)	Ground Elm	6.692	0.88	17,200,000	101,290,112	0.85	86,096,595	86.10	**Flock 1**
	Hog Fuel	2.870	0.92	17,200,000	45,414,880	0.85	38,602,648	38.60	**124.70**
2 (10/4/15 - 12/8/15)	White Oak	14.86	0.85	17,200,000	217,253,200	0.85	184,665,220	184.67	**Flock 2**
	Hog Fuel	7.43	0.92	17,200,000	117,572,320	0.85	99,936,472	99.94	**284.60**
3 (12/9/15 - 2/8/16)	White Oak	28.97	0.85	17,200,000	423,541,400	0.85	360,010,190	360.01	**Flock 3**
	Hog Fuel	**14.48**	0.92	17,200,000	229,131,520	0.85	194,761,792	194.76	**554.77**
4 (2/9/16 - 4/6/16)	White Oak	14.44	0.85	17,200,000	211,112,800	0.85	179,445,880	179.45	
	Hog Fuel	14.44	0.92	17,200,000	228,498,560	0.85	194,223,776	194.22	**Flock 4**
	Waste Trim	4.26	0.93	17,200,000	68,142,960	0.85	57,921,516	57.92	**431.59**
5 (4/7/16 - 6/3/16)	White Oak	1.33	0.85	17,200,000	19,444,600	0.85	16,527,910	16.53	**Flock 5**
	Waste Trim	0.667	0.93	17,200,000	10,669,332	0.85	9,068,932	9.07	**25.60**
6 (6/4/16-7/29/16)	None	0	0	17,200,000	-	0.85	-	-	**Flock 6**
	None	0	0	17,200,000	-	0.85	-	-	**0**
7 (7/30/16 - 9/27/16)	White Oak	2.925	0.85	17,200,000	42,763,500	0.85	36,348,975	36.35	**Flock 7**
	Waste Trim	0.975	0.93	17,200,000	15,596,100	0.85	13,256,685	13.26	**49.61**
8 (9/28/16 - 11/25/16)	White Oak	6.19	0.85	17,200,000	90,497,800	0.85	76,923,130	76.92	
	Hog Fuel	10.59	0.92	17,200,000	167,576,160	0.85	142,439,736	142.44	**Flock 8**
	Waste Trim	5.78	0.93	17,200,000	92,456,880	0.85	78,588,348	78.59	**297.95**
9 (11/30/16 - 1/24/17)	Hansen I	18.91	0.9	17,200,000	292,726,800	0.85	248,817,780	248.82	
	Hog Fuel	8.18	0.92	17,200,000	129,440,320	0.85	110,024,272	110.02	**Flock 9**
	Waste Trim	20.35	0.93	17,200,000	325,518,600	0.85	276,690,810	276.69	**635.53**
10 (1/25/17 - 3/22/17)	Hog Fuel	12	0.92	17,200,000	189,888,000	0.85	161,404,800	161.40	**Flock 10**
	Hansen II	12	0.85	17,200,000	175,440,000	0.85	149,124,000	149.12	**310.53**
11 (4/3/17 - 5/14/17)	Hog Fuel	11.39	0.92	17,200,000	180,235,360	0.85	153,200,056	153.20	**Flock 11**
	Hansen II	11.39	0.85	17,200,000	166,521,800	0.85	141,543,530	141.54	**294.74**
5/15/2017 (start 6/6/17	Hog Fuel	4.3	0.92	17,200,000	68,043,200	0.85	57,836,720	57.84	**Flock 12**
	Hansen II	4.3	**0.85**	17,200,000	62,866,000	0.85	53,436,100	53.44	**111.27**

Appendix 3: Air Compound Analyses

PO Box 599
Crookston, MN 56716
800.279.5010

1501 State Street
Marshall, MN 56258
507.537.7440

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1475 Gortner Avenue
St. Paul, MN 55108
612.624.8816

PO Box 251
Waseca, MN 56093
507.835.8990

auri
Agricultural Utilization Research Institute

www.auri.org

March 24, 2017

Viking Company Project, Albany, Minnesota

Fritz Ebinger
Clean Energy Program Manager
1885 University Avenue
Suite 315
St. Paul, MN 55104
Phone: 651.645.6159

Dear Fritz:

Following is the summarized information for the three air samples collected within Viking Company poultry barns on April 1, 2016 and May 1, 2016. The samples were submitted to Pace Analytical located in Minneapolis, Minnesota for analysis of ammonia (NH_3), carbon monoxide (CO_2) and oxygen (O_2). The focus on ammonia was to identify differences between the test and control barns for ammonia presence. Secondly, carbon monoxide and oxygen levels were evaluated to identify heat source efficiency and building ventilation. All three compounds or molecules can have a direct effect on bird health and growth performance.

