**M.L. 2014 Project Abstract**
For the Period Ending June 30, 2017

**PROJECT TITLE:** Transitioning Minnesota Farms to Local Energy
**PROJECT MANAGER:** Michael Reese
**AFFILIATION:** University of Minnesota West Central Research and Outreach Center
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**WEBSITE:** https://wcroc.cfans.umn.edu/research-programs/renewable-energy
**FUNDING SOURCE:** Environment and Natural Resources Trust Fund
**LEGAL CITATION:** M.L. 2014, Chp. 226, Sec. 2, Subd. 08d

**APPROPRIATION AMOUNT:** $ 500,000
**AMOUNT SPENT:** $ 429,012
**AMOUNT REMAINING:** $ 70,988

**<u>Overall Project Outcomes and Results</u>**

Agriculture production requires large amounts of fossil energy. The use of fossil energy for agriculture impacts the environment, air, water, and economy. The goal of this project was to provide swine producers with research-based information enabling the transition to clean, locally-produced energy. The project was organized into four tasks.

The first task was to design clean energy systems for modern swine facilities.

- Energy consumption was audited at six commercial swine production facilities and the West Central Research and Outreach Center (WCROC).
- Facilities included breed-to-wean, nursery, and finishing buildings.
- Energy consumption data enabled rankings of energy loads for each phase of production.
- Results, for example, indicated that heat lamps for piglets used on average 49% of the electrical energy consumed in a farrowing facility. Producers would benefit by upgrading to energy efficient heating for piglets.
- An engineering firm analyzed several energy efficiency measures (EEM) appropriate for swine production to reduce energy consumption.
- Return on Investments (ROI) were calculated for each EEM.

Task two involved field testing of a clean energy system.

- A 27 kW solar PV system was installed and tested on the WCROC swine finishing facility.
- The system provided all energy consumed within the facility generating 30,000 kWhr per year.
- Solar PV system ROIs were modeled for commercial swine facilities. Installation costs are declining but incentives are still needed to achieve simple paybacks under 10 to 15 years.

Life Cycle Assessment (LCA) was employed in Task 3.

- LCA was used to analyze the amount of fossil energy consumed and carbon dioxide emitted during swine production. Energy improvements were also modeled.
- Results indicated the Global Warming Potential (GWP) emissions in the broader swine lifecycle were highest for feed production, which accounted for almost 60% percent of fossil energy and 50% of greenhouse gas emissions.
- Producers have management control on roughly 25% of the fossil energy consumed.
- On-farm renewable energy systems can significantly lower fossil energy use on farms.

Task 4 involved dissemination of results and education which is described below.

**Project Results Use and Dissemination**

The Midwest Farm Energy Conference was hosted at the WCROC in June 2017. Approximately 90 farmers and other guests participated in the event. Swine energy workshops were conducted in other regions of the State. Energy information was provided to producers, who in total, market over 3 million pigs per year and represent over 90% of the State's annual production. In addition, energy curriculum was developed for agriculture and science educators teaching secondary and post-secondary technical students. The curriculum is being made available on-line. Additional materials including conference video and slide presentations can be accessed at https://wcroc.cfans.umn.edu/research-programs/renewable-energy.

# Environment and Natural Resources Trust Fund (ENRTF) M.L. 2014 Work Plan Final Report

**Date of Report:** August 11, 2017

**Final Report**

**Date of Work Plan Approval:** June 4, 2014

**Project Completion Date:** June 30, 2017

**Does this submission include an amendment request?** No

**PROJECT TITLE: Transitioning Minnesota Farms to Local Energy**

**Project Manager:** Michael Reese

**Organization:** University of Minnesota West Central Research and Outreach Center

**Mailing Address:** 46352 State Hwy 329

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**Location:**

The research and conference will be conducted in Stevens County. Two workshops will be held in southern Minnesota. The impact will be statewide.

| | | |
|---|---|---|
| **Total ENRTF Project Budget:** | **ENRTF Appropriation:** | **$500,000** |
| | **Amount Spent:** | **$429,012** |
| | **Balance:** | **$ 70,988** |

**Legal Citation:** M.L. 2014, Chp. 226, Sec. 2, Subd. 08d

**Appropriation Language:**
$500,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the West Central Research and Outreach Center in Morris to develop clean energy strategies for Minnesota farms in order to reduce fossil fuel energy use and increase local energy production. Any installation of infrastructure or improvements must be at the University of Minnesota West Central Research and Outreach Center. This appropriation is available until June 30, 2017, by which time the project must be completed and final products delivered.

**I. PROJECT TITLE: Transitioning Minnesota Farms to Local Energy**

**II. PROJECT STATEMENT:**

The University of Minnesota West Central Research and Outreach Center (WCROC) has a strategic goal to reduce fossil energy consumption within production agriculture. This project will leverage current efforts by further developing clean energy strategies for Minnesota swine farms. The 2008 MN Climate Change Advisory Group Final Report indicates agriculture contributes 14% of the total greenhouse gas emissions in the state; second only to electrical generation. Production agriculture's dependence on fossil energy carries significant economic and ecological risks. Current research at WCROC is focused on lowering the carbon footprint of grains and feeds through renewable synthetic fertilizer production and reduced field tillage. However, research is needed to optimize clean energy strategies for livestock facilities. According to the National Agricultural Statistic Service, Minnesota has 468,000 dairy cows and 7.8 million pigs (2012). The energy consumed within livestock facilities is the equivalent consumption of several large cities. Minnesota farmers historically have adopted technology to efficiently use resources and optimize production. However, implementation of clean energy technologies on farms has been extremely slow. In lieu of proven systems, farmers continue to opt for conventional fossil-based energy. Adoption of clean energy systems in crop and livestock production will position the State's agricultural sector to be globally competitive particularly as consumers are increasingly demanding low carbon footprint products. The overall project goals are to significantly decrease use of fossil energy, reduce carbon emissions within production agriculture, and to increase adoption of locally-produced renewable energy technologies. The project team proposes to evaluate applicability and implementation of clean energy technologies in swine production. The team will leverage current research by designing and testing integrated clean energy systems, conduct life cycle assessment, and provide producers with tested clean energy designs for swine facilities. Agricultural producers and secondary students will learn about clean energy strategies through research, demonstration, and hands-on learning experiences. Results from this project are anticipated to have a significant impact on transitioning commercial swine production facilities to locally produced, clean energy.

**III. PROJECT STATUS UPDATES:**

**Project Status as of January 1, 2015**:

The project is proceeding according to plan, but it has taken a little longer than planned to get all the electric usage data loggers installed in swine barns. All data loggers are now in operation. In addition to total barn electric, LP gas, diesel, and water usage, 76 individual electric loads are being monitored on 6 commercial barns. This data will be used to perform Life Cycle Analyses (LCA) of the various stages of pork production and inform an energy modeling study of swine barns with the goal of developing more efficient and economical energy systems.

By the next report, a solar PV array will be installed on the roof of one of the swine barns on the WCROC campus. Moreover, energy monitoring data collected on WCROC barns and commercial barns will begin to provide an unprecedented view of energy use in pork production.

**Project Status as of July 1, 2015:**

Energy monitoring in swine barns is continuing. Additional sensors and data loggers have been installed to resolve site specific uncertainties in the electricity usage. Data from these data loggers was presented at the 2015 Midwest Farm Energy Conference held at the WCROC from June 17$^{th}$ to the 19$^{th}$.

A contract has been initiated to model barns with energy efficiency measures (EEM) to determine what steps could be taken to reduce energy use in swine barns. This should be complete by the next reporting period.

A 27 kW solar PV system was installed on the roof of the finishing barn on the WCROC farm site. The system was interconnected to the utility grid on June 10$^{th}$, 2015.

**Project Status as of January 1, 2016:**
Commercial swine building energy monitoring is proceeding on schedule, although several additional sensors and data loggers were added into the buildings to resolve measurement discrepancies.

A contract for swine building energy modeling was executed with the AKF Group, an engineering and design firm with an office located in Minneapolis. Baseline energy models have been completed for three swine buildings on the WCROC campus. Models incorporating energy efficiency measures (EEM) in each building are underway and should be complete by the next reporting period.

Problems with the internet connection to the solar array inverters on the WCROC finishing barn were resolved to allow for more streamlined data collection.

The baseline life cycle assessment model is near completion with the next steps of adding actual energy and production data.

An initial course curriculum outline for secondary and technical students has been completed. The format will allow for the addition of results from this project.

**Project Status as of July 1, 2016:**
Commercial swine building energy monitoring continues to go well. There have, however, been power issues with several data loggers requiring replacement of the faulty loggers. Originally, 19 data loggers with 76 electric current sensors were installed in 6 commercial swine facilities to monitor electricity usage. It was hoped that the installed sensors would capture 70 to 80% of the total electricity usage in each facility, but there were several more circuits in some of the facilities than expected leaving an undesirably large amount of electricity usage unaccounted for. To remedy this situation, 11 data loggers and 44 current sensors have been added bringing the total to 30 data loggers with 120 sensors across all 6 facilities. There are an additional 3 data loggers with 48 current sensors installed in the three WCROC swine barns.

The AKF Group has completed analysis and modeling of energy efficiency measures (EEM) for all three barns (breed-to-wean, nursery, and finishing). An intern was hired for the summer of 2016 to complete Return on Investment (ROI) calculations for these EEMs, and has made progress on completing this task.

We have continued to monitor solar production from the WCROC finishing barn solar PV panels and an update on production has been included. A second intern was hired for the summer of 2016 to analyze and summarize the data from the WCROC finishing barn's solar array and analyze solar production compared to the electric load profile of the barn.

**Amendment Request (August 19, 2016):**
Additional funds, over what was originally budgeted, were used to purchase data loggers and AC current sensors for the swine energy monitoring project as part of the LCCMR grant to transition MN farms to local energy. There are three primary reasons that led to the unexpected expenses.

First, the commercial hog farms had complicated electrical systems often with several buildings being powered from a single electrical panel. Moreover, some of the facilities constructed new buildings during our monitoring period which were fed from the same panels and meters we are monitoring. These complications required several additional loggers and sensors to adequately monitor the electrical loads directly related to swine production and to subtract out the new building loads that are not a part of the production activities we are monitoring.

Second, several of the installed HOBO brand data loggers proved to be unreliable by running the batteries down prematurely. Some of these units just need more frequent battery replacement (the advertised battery life is longer than our monitoring period), but some needed to be replaced.

Finally, it was discovered that the primary meter for the nursery barn at the WCROC has been mislabeled on our electric bill for many years. In fact, there is no meter monitoring the nursery barn. A new logger and current sensor set was required to remedy this situation.

The costs associated with installation of the solar PV system for the swine facility came under budget by $24,105. These funds were originally requested if additional supports were necessary on the swine facility roof for mounting the solar system. The added supports were not necessary. Therefore, we request $12,000 be re-budgeted from this budget line to the “Equipment / Tools / Supplies” category with $6,000 each for the “Energy Meters” budget line and the “Data Loggers” budget line. A portion of this request is retroactive to the purchase date of additional meters, sensors, loggers, and similar components. The remaining balance will be used to cover the unforeseen need of battery and component replacement.

As a second request, we wish to re-budget the remaining $12,105 from the “Solar PV System” to the “Personnel” category and the “Junior Scientist” budget line. The collaborating swine producers have agreed to allow a second year of data collection at no-cost / no further stipend. The re-budget will allow us to retain the junior scientist to collect data from the commercial swine facilities on a continued basis.

**Amendment Approved by LCCMR 08/30/2016**

**Project Status as of January 1, 2017:**
Energy monitoring in commercial swine barns continues. No additional data loggers or sensors have been added to the commercial facilities. As a minimum, 70% of the total electricity usage in each facility is being measured. There were power issues with several loggers, again, requiring replacement of the faulty loggers. One additional sensor has been added to the WCROC farrowing barn to capture usage from a previously unmeasured circuit.

The AKF Group has completed the final report, “WCROC Swine Barn Energy Modeling Narrative”. The report contains final analysis and modeling of energy efficiency measures (EEMs) for all three WCROC swine barns. The intern hired for the summer of 2016 has completed Return on Investment (ROI) calculations for each EEM included in AKF’s final report.

Solar production from the WCROC finishing barn solar PV panels continues to be monitored and an update on production has been included. The intern hired for the summer of 2016 has analyzed and summarized data from the WCROC finishing barn’s solar array and compared it to the electric load profile of the barn.

Course curriculum for secondary and technical students continues to be developed. A planning committee has been established and dates have been set for the 2017 Midwest Farm Energy Conference which will be June 13th and 14th, 2017. The conference will showcase project results and energy systems to farmers and other agricultural and energy professionals.

**Amendment Request (January 30, 2017)**
An amendment is requested to the “Other” category within the budget. This requests only impacts Activity 4 and is re-budgeting funds from supporting conference transportation (buses) to other conference budget needs (printing and postage). We propose to reduce the budget for “Buses for the Ag Energy Conference” to $2,000, add a line “Postage for conference brochures and cards” with a budget of $1,800, and add $1,000 to “Publications and printing”. The conference planning committee has decided that three buses will not be necessary. For past conferences, we have needed three buses to transport participants to renewable energy sites away from the West Central Research and Outreach Center. The planning committee has decided this past

year that we will only be touring sites at the WCROC which means that one bus will be sufficient to move people back and forth. In addition, we will not be providing transportation with a bus from the Twin Cities as the committee did not feel this has been utilized enough in the past. Therefore, we are requesting postage and additional printing to cover costs of promoting the conference. Our contact listed has been greatly expanded over the past two and a half years since this project began so additional printing and postage is required beyond what was initially projected.

**Amendment Approved by LCCMR 02/06/2017**

**Overall Project Outcomes and Results:**
Agriculture production is a large industry within Minnesota and currently requires large amounts of imported fossil energy. The use of fossil energy for agriculture impacts the environment, air, water, and economy. The goal of this project was to provide swine producers with research-based information enabling the transition to clean, locally-produced energy. The project was organized into four tasks. The first task was to design clean energy systems for modern swine facilities. Research began by auditing energy consumption at six commercial swine production facilities as well as the University of Minnesota West Central Research and Outreach Center (WCROC). Commercial swine facilities included breed to wean, nursery, and finishing facilities. Baseline energy consumption data enabled researchers to prioritize high to low energy loads for each phase of production. Then an engineering firm analyzed several energy efficiency measures (EEM) appropriate for swine production. Return on Investments (ROI) were calculated for each EEM.

The second task, was to field test clean energy systems and develop effective control strategies. A 27 kW solar PV system was installed and tested on the WCROC swine finishing facility. On an annual basis, the system provided all energy consumed within the facility generating roughly 30,000 kWhr per year. Solar PV system ROIs were then modeled for commercial swine facilities including incentives available to swine producers.

Life Cycle Assessment was employed in Track 3 to identify areas where swine farm operations could be changed to improve the sustainability of the pork supply chain. LCA methodology was used to analyze the amount of fossil energy used by and carbon dioxide emitted during the swine production cycle. The specific goal of the work was to develop a model for understanding how energy use and greenhouse gas emissions could be reduced using conservation techniques or renewable electricity. Results indicated the Global Warming Potential (GWP) emissions in the broader swine lifecycle were highest for feed production, which accounted for almost 60% percent of fossil energy and 50% of greenhouse gas emissions. The fossil energy portion of the production system that can be directly controlled by the hog growers is producer is roughly 25% of the energy of producing pork. Renewable energy replacements for fossil based electricity, such as solar PV, can significantly lower fossil energy use for swine production.

Track 4 involved dissemination of results and education. The Midwest Farm Energy Conference was hosted at the WCROC in June 2017. Approximately 90 farmers and other guests participated in the event. Swine energy workshops were conducted in other regions of the State. Energy information was provided to producers, who in total, market over 3 million pigs per year and represent over 90% of the State’s annual production. In addition, energy curriculum was developed for agriculture and science educators teaching secondary and post-secondary technical students. The curriculum is being made available on-line. Additional materials including conference video and slide presentations can be accessed at https://wcroc.cfans.umn.edu/research-programs/renewable-energy.

**IV. PROJECT ACTIVITIES AND OUTCOMES:**

**ACTIVITY 1: Design clean energy systems for modern swine facilities**
**Description:** The team will utilize the model swine facilities at the WCROC to determine baseline energy use. An engineering firm with experience in modeling and incorporating clean energy systems will use the

information to recommend clean energy systems and rank them based on energy savings and / or return on investment. The engineering firm will complete designs incorporating thermal and electrical energy systems into swine facilities.

Most pork production systems consist of three distinct phases: breeding-to-wean, nursery, and finishing. The breeding-to-wean phase includes adult sows that are mated, housed during pregnancy, give birth to piglets, and raise piglets to weaning age of about 21 days. When piglets are weaned, they are moved to the nursery phase. The nursery phase entails raising a piglet from 3 weeks of age (about 12 lb body weight) to 9 weeks of age (about 50 lb body weight). At the end of the nursery phase, pigs are moved to the finishing phase which houses the pig until about 25 weeks of age (265 lb body weight) when they are marketed. In some production systems, the nursery and finishing phases are combined. During each phase of production (breed-to-wean, nursery, finishing), pigs have very different requirements for the ideal environmental temperature which demands very different inputs of fossil fuels. Previous researchers (Lammers et al. 2010, 2012) have reported the energy use for pork production systems in the Upper Midwest region of the U.S. However, these researchers relied solely on data from the scientific literature to estimate energy use in a variety of pork production systems. They never actually measured the energy consumption of operating, commercial pork production systems.