Following is a summary of the three air sample results submitted:

Analysis	Ammonia (NH_3) Avg. PPMV	Carbon Monoxide (CO_2) %	Oxygen (O_2) %
Test 1 – Control 4.1.16	0.254	0.4	21.0
Test 2 – Propane Barn 5.1.16	0.246	0.4	20.7
Test 3 – Biomass Barn 5.1.16	0.272	0.4	20.4

1. Results indicate there is a slight reduction in ammonia content from the barn heated with propane (Test #2). However, statistically the barns were the same based on the low and narrow ammonia readings.
2. Both barns showed a slight reduction in atmospheric oxygen when compared to the control sample (Test #1). However, the barn heated with biomass (Test #3) did show the greatest reduction in available oxygen, but the change may not be significant.
3. None of the barns showed a difference in presence of carbon monoxide.
4. Data will not correspond with actual daily measurements due to potential delays in gas sampling time.

Disclaimer: Analysis results were obtained from a single air quality sampling. Data reported was replicated, but only one test occurred.

Appendix 3 cont.

Pace Analytical®
Field Services Division

July 22, 2016

Scott Unze
Pace Analytical Minnesota
1700 Elm Street SE, Suite 200
Mineapolis, MN 55414

Project ID: MN Lab-10354887
Project #: 12-16-0801

Dear Mr. Unze

Enclosed are the analytical results for samples received by the laboratory on 7/12/16. Results reported herein were determined by EPA, NCASI or other approved methodologies.

If you have any questions concerning these reports, please feel free to contact me.

Sincerely,

Brett Erickson, QSTI
Field Analyst III
Pace Analytical Services, Inc.
1700 Elm Street, Suite 200
Minneapolis, Minnesota 55414
Phone: 612-437-5703
E-mail: brett.erickson@pacelabs.com

Appendix 3 cont.

Report of Laboratory Analysis

Scott Unze
Pace Analytical Minnesota
1700 Elm Street SE, Suite 200
Mineapolis, MN 55414

Project ID: MN Lab-10354887
Project #: 12-16-0801

Date Collected: 04/01/16, 05/01/16
Date Received: 07/12/16
Date Analyzed: 07/14/16
Analyst: DJL/BDE

Ammonia Analysis, PPMv

Sample ID	Average
Modified EPA 320, FTIR	
10354887-001	0.254
10354887-002	0.246
10354887-003	0.272

Sample Analysis Reporting Limit 0.21 PPMv

Date of Report: 07/22/16

Pace Analytical Services, Inc. 1700 Elm Street, Suite 200, Minneapolis, Minnesota 55414
Phone: 612-607-1700, Fax: 612-607-6444, Web Address: www.pacelabs.com

Appendix 3 cont.

Pace Analytical® Field Services Division

Report of Laboratory Analysis

Scott Unze
Pace Analytical Minnesota
1700 Elm Street SE, Suite 200
Mineapolis, MN 55414

Project ID: MN Lab-10354887
Project #: 12-16-0801

Quality Control/Quality Assurance Report

Date Analyzed: 07/14/16
Analyst: DJL/BDE

Calibration Verification	Measured Concentration PPMv		Certified Concentration PPMv	Percent Recovery %	
	Initial	End		Initial	End
Ethylene (EPA 320)	20.1	20.0	20.1	100	99.6

Acceptable Range: 95 to 105%

Date of Report: 07/22/16

Page 3 of 3

Pace Analytical Services, Inc. 1700 Elm Street, Suite 200, Minneapolis, Minnesota 55414
Phone: 612-607-1700, Fax: 612-607-6444, Web Address: www.pacelabs.com

Appendix 4: Ash Mineral Oxide and Proximate Analyses

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March 24, 2017

Fritz Ebinger
Clean Energy Program Manager
1885 University Avenue
Suite 315
St. Paul, MN 55104
Phone: 651.645.6159

Re: Viking Company Ash Analysis

Dear Fritz:

Attached is the ash analysis results obtained from the Viking Company project. The ash sample was submitted to Twin Ports Testing in Superior, Wisconsin, for a complete mineral oxide analysis of ash. I also had them run a proximate analysis primarily to evaluate biomass burner efficiency.

Regarding burner efficiency, ash results came back less than 1 BTU per pound of sample or 0.0001% of the original energy value. Although not surprising, AURI has seen ash samples that still contained 30% to 50% of their original energy value. This is a good indicator of efficient burner operation. Secondly, you will note that the ash sample has 0.595% sulfur which is a valuable micro crop nutrient if it can be obtained in sufficient volumes.

The mineral oxide analysis provided no surprises. Ash content was very high in calcium oxide at 36.28% of the total mass; however, calcium provides limited benefit to crop and plant production. The focus, however, was to evaluate the phosphorus and potassium content of the ash which are both macro nutrients for plant production. The ash sample contained 2.83% phosphorus pentoxide. This form is also written as P_2O_5 and the common form phosphorus is marketed for agronomic applications. Likewise, potassium's common form for agronomic applications is K_2O. The ash sample contained 11.5% potassium oxide; also a macro nutrient for crop production.

Ash mineral values could have a significant value based solely on quantity and availability for agronomic applications. However, the sample evaluated also contained relatively high levels of sodium oxide which can be detrimental to plant growth. Application of the ash sample evaluated would be limited by sodium content based on the targeted plant application.