The study proposed herein will provide actual energy consumption data for commercial pork production systems. The data will be invaluable to our group and other researchers that seek to improve the energy efficiency of pork production systems. We propose to monitor the energy consumption of operating, commercial pork production systems for one calendar year. One year of monitoring is essential to understand influences of seasons and weather patterns on energy use in commercial systems. We will identify commercial pork producers that operate swine facilities that are characteristic of production systems in Minnesota. We will select 2 breed-to-wean, 2 nursery, and 2 finishing farms for monitoring. At each farm, we will record monthly the consumption of electricity and heating fuel. Electric metering / sensing devices will be installed at each farm to record the total amount of electricity used by the farm. Most farms use liquid propane to heat their buildings so we will record the gallons of liquid propane used each month. In some cases, natural gas may be used to heat barns. In those cases, we will use their existing gas meter to record monthly consumption. In addition, we will record monthly inventory of pigs in the building and monthly output of pigs from the farm. The pig outputs on the breed-to-wean farms will be weaned piglets and cull sows. The pig outputs in the nursery phase are the number of pigs moved to finishing and the pig outputs from the finishing phase are the number of pigs marketed for harvest. In addition, we will collect monthly weather conditions from the NOAA weather observation site closest to each pig production farm that we are monitoring.

Based on the analysis of the data, the AKF Group (or an equivalent firm) will model clean energy alternatives for conventional Minnesota swine facilities and will assist in projecting Return-on-Investment for the clean energy systems. As a full service consulting engineering company, the Minneapolis office of the AKF Group has considerable experience in energy design and modeling. AFK has specific experience modeling the variable energy production of on-site renewable energy systems and then matching the generation technologies to the loads. The engineering firm will utilize the baseline energy consumption data measured at the WCROC and on-farm swine facilities to model energy-optimized retrofits. The project team will direct an undergraduate student intern to project the Return-on-Investment (ROI) for a suite of energy-optimized retrofits. The student will also evaluate the impact of Minnesota's new solar incentives on the ROI for producers.

Within the model, potentially all energy loads may be converted to electricity and these loads will be made as small as possible with efficiency upgrades. Eventually, on-site renewable electric generation could supply some or the entire electric load allowing the buildings to approach net-zero (producing as much energy as is used). For example, the swine nursery at the WCROC is representative of current industry practices and uses about 12,000 kWh of electricity and 7,500 therms of natural gas per year. The largest energy load in a nursery is space heating due to the small size of the pigs. In fact, some heating is often required even in the summertime. Heating loads can be efficiently converted to electricity by using a heat pump which has a Coefficient of

Performance (COP) of about 2.5 in a Minnesota climate. The natural gas used in the nursery (7,500 therms) delivers about 132,000 kWh of actual heating energy assuming a 60% efficient furnace. This study will investigate potential heat sources for the heat pump including the ground and air, as well as other unconventional sources like manure lagoons. A heat pump will require about 53,000 kWh of electrical energy to replace the current gas furnaces. One of the goals of the study will be to see if enough energy savings can be obtained to make a building's energy usage less than what can be produced on the roof of that building with a solar PV system. Additional generation could be provided by a small-scale wind turbine or ground mounted solar PV array.

A finishing barn does not have a significant heating load, but does require cooling (even in winter). Cooling is usually accomplished with large amounts of ventilation. Another possibility that will be investigated is using an air source heat pump to provide cooling using chilled beams. Chilled beams are an efficient way to cool a space, but require careful management of humidity to prevent condensation on the beams. Condensation is probably not an issue in a pig barn and may even provide more cooling by dripping water on the pigs. An advantage of chilled beams is they can be installed into existing barns without altering the existing ventilation system and do not place delicate cooling coils in the harsh environment of a pig barn. Cooling may even enhance pig performance on hot days and cooling loads naturally coincide with high solar resource days. One of the questions that will be answered with this study is whether or not the energy needed to provide cooling can be offset by reduced ventilation demands.

Finally, the engineering firm will provide professionally engineered design for installing a 20 kW solar PV system at the West Central Research and Outreach Center swine facilities. Efforts will be made to standardize the design of the solar installation as it potentially may then be utilized for similar on-farm swine facilities. The use of solar photovoltaic (PV) systems is a logical choice to performance test for the production of electrical energy for swine facilities. Standard swine buildings are generally configured in an east to west layout providing an almost ideal southern exposed roof. In addition, new solar PV programs were put in statute during the 2013 Minnesota Legislative Session. Combined with the availability of federal USDA REAP grants and declining costs for solar PV, swine producers may be able to cost effectively generate electricity to meet their load requirements. Solar PV also has peak production capacity during hot summer days which also matches high-energy load times for swine facilities (ventilation and water pumping).

| **Summary Budget Information for Activity 1:** | **ENRTF Budget:** | **$ 186,444** |
|---|---|---|
| | **Amount Spent:** | **$ 159,539** |
| | **Balance:** | **$ 26,905** |

**Activity Completion Date:** August 31, 2015

| **Outcome** | **Completion Date** | **Budget** |
|---|---|---|
| **1.** *Install energy meters at the swine facilities and record energy consumption data for one year* | 7/30/2015 | $109,939 |
| **2.** *Model clean energy alternatives for Minnesota swine facilities and project return-on-investment* | 7/30/2015 | $39,058 |
| **3.** *Complete designs of clean energy systems for field testing at the WCROC swine facilities* | 8/31/2015 | $37,447 |

**Activity Status as of January 1, 2015:**

To begin the research, protocols were established to monitor the WCROC and on-farm swine facilities. A junior scientist was hired on November 3rd to help with installation and monitoring of data logging equipment in swine barns. Since then, all 6 commercial monitoring sites have been selected (2 sow/farrowing units, 2 nurseries, and 2 finishing units) and energy sensors have been installed and are in operation. Additionally, 3 barns on the WCROC campus have been instrumented and data is being recorded. The goal is to collect data for a full year to capture any seasonal variations in energy usage. Monitoring will, therefore, need to be extended through December of 2015.

Arrangements have been made with barn owners to collect purchase records for other energy sources used in the barns like propane and diesel. Water consumption will also be monitored where meters are present or estimated from well electricity sensors where meters are not present. Barn owner pig inventory records will also be provided so energy use can be calculated on a per pig or per pound of pork basis. This information will be the basis of Life Cycle Analyses to be conducted under Activity 3.

The data gathered will also provide the baseline case to be used in the modeling study conducted by AKF. The contract for AKF is in final negotiations so the study should be completed on time.

**Activity Status as of July 1, 2015:**
Energy monitoring on six commercial farms continues, but there have been unique circumstances on four of the six barns that have required additional sensors. For example, one of the commercial sow units completed construction on a gilt development unit (GDU) on the same site early in our monitoring period. The GDU draws electricity from the monitored sow unit so additional sensors were required to measure the GDU usage so it could be subtracted from the total sow unit usage. Another interesting discovery is that most commercial swine barns have a back-up electric generator with an electric oil heater running year round. These heaters use a surprising amount of electricity requiring additional monitoring or accounting. It is also common for farmers to use portable electric heaters to supplement heat in offices and other areas where water lines might freeze. These are the kind of discoveries that were expected, but they have required modifications to the monitoring plan which will extend the time it takes to get a full year of data. Examples of initial results are presented in Attachment Figures 3 and 4.

The contract to model swine barns including energy efficiency measures (EEM's) has been initiated with AKF Group in Minneapolis. The final report including recommendations for the best facility modifications and clean energy options should be complete by September of this year.

**Activity Status as of January 1, 2016:**
<u>Commercial swine barn energy monitoring</u>: Both breed to wean facilities added a Gilt Development Unit (GDU) to develop their own breeding sows. However both GDUs use the same utility electric meter as their respective existing facilities - the same meters being used to monitor the total electrical usage at the breed to wean barns for this project. Additional data loggers and sensors were installed to measure the electrical energy passing through the main feeds to both GDUs so it could be subtracted from the meter readings. Additional sensors were also added to several barns to better measure some of the miscellaneous loads like storage room heaters and lights, office equipment, water heaters for worker showers, and heat and air conditioning in office areas because the total size of the unmeasured, miscellaneous load was larger than expected. The additional sensors have resulted in much higher ratios of monitored loads to total metered loads. Ratios of monitored loads range from about 75% in the sow units to over 90% at the finish units. The sow units are very large, complex facilities requiring a lot of workers and continuous effort breeding and caring for the needs of sows as well as the needs of piglets which are being born daily. By comparison, finishing units are much simpler with pigs being housed in group pens for several months needing relatively little human care thanks to automatic feed augers and waterers. Therefore it is expected that there will be more unmeasured miscellaneous loads at the sow facilities than at the finish facilities with the nurseries falling somewhere in the middle. Monitoring will continue through the next reporting period. Data analysis will also continue with the final report containing a summary of all the data from all the barns.

<u>Energy modeling of swine barns</u>: AKF has completed the initial energy model for each type of swine facility – breed to wean, nursery, and finish. The models account for the building geometry, construction materials, energy infrastructure, and management practices. Also, a preliminary decision matrix has been created listing

possible energy efficiency measures (EEM) for each barn type with pros, cons, and relative cost opinions. The next stage of modeling will incorporate the selected EEM's to predict potential energy savings and obtain engineering cost estimates so an economic analysis can be completed as well.

**Activity Status as of July 1, 2016:**

Commercial swine building energy monitoring: Miscellaneous and unknown loads from the commercial barns have been pinpointed, so there is a good grasp on each of the commercial building as a whole in regards to where electricity is being used. As it would be cost prohibitive to purchase more data loggers and sensors to capture 100% of the use in each building, it has been determined where miscellaneous energy is being used by moving sensors around to capture the use of different, miscellaneous loads in these large facilities. At the sow units, electrical energy captured has increased to closer to 80% of the total electrical energy being used. At the nurseries, 70-80% of the energy is being captured; and at the finishing units, 80-90% of energy is being captured by data loggers and sensors. The electrical and thermal data collected from the barns has been analyzed on a per pig basis to obtain preliminary estimates of the amount of electrical energy used and the electrical cost to produce one pig. Electrical, thermal, water, and pig inventory data will continue to be collected on a monthly basis, and the final report is continually being updated with analyzed data. We have been granted permission from the producers to continue to monitor energy use in their facilities until the spring of 2017, allowing us to obtain more consumption data from a second fall and winter.

Energy modeling of swine barns: The AKF Group has completed their final draft on energy efficient measures (EEMs) and it is currently being reviewed by University staff. AKF's final report will be included in the next update. Cost analysis of these retrofits, annual energy savings, and pros and cons for each EEM are included in the draft report. An intern was hired for the summer of 2016 and is performing a Return on Investment (ROI) analysis for each EEM outlined in the model. The intern is also working to evaluate the impact of Minnesota's solar incentives on the ROI.

**Activity Status as of January 1, 2017:**

Commercial swine building energy monitoring: Electrical energy use captured by installed data loggers remains at 80% in the large commercial sow units, 70-80% in the nurseries, and 80-90% in the finishing barns. The electrical and thermal data collected from the barns has been analyzed on a per pig basis to obtain preliminary estimates of the amount of electrical and thermal energy used and the electrical and thermal cost to produce one pig. The chart below provides preliminary data for the electrical and thermal costs to produce one pig in 2015. Electrical, thermal, water, and pig inventory data will continue to be collected on a monthly basis, and will be included in the final report.

| Preliminary 2015 Electric and Thermal Cost to Produce One Pig | | | | | |
|---|---|---|---|---|---|
| Barn | kWh | Cost in electricity | Gallons of propane | Cost in propane | Total energy cost |
| BW2 | 11.4 | $1.14 | 0.34 | $0.41 | $1.55 |
| BW6 | 12.2 | $1.22 | 0.31 | $0.37 | $1.59 |
| N3 | 2.3 | $0.23 | 0.43 | $0.52 | $0.75 |
| N7 | 2.1 | $0.21 | 0.41 | $0.49 | $0.70 |
| F4 | 15.4 | $1.54 | 0.25 | $0.30 | $1.84 |
| F5 | 3.1 | $0.31 | 0.34 | $0.41 | $0.72 |

BW= Breed-to-wean, N=Nursery, and F=Finishing

Energy modeling of swine barns: The AKF Group has completed the final report which has been reviewed by University staff. The report, entitled, "WCROC Swine Barn Energy Modeling Narrative", includes cost analysis of the retrofits, annual energy savings, and pros and cons for each EEM in all three WCROC swine barns. AKF's final report is attached to this report. The intern hired for the summer of 2016 completed Return on Investment (ROI) calculations for each EEM included in AKF's final report. As a requirement of the internship, a research paper was completed and a public presentation was given in August, 2016.

**Final Report Summary:**

**Install energy meters at the swine facilities and record energy consumption data for one year**

Understanding energy consumption in conventional swine production facilities is the first critical step towards improving energy systems. Energy monitoring of commercial swine production facilities was performed from November 2014 to April 2017 which was essential in understanding the influences of seasons and patterns on energy usage. To collect baseline energy data, two commercial facilities from west central Minnesota that are representative of typical Upper Midwest swine production systems were selected from each phase of production (Table 1.): two breed-to-wean barns (BWA & BWB), two nursery barns (NBA & NBB), and two finishing barns (FBA & FBB). At each of these facilities, researchers recorded and analyzed monthly consumption of electricity and heating fuel. In addition, monthly pig inventories and monthly pig production of each facility were recorded. All barns were located in west central Minnesota.

*Facility Information*

Breed-to-Wean Barn A (BWA) was a 2,600 sow facility. The farrowing and north gestation rooms in this barn were power-ventilated, while the south sow gestation rooms were curtain-sided with stirring fans for air movement. The floors were fully slatted with shallow manure pits and scrapers for manure management. The north gestation room consisted of 763 stalls and 8 pens. The south east gestation room consisted of 756 stalls, and the south west gestation room consisted of 612 stalls. The north farrowing barn consisted of four rooms with 52 stalls in each room, which were identical in size, structure, and electrical loads. The south farrowing barn was different than the aforementioned barn and was made up of 9 rooms with 24 stalls in each room. The 9 rooms in the south barn were identical in size, structure, and electrical loads. There were several miscellaneous rooms within the unit used for pressure washers, mechanical rooms, wash rooms, and storage rooms. The unit had a central office area with showers, bathrooms, laundry area, and a kitchen. Lastly, an additional gilt developer unit (GDU) was commissioned during January of 2015 and was dedicated to providing replacement gilts to the main sow unit.

Breed-to-Wean Barn B (BWB) was a 3,300 sow facility. The farrowing rooms in this facility were power-ventilated, and the gestation room was tunnel-ventilated in the summer and power-ventilated in the winter. The floors were fully slatted over deep manure pits for manure management. There were 10 farrowing rooms which were identical in size, structure, and electrical loads. Each room consisted of 48 farrowing stalls. There was one additional farrowing room that was half the size of the other rooms and consisted of 24 stalls. The unit had several miscellaneous rooms that served as a pressure washer room, storage rooms, work room, and refrigerator and wash rooms. The unit had a central office area with showers, bathrooms, laundry area, and a kitchen. During late June of 2015, a new GDU was added to provide replacement gilts for the main gestation unit.

Nursery Barn A (NBA) was a 3,000 head, power-ventilated facility. There were 3 nursery rooms that housed 1,000 pigs each and had fully-slatted floors and were identical in size, structure, and electrical loads. The unit also consisted of a load out and storage area, office and laundry area, and shower room.

Nursery Barn B (NBB) was a 10,200 head, power-ventilated facility. There were 8 nursery rooms that housed 1,000 pigs each and had fully-slatted floors and were identical in size, structure, and electrical loads. There were two additional 1,100 head nursery rooms which also had fully-slatted floors and were identical to each other in size, structure, and electrical loads. The unit had several miscellaneous rooms including a pressure washer room, mechanical room, and storage room. There was also a central office area which had showers, a bathroom, laundry area, and kitchen.

Finishing Barn A (FBA) was a 2,400 head, tunnel-ventilated facility. There were 2 finishing rooms that housed 1,200 pigs each and had fully-slatted floors and were identical in size, structure, and electrical loads. The unit also consisted of a load out and storage area, office and laundry area, and shower room.

Finishing Barn B (FBB) was a 1,060 head, curtain-sided facility. There were 2 finishing rooms that housed 530 pigs each and had fully-slatted floors and were identical in size and structure and consisted of the same electrical loads. The unit also had a central storage room and pressure washer room and a load out hallway.

Table 1. Commercial swine barn details

| Barn | Barn Capacity | Barn Type |
|---|---|---|
| Breed-to-Wean Barn A (BWA) | 2,600 sows | Power-ventilated farrowing and north gestation rooms, curtain-sided south gestation rooms |
| Breed-to-Wean Barn B (BWB) | 3,300 sows | Power-ventilated farrowing rooms and tunnel/power-ventilated gestation room |
| Nursery Barn A (NBA) | 3,000 feeder pigs | Power-ventilated |
| Nursery Barn B (NBB) | 10,000 feeder pigs | Power-ventilated |
| Finishing Barn A (FBA) | 2,400 finishing pigs | Tunnel-ventilated |
| Finishing Barn B (FBB) | 1,060 finishing pigs | Curtain-sided |


Figure 1. An example of a power-ventilated

Figure 2. An example of a curtain-sided pig barn.

*Biosecurity*

Preventing the introduction of potentially devastating disease agents has always been a challenge for pork producers. Typically, strict biosecurity programs are put into effect on pig farms to maintain the health and welfare of the swine and to protect the farmer's financial interests. Renewable energy scientists from the University of Minnesota West Central Research and Outreach Center (WCROC) followed the biosecurity protocols for all commercial facilities and complied with any adjustments throughout the monitoring period. Most breed-to-wean, nursery, and finishing facilities are operated on a continuous basis, therefore they always contain pigs of different ages and weights. To combat the spreading of diseases and sicknesses through a production system, producers follow an All-In/All-Out (AIAO) production method which involves grouping pigs of similar age and weight together. Pigs are farrowed in specific rooms. Weaned pigs from each specific room are kept together and moved to a nursery room and eventually to a finishing room without commingling pigs from other rooms. Marketing is done one room at a time, and rooms are pressure washed and disinfected between groups of pigs to minimize the transmission of disease and sickness (Clark et al., 1995).