Regards,

Alan Doering
AURI, Waseca, MN
507.835.8990

Appendix 4 cont.

Twin Ports Testing Inc.

Twin Ports Testing, Inc.
1301 North 3rd Street
Superior, WI 54880
p: 715-392-7114
p: 800-373-2562
f: 715-392-7163
www.twinportstesting.com

Analytical Test Report

Report No:	USR:W217-0238-01
Issue No:	1

This report replaces all previous issues

Client:	AURI		
	12298 350th Avenue		
	Waseca	MN	56093
Attention:	Alan Doering		
PO No:	verbal w/ Stephan		

Signed: Stephen Sundeen

Stephen Sundeen
Chemistry Laboratory Manager

Date of Issue: 3/21/2017

THIS DOCUMENT SHALL NOT BE REPRODUCED EXCEPT IN FULL

Sample Details

Sample Log No:	W217-0238-01	Sample Date:	
Sample Designation:	Wood Ash/Viking	Sample Time:	
Sample Recognized as:	Wood Ash	Arrival Date:	3/13/2017

Test Results

ASH FUSION - ASTM D1857

Reducing Atmosphere	
Initial Def. Temp.	°F
Softening Temp.	°F
Hemispherical Temp.	°F
Fluid Temp.	°F

Oxidizing Atmosphere	
Initial Def. Temp.	°F
Softening Temp.	°F
Hemispherical Temp.	°F
Fluid Temp.	°F

MINERAL ANALYSIS OF ASH - ASTM D3682

Silicon Dioxide in Ash	21.61 wt. %
Aluminum Oxide in Ash	0.59 wt. %
Titanium Dioxide in Ash	0.47 wt. %
Iron Oxide in Ash	1.17 wt. %
Calcium Oxide in Ash	36.28 wt. %
Magnesium Oxide in Ash	5.93 wt. %
Potassium Oxide in Ash	11.50 wt. %
Sodium Oxide in Ash	12.50 wt. %
Sulfur Trioxide in Ash	1.50 wt. %
Phosphorus Pentoxide in Ash	2.83 wt. %
Strontium Oxide in Ash	0.08 wt. %
Barium Oxide in Ash	0.34 wt. %
Manganese Dioxide in Ash	0.63 wt. %
Undetermined	4.57 wt. %
Total	100.00 wt. %

Comments

Appendix 4 cont.

Twin Ports Testing Inc.

Twin Ports Testing, Inc.
1301 North 3rd Street
Superior, WI 54880
p: 715-392-7114
p: 800-373-2562
f: 715-392-7163
www.twinportstesting.com

Analytical Test Report

Report No: USR:W217-0238-01
Issue No: 1

Client: AURI
12298 350th Avenue
Waseca, MN 56093
Attention: Alan Doering

PO No: verbal w/ Stephan

Signed:

Stephen Sundeen
Chemistry Laboratory Manager

Date of Issue: 3/21/2017

THIS DOCUMENT SHALL NOT BE REPRODUCED EXCEPT IN FULL

Sample Details

Sample Log No:	W217-0238-01	Sample Date:	
Sample Designation:	Wood Ash/Viking	Sample Time:	
Sample Recognized As:	Wood Ash	Arrival Date:	3/13/2017

Test Results

	METHOD	UNITS	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM E871	wt. %		10.08
Ash	ASTM D1102	wt. %	85.58	76.96
Volatile Matter	ASTM D3175	wt. %	15.96	14.35
Fixed Carbon by Difference	ASTM D3172	wt. %	< 0.01	< 0.01
Sulfur	ASTM D4239	wt. %	0.595	0.535
SO_2	Calculated	lb/mmbtu		N/A
Net Cal. Value at Const. Pressure	ISO 1928	GJ/tonne		
Net Cal. Value at Const. Pressure	ISO 1928	J/g		
Gross Cal. Value at Const. Vol.	ASTM E711	J/g	< 1	< 1
Gross Cal. Value at Const. Vol.	ASTM E711	Btu/lb	< 1	< 1
Carbon	ASTM D5373	wt. %		
Hydrogen*	ASTM D5373	wt. %		
Nitrogen	ASTM D5373	wt. %		
Oxygen*	ASTM D3176	wt. %		
Chlorine	ASTM D6721	mg/kg		
Fluorine	ASTM D3761	mg/kg		
Mercury	ASTM D6722	mg/kg		
Bulk Density	ASTM E873	lbs/ft^3		
Fines (Less than 1/8")	TPT CH-P-06	wt.%		
Durability Index	Kansas State	PDI		
Sample Above 1.50"	TPT CH-P-06	wt.%		
Maximum Length (Single Pellet)	TPT CH-P-06	inch		
Diameter, Range	TPT CH-P-05	inch		to
Diameter, Average	TPT CH-P-05	inch		
Stated Bag Weight	TPT CH-P-01	lbs		
Actual Bag Weight	TPT CH-P-01	lbs		

*Note: As received values do not include hydrogen and oxygen in the total moisture.

Comments