*Data collection*

In each swine facility, data were collected from two general categories of energy used in pork production: electrical energy and thermal energy provided by heating fuel (propane or natural gas).

*Electrical Energy*

In this study, we measured energy of loads directly related to the pigs. However, to determine if an adequate amount of these loads were being monitored, researchers compared the monthly data recorded by sensors located in the barn (in kilowatt hours) to the electricity provider's billed kilowatt hours used per month. In some facilities where the collected data were not representative of the entire barn, we measured loads that were not directly related to pigs, such as outbuildings not related to the production units, but powered from the same utility meter. Researchers monitored these circuits separately to subtract the usage of these outbuilding loads from the swine barn data.

For BWA and BWB, gilt development units (GDUs) were added in 2015 after monitoring of the barns began. A GDU supports breed-to-wean units but is not directly involved in weaned pig production. So, electrical and thermal energy used in these units was subtracted from the total use of the breed-to-wean barns.
Stand-alone HOBO (HOBO UX120-006M, Onset Computer Corporation, Bourne, MA) data loggers were installed to monitor key individual electric loads. These loads were chosen based on categories known to consume the most energy (e.g. ventilation fans, heat lamps, feed lines) and other loads that are representative of swine production systems (see Table 2). Electrical energy monitoring required access to the barn's circuit breaker boxes to install the data loggers and apply current sensors to specific loads. No wiring was added or altered, and the current sensors simply snapped around existing electrical wiring (Figure 4). CR Magnetic CR9580-10, 20, and 50 ampere (amp) sensors (CR Magnetics, St. Louis, MO) were connected to input adapter cables (CABLE-ADAP10, Onset Computer Corporation, Bourne, MA) using wire nuts and were then plugged into one of the 4 available channels in the data logger. Magnelab DCT 25, 50, 100, 250, and 500 amp sensors (Magnelab Inc., Longmont, CO) were also used. The Magnelab sensors connected directly to input adapter cables which were then plugged into the data logger. The adapter cables were strung through cable gland joints which were installed on the side of the electrical box and the data loggers attached to the side of the boxes using magnets (Figure 5). The self-powered, split core current sensors generate a 0-5 volts direct current (DC) signal proportional to the input alternating current (AC) current. The output signal is average sensing (as instantaneous power varies from one moment to the next) and calibrated to Root Mean Square (RMS) (CR Magnetics).
Each data logger was programmed to collect a current reading every 30 seconds and an average recording from each 30 second recording was stored on the logger every 10 minutes. Data was collected using a laptop equipped with "HOBOware" software (HOBOware Pro Version 3, Onset Computer Corporation, Bourne, MA) and a USB cable connecting the data logger to the laptop. The data were collected monthly and exported from the HOBOware Program into Microsoft Excel (2013). Each 10 minute average value of electric current was converted into power using the power equation described below and multiplied by 1/6 of an hour to determine energy usage in kilowatt hours. The resulting 10 minute average energy usage values were then summed for each load each day to obtain a total energy usage per day.

The measured current is used to calculate the power (kilowatts) and energy (kilowatt hours) consumed by the measured load using the following equation (U.S. Department of Energy, 2001):

$$P = V * I * \ phase * PF$$

Where: *P*= Power in watts

*V*= Voltage, line to ground, in volts

*I*= Current, on one phase, in Amperes (Amps)

*Phase*= Number of phases in the circuit, unitless

*PF*= Power Factor, unitless

An instantaneous power measurement requires instantaneous measurement of the current and voltage on all phases of the supply lines to every load measured. This would require 6 sensors on a three phase load and would make the number of sensors and data loggers needed for a typical barn cost prohibitive. Several reasonable assumptions were made to simplify the measurement set-up without significantly sacrificing measurement accuracy.

In calculating power, it is important that the voltage is measured between one phase line and neutral. The voltage was measured once when the sensors were installed and was considered to remain constant. This is a reasonable assumption since supply voltage changes very little in a properly wired electrical system. Multi-phase loads were assumed to be balanced meaning the same amount of current flows in each phase line. All multi-phase loads measured in the swine barns were AC motors which, theoretically, produce balanced loads. Assuming balanced loads means only one current sensor is required for each load and that the measured current is multiplied by the number of phase lines to calculate the total current.

The final element in the power equation is the power factor (PF) which varies between zero and one. A purely resistive load like a heating element or incandescent light bulb has a power factor equal to one. An AC motor has a power factor that varies with the load on the motor; higher loading produces a higher power factor. The power factor accounts for the fact that some of the supplied power to a motor is not consumed by the motor, but instead creates the magnetic field that allows the motor to operate. Adding the power factor to the power equation allows the calculation of the power actually consumed by the motor. Operating motors at a low power factor is undesirable, so motors are typically sized so they are at least 70% loaded under normal conditions. A study by the U.S. Department of Energy (U.S. Department of Energy, 1997) shows that a typical motor loaded between 70% and 100% of its rated load will operate with a power factor generally between 80% and 90%. For this study the power factor of all motor loads was set at 85%. These assumptions allow a reasonable estimate of power consumption with a manageable amount of sensor and data logging equipment. . The power factor of loads which had mixed resistive and inductive loads combined into one sensor, for example when measuring a whole electric sub feed panel, were estimated based on the ratio of resistive to inductive loads within the sensor.

Additionally, as measuring the current on all of the loads in each barn was not feasible, other assumptions were made to compare the utility meter data to data collected by researchers. In each barn in this study, the loads from only one whole room in the facility were measured. There were 2 to 11 identically sized rooms within a facility, each containing identical loads. The data recorded from the loads in the measured room were multiplied by the appropriate number of identical loads in the other rooms in the barn. Pig flow through each barn is a continuous process with each period or turn occurring multiple times per year in each room. Therefore, the energy used by each load in a monitored room is representative of all other similar rooms in the facility on an annual basis even though the actual size and weight of pigs is not the same in each room at any given time. Thirty four total data loggers were installed and 133 total loads were monitored across all 6 commercial swine barns.

*Equipment uses*

<u>Feed system</u>- actuators are a component of a feedline which control the switching on of motors within the feed system to move feed down the line. Feedline motors and feed auger motors are used to move pig feed from feed bins, down the feedline, and into pig feeders. The horsepower (HP) of these motors typically range from 1/4 HP to 2 HP.

<u>Lighting</u>- lighting is used in all areas of a barn. The way lights are used varies across each individual facility due to management practices. Lights might be left on all day in some barns or only used for a short amount of time in other barns. The type of lighting can vary across barns as well. For example, in BWA, compact fluorescent lights (CFLs) were used, whereas light-emitting diodes (LEDs) were used in BWB.

<u>Ventilation</u>- one of the most important components of all pig barns, mechanical ventilation can include different types of fans which can serve different purposes. Ventilation systems are used to control the moisture and heat produced by the animals in the barn. In addition, ventilation systems remove air contaminants produced from manure, feed, and the pigs themselves (Jacobson, 2004). Basket/stirring fans are typically hung inside a room and are used for supplemental cooling and air distribution. Pit fans are mounted on manure pit access ports of deep-pitted barns to remove gases generated by manure. Pit fans are typically used for minimum ventilation. Wall/exhaust fans are used to exchange the desired amount of air in a pig housing unit (Jacobson, 2004). The

primary function of a cool cell is to cool the pigs, and air needs to be drawn through the cool cell by ventilation fans. Therefore, cool cells are part of a ventilation system. Cooling cells work by evaporating water into incoming air which decreases the incoming air temperature.
Manure system- there are different ways in which producers manage their manure. Monitoring in this study included under-slat manure scrapers, which push the manure into a storage system. Water pumps are used to flush shallow manure pits into a manure storage system. Lift pumps are used to lift slurry from the facility into a manure storage system.
Heat (for pigs)- heaters for pig rooms consist of propane, or in some instances, natural gas- fired heaters. The electric load being measured is the heater fan.
Pressure washer- pressure washers are used to clean rooms after a group of pigs has left the room. This minimizes the spread of disease and sickness through the production system.
Curtains- although this is a form of ventilation, curtain ventilation is different than mechanical ventilation, as buoyancy and wind forces are used to naturally ventilate the barn. Curtains can be adjusted to let more outside air through the barn while using minimal electricity.
Heat lamps- as piglets require higher temperatures, especially during the first several days after birth, heat lamps are typically used in breed-to-wean barns to provide supplemental heating. Heat lamps can range from 100 watt bulbs to 250 watt bulbs, depending on management style of the barn.
Controllers- controllers in pig barns rely on sensors in the pig rooms to provide optimal environmental conditions for pigs. Controllers regulate ventilation, heating, and humidity within a room.
Office (human use)- office use includes electrical loads such as space heaters, washing and drying machines for clothes, refrigerators, computers, stoves, lighting, bathroom and shower rooms, water heaters, etc.
Gilt developer- gilt developer units (GDUs) are facilities dedicated to raising replacement females for the sow herd. In the case of both breed-to-wean barns in this study, GDUs were located on the same site. However, the GDUs were managed separately from the breed-to-wean units and could therefore be monitored separately from the sow unit.
Miscellaneous loads- miscellaneous loads included hallway heaters and lights, workrooms, storage rooms, etc.

*Thermal energy*

For the purpose of this study, data from both electrical and heating fuel consumption was obtained. Heating fuel consumption was obtained from the producer's records and receipts from gas utility companies. Each of the six commercial buildings used propane to heat their buildings and pressure wash. However, BWA and NBA switched from propane to natural gas during the summer of 2016 and FBB used diesel for pressure washing. At each swine facility, propane tank fill reports and natural gas consumption reports were obtained from the producers and analyzed to observe monthly and yearly use. Due to fluctuations of oil prices throughout the year and variations in costs to each barn, the yearly average price of propane across the six commercial barns was $1.21 per gallon in 2015 and $1.20 per gallon in 2016. These costs were used to calculate the cost of propane per pig produced.

*Pig inventories*

Monthly pig inventories were reported by each producer, because these numbers can drastically affect energy used in the barn and help in identifying daily routines in the barn. Pig production records were also collected to calculate amount of energy (both electric and thermal) used to produce one pig from each phase of production.

***Swine Energy Audit Results and Discussion***

The overarching goal of this commercial swine energy monitoring project was to understand how much energy is used to produce weaned piglets, feeder pigs, and market weight hogs, and to determine where, specifically, that energy is used within each production stage. This energy use data can then point to areas where both cost and energy consumption might be reduced.

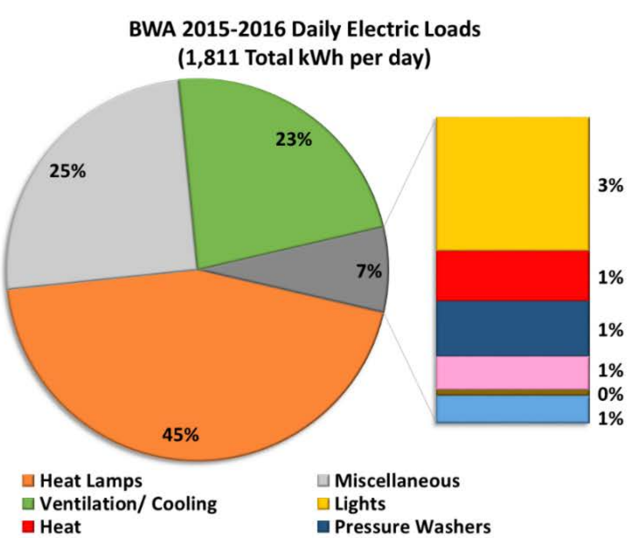
*Breed-to-Wean Barn A and Breed-to-Wean Barn B (BWA and BWB)*

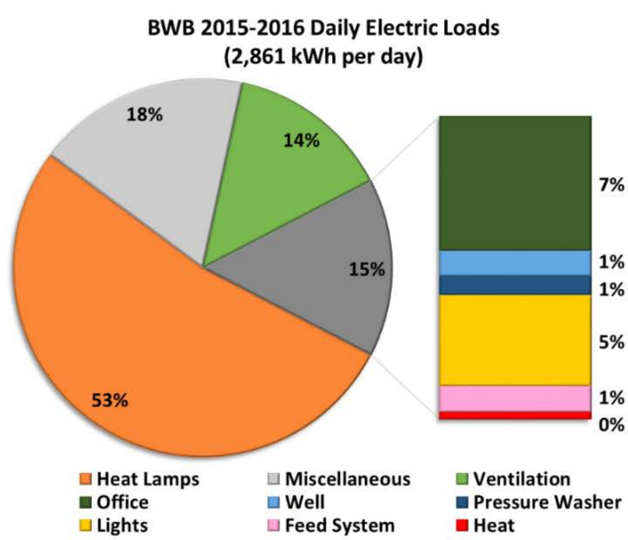
Electric and thermal energy was calculated using $ .10/kWh for both years (average price per kWh across the Midwest) and $1.21/gal in 2015 and $1.20/gal in 2016 (using the average price per gallon across all units in this study). The kWh used per pig and the associated costs per pig remain fairly constant over the course of both 2015 and 2016 (Table 3). This can be expected, as electricity is used to maintain production and facility management throughout the building and to power fixed and constant loads. Both facilities used comparable amounts of electrical energy to produce one weaned piglet, regardless of barn size and structure.

The daily average electricity distribution across loads in BWA and BWB is shown in Figures 6 and 7. The largest electric load across both units were heat lamps followed by miscellaneous loads. Heat lamps accounted for about 50% of the total electricity used in each facility. Miscellaneous loads are the difference between the facility utility electric meter and the total of all loads monitored during this study. As these breed-to-wean units were extensive in size and complexity, it was simply not feasible to have sensors installed on every single load within the unit. Loads in the miscellaneous category are comprised of loads not directly related to pig care such as hallway heaters and lights, workroom heaters and lights, storage rooms, etc.

Table 3. Electric and thermal consumption and total costs per weaned pig produced.

| Year | Barn | Total pigs weaned | Total electricity used by facility (kWh) | kWh/ pig | $ electricity/ pig | Total propane used by facility (gal.) | Gal. propane/ pig | $ propane/ pig | Total energy cost/pig |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | BWA | 57,965 | 658,558 | 11.36 | $1.14 | 19,668 | 0.34 | $0.41 | $1.55 |
| | BWB | 85,874 | 1,045,541 | 12.18 | $1.22 | 27,016 | 0.31 | $0.38 | $1.60 |
| 2016 | BWA | 58,872 | 663,751 | 11.27 | $1.13 | 4,168 | 0.07 | $0.09 | $1.29 |
| | BWB | 89,469 | 1,043,038 | 11.66 | $1.17 | 27,008 | 0.30 | $0.36 | $1.53 |




Figures 6 and 7. The average daily electricity use across electrical loads in BWA and BWB.

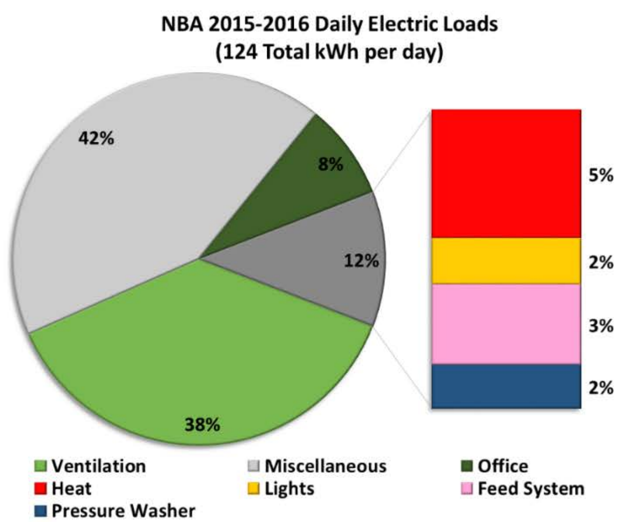
*Nursery Barn A and Nursery Barn B (NBA and NBB)* Electric and Thermal Energy Summary

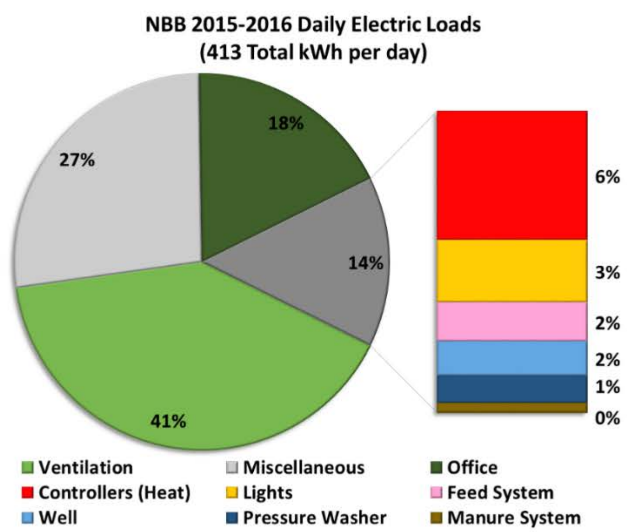
The kWh used per pig and the associated costs per pig remain fairly constant over the course of both 2015 and 2016 (Table 4). This can be expected, as electricity is used to maintain production and facility management throughout the building and to power fixed and constant loads. Both facilities used comparable amounts of electrical energy to produce one weaned piglet regardless of barn structure and, most notably, regardless of the fact that NBB was 4 times as large as NBA.

Table 4. Electric and thermal consumption and total costs per feeder pig produced.

| Year | Barn | Total feeders produced | Total electricity used by facility (kWh) | kWh /pig | $ electricity/ pig | Total propane used by facility (gal.) | Gal. propane / pig | $ propane / pig | Total energy cost/pig |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | NBA | 19,596 | 44,354 | 2.26 | $0.23 | 8,434 | 0.43 | $0.52 | $0.75 |
| | NBB | 71,522 | 157,313 | 2.20 | $0.22 | 31,175 | 0.44 | $0.53 | $0.75 |
| 2016 | NBA | 18,609 | 46,428 | 2.49 | $0.25 | 4,192 | 0.23 | $0.27 | $0.76 |
| | NBB | 71,778 | 143,882 | 2.00 | $0.20 | 26,975 | 0.38 | $0.45 | $0.65 |

The daily average electricity distribution across loads in NBA and NBB is shown in Figures 8 and 9. The largest electric load across both units was ventilation, which used about 40% of the electricity used by the whole unit. Miscellaneous loads used the second-most amount of electrical energy. Specifically, in NBA, there was an additional shed onsite which contained several smaller electrical loads and a back-up generator equipped with an engine block heater. Monitoring an engine block heater at another site revealed that a block heater can use a significant amount of electricity- up to 36 kWh per day.




Figures 8 and 9. The average daily electricity use across electrical loads in NBA and NBB.

<u>Finishing Barn A and Finishing Barn B (FBA and FBB) Electric and Thermal Energy Summary</u>

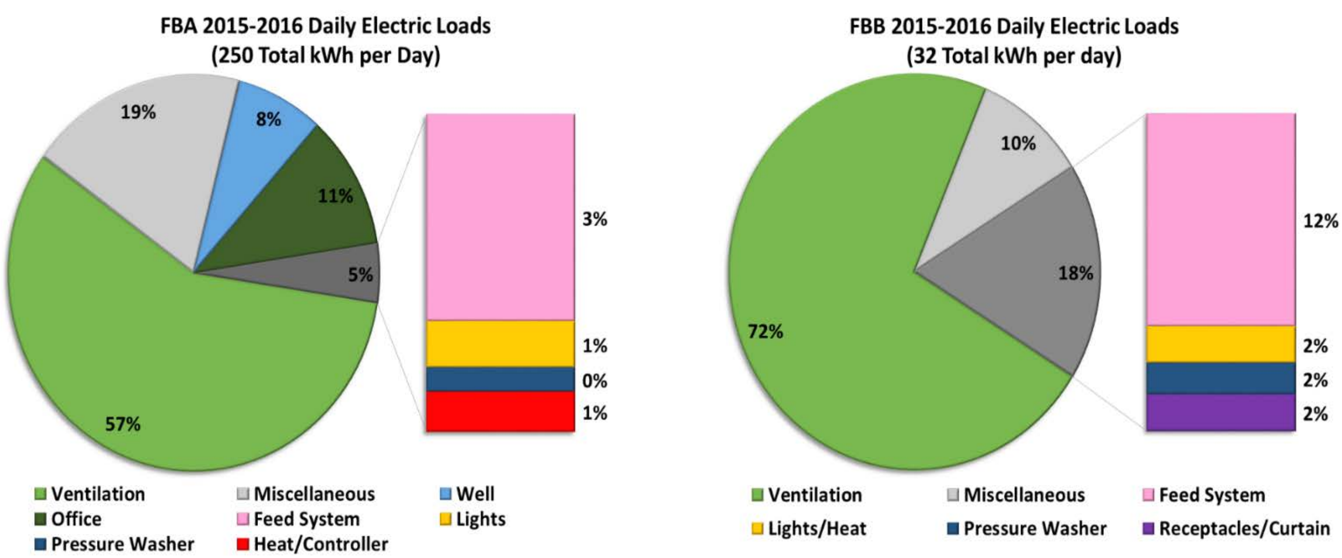
In comparing FBA and FBB (Table 5), a relatively large difference is seen in the electrical use of each barn. As FBA was a tunnel-ventilated barn and FBB was a curtain-sided barn, FBA was expected to use (proportionally) more electrical energy than FBB due to the increased ventilation requirements. There was also a slight rise in the amount of electricity used at FBB from 2015 to 2016. This can be attributed to the fact that during 2016, the pigs entered the barn at a lower weight which required heater fans to be used more to provide adequate heating for the smaller pigs. Another reason FBB saw a rise in electricity use was because from May 2015 to March 2016, one pit fan motor was not working. When the fan was fixed in March 2016, a rise in ventilation occurred. Comparing propane use of FBA and FBB in Table 5, FBB used slightly more propane per market pig than in FBA. This result was expected due to the fact that FBB was a curtain-sided barn, meaning there is typically less insulation on the curtains than there would be on a solid-walled barn such as FBA. Another result to note is that propane use in FBB was higher during 2016 than 2015. Again, propane use increased due to the fact that the pigs in this barn were placed in FBB when they were at a lower weight compared to 2015. The smaller pigs therefore required more heating to maintain pig performance and comfort.

Table 5. Electric and thermal consumption and total costs per finished pig produced.

| Year | Barn | Total Market Hogs produced | Total electricity used by facility (kWh) | kWh/pig | $ electricity / pig | Total propane used by facility (gal.) | Gal. propane / pig | $ propane / pig | Total energy cost/pig |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | FBA | 5,837 | 90,048 | 15.43 | $1.54 | 1,440 | 0.25 | $0.30 | $1.84 |
| | FBB | 2,970 | 9,282 | 3.13 | $0.31 | 996 | 0.34 | $0.41 | $0.72 |
| 2016 | FBA | 6,819 | 92,231 | 13.53 | $1.35 | 2,990 | 0.44 | $0.53 | $1.88 |
| | FBB | 2,655 | 13,928 | 5.25 | $0.52 | 1,695 | 0.64 | $0.77 | $1.29 |

*FBB used diesel to provide fuel to a pressure washer. As the diesel tank is located on the farm site and is used for other machinery, an estimate of 75 gallons of diesel per year was used by the pressure washer as estimated by the producer.

The daily average electricity distribution across loads in FBA and FBB is shown in Figures 10 and 11. The largest electric load across both units was ventilation, which used over 50% of the electricity used by the entire barn. In the case of FBA, there was an additional shed onsite which was powered from the same utility meter. The shed had several smaller electrical loads as well as a generator engine block heater. Through monitoring of an engine block heater on another site, researchers concluded that the block heater may have used a significant amount of electricity- up to 36 kWh per day if running all hours of the day (during winter, for example). We are confident that in both units, electrical energy used directly for the care of the pigs was adequately captured.




Figures 10 and 11. The average daily electricity use across electrical loads in FBA and FBB.

The objective of this study to provide actual baseline electric and thermal energy consumption within pork production systems in the Upper Midwest was accomplished. Previous studies have reported energy use within these systems, however, this is the first study of its kind to parcel out individual electric use past the utility meter. This unique aspect allows insight into where electrical energy is specifically being used within each phase of pork production and where there is potential to reduce usage.

The findings from this study are comparable to other industry reported measures. Anecdotal evidence from a breed-to-wean production system of 70,000 sows, indicates average electrical use per weaned pig was 9.7 kWh across the whole system. Units within this system ranged from 5 kWh to 12 kWh per weaned pig, the 5 kWh per weaned pig unit having put various efficiency measures into place. Comparing these industry findings to this study where results ranged from 11.27 to 12.18 kWh per weaned pig produced, the findings from this study are comparable with those of the previously mentioned measures. As electric energy was further parceled out among various loads within the breed-to-wean units, the findings of this study point to areas within barns where there is a potential to reduce usage such as in heat lamps, which were found to be the top users of electrical energy by far across breed-to-wean units.

Nursery findings from this study are also comparable to other industry measures. Brumm (2015) reported industry measures of about 1.8 kWh and 0.31 gallons of propane per feeder pig produced. These measures are comparable to our findings, which ranged from 2.0 kWh to 2.49 kWh per feeder pig produced and from 0.38 to 0.44 gallons of propane per feeder pig produced.

Finishing industry measures from Brumm, (2015) also report 11.2 kWh per finished pig produced in a tunnel-ventilated unit. Our findings, which ranged from 13.53 kWh to 15.43 kWh per finished pig produced in FBA, are comparable with the aforementioned measure. The differences may arise from several factors such as overventilation (especially during the winter), additional space heating, or geographical location.
All barns are unique based on barn size and structure, ventilation systems, manure systems, climate and geographical location and management style. Therefore, it was expected that there may be some differences within this study from unit to unit. However, differences are minimal, and we are fully confident that our results capture an accurate depiction of Midwest pork production units and point to areas with production phases where there is potential to reduce both electric and thermal energy consumption.

The complete swine energy audit report is included in the supporting documents.

**Swine Energy Audit References**

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**Model clean energy alternatives for Minnesota swine facilities and project return-on-investment**

The following swine energy modeling results are summarized from information developed by the AKF Group, the engineering firm that was commissioned for this task. The WCROC swine program consists of barns for each of the three major swine production stages. These barns are representative of typical commercial operations for gestation/farrowing, nursery, and finishing. The barns are located at the WCROC facility in Morris, MN.

AKF Group has prepared energy models to determine the energy cost impacts of the proposed design and renovations. The existing buildings were calibrated using owner provided energy use data as well as data collected from typical commercial barns serving the same functions. The calibrations are intended to represent the actual facilities at the WCROC with commercial production operating schedules. The calibrated models were then used to analyze the results of potential energy conservation measures (ECMs). The ECM’s were determined prior to developing the energy models using a decision matrix for each barn type.

The energy models used to estimate and compare annual energy consumption have been created with the software program eQUEST, version 3-64, using the DOE-2.2 simulation engine developed by the US Department of Energy. The program calculates building energy use on an hourly basis for 8,760 hours per year (full year) and utilizes typical meteorological year (TMY) weather data.

Table 6. Summary of Energy Conservation Measures Modeled for the WCROC Swine Facilities (AKF Group)

| ECM | Barn | Electrical Savings (kWh/yr) | Natural Gas Savings (therms/yr) | Propane Savings (gallons/yr) | Energy Savings (MBtu) | Energy Cost Savings ($) | Energy Cost Savings Propane ($/yr) | Installed Cost Opinion* ($) | Natural Gas Payback (yrs) | Propane Payback (yrs) |
|---|---|---|---|---|---|---|---|---|---|---|
| LED Lighting | | | | | | | | | | |
| | Nursery | 6,173 | (88) | (97) | 12.3 | 530 | 430 | 6,000 | 11.3 | 14.0 |
| Daylight Harvesting | | | | | | | | | | |
| | Nursery | 4,999 | (70) | (77) | 10 | 430 | 351 | 1,500 | 3.5 | 4.3 |
| Solar Chimney | | | | | | | | | | |
| | Nursery | 2,100 | - | - | 7.2 | 202 | 202 | 6,000 | 29.7 | 29.7 |
| Curtain Sided Barn | | | | | | | | | | |
| | Finishing | 10,607 | (224) | (246) | 13.8 | 856 | 603 | | | |
| Earth Tube Pre-conditioning | | | | | | | | | | |
| | Farrowing | (1,736) | 1,349 | 1,482 | 129.0 | 823 | 2,353 | 10,000 | 12.2 | 4.3 |
| | Nursery | (4,388) | 1,899 | 2,087 | 174.9 | 944 | 3,125 | 20,000 | 21.2 | 6.4 |
| | Finishing | (1,873) | 493 | 542 | 42.9 | 181 | 741 | 10,000 | 55.2 | 13.5 |
| Variable Speed Fans | | | | | | | | | | |
| | Nursery | 1,979 | - | - | 6.8 | 191 | | 1,000 | 5.2 | |
| | Finishing | 347 | - | - | 1.2 | 33 | | 1,000 | 29.9 | |
| Heat Lamp Controllers | | | | | | | | | | |
| | Farrowing | 7,431 | (194) | (213) | 6.0 | 573 | 353 | 3,000 | 5.2 | 8.5 |
| Night Temperature Setback | | | | | | | | | | |
| | Nursery | - | 928 | 1,020 | 92.8 | 690 | 1,734 | 500 | 0.7 | 0.3 |
| | Finishing | - | 471 | 518 | 47.1 | 340 | 880 | 500 | 1.5 | 0.6 |
| Water to Water Heat Pump | | | | | | | | | | |
| | Farrowing | 7,500 | - | - | 25.6 | 722 | | 50,000 | 69.2 | |
| Air Conditioning (Traditional) | | | | | | | | | | |
| | Nursery | 2,593 | (17) | (19) | 7.2 | 237 | 218 | 80,000 | 337.6 | 367.1 |
| | Finishing | 3,265 | 33 | | 14.5 | 338 | 314 | 80,000 | 236.7 | 254.4 |
| Air Conditioning (Geothermal) | | | | | | | | | | |
| | Farrowing | (30,671) | 4,607 | 5,063 | 356.0 | 427 | 5,653 | 175,000 | 409.8 | 31.0 |
| | Nursery | (34,711) | 4,634 | 5,092 | 345.0 | 59 | 5,314 | 200,000 | 3,389.8 | 37.6 |
| | Finishing | (4,780) | 1,229 | 1,351 | 106.6 | 441 | 1,836 | 150,000 | 340.1 | 81.7 |

*Energy Modeling Conclusions*

Outdoor air ventilation is required 24 hours per day in all swine barn types to control moisture and odor from the manure pits below the pens. This heating load caused by the ventilation is the largest energy user in the barns. ECMs that reduce the heating load of the required ventilation, such as earth tube pre-conditioning, can be very effective in reducing the energy use and cost of swine barns.

The decision to implement any of the above ECMs will largely depend on the goals of the owner. Options like LED lighting and night temperature setback are relatively simple to install and could provide value regardless of the goals. Other ECMs, like geothermal, have large energy and cost savings but will have high initial capital costs and the simple payback on investment may be too high to be effective on a cost saving basis. However, if the goal were to eliminate natural gas/propane usage and to have a Net Zero facility that could run on renewables, then geothermal may be worth the investment.

Combining ECMs will reduce the impact of some of the individual measures but can result in a final product that has a great savings and shorter simple payback. This would require further energy modeling to determine the value of the different combinations of options. The driving factor in the cost of the geothermal option is the heating load it is sized to handle. As this load is reduced through ECMs like earth tube pre-conditioning and night temperature setback the size and cost of the geothermal wellfield will decrease and make it a more attractive solution. As technology develops, costs tend to decrease so the economic viability may improve with time.

The complete AKF Swine Energy Modeling report is included in the supporting documents.

**ACTIVITY 2: Field test clean energy systems and develop effective control strategies**
**Description:** A 20 kW solar photovoltaic system will be installed at the WCROC swine facilities. Control systems will be installed and field tested. The control of farm-scale clean energy systems is deficient and a barrier to adoption of clean energy systems. The control system will integrate building control regimens with the often variable solar PV generation. The solar PV system will be performance tested for two years for production and reliability. Once installed, production data from the 20 kW solar PV system will be measured and analyzed over a two year time frame to determine gross and net energy production including diurnal and seasonal variation. The project team will direct an undergraduate student intern to assist in collecting data and evaluating the results. The student intern will develop a written report and provide a public presentation summarizing the results from the field test of the solar PV system.

**Summary Budget Information for Activity 2:** **ENRTF Budget: $ 203,089**
**Amount Spent: $ 170,879**
**Balance: $ 32,210**

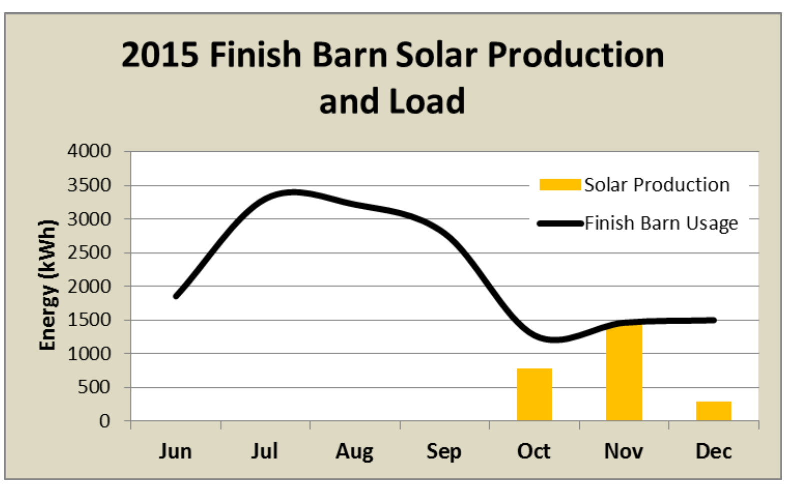
**Activity Completion Date:** June 30, 2017

| **Outcome** | **Completion Date** | **Budget** |
|---|---|---|
| **1.** *Install a 20 kW solar PV system at the WCROC swine facilities* | 7/15/2015 | $104,048 |
| **2.** *Install automated control systems to integrate clean energy systems* | 7/15/2015 | $33,650 |
| **3.** *Conduct field tests with control systems* | 6/1/2017 | $30,207 |
| **4**. *Performance test of the solar PV system for up to two years* | 6/30/2017 | $35,183 |

**Activity Status as of January 1, 2015:**
One of the swine barns on the WCROC campus will host a solar PV array. Two of three bids have been received for this system and both are within the allotted budget so this task should be completed on time.

**Activity Status as of July 1, 2015:**
A 27 kW PV system was installed by Zenergy LLC from Sebeka, MN, and was interconnected to the utility grid on June 10th. The system consists of 96 Heline 60M, 280 Watt modules (See Pictures 3 and 4) meeting the Made in Minnesota (MiM) program requirements. The system came within budget and should produce about 36,000 kWh of electricity per year. Additional larger expenses have been incurred as a result of the solar installation but are not shown in the Summary Budget Information as the expenses did not reconcile prior to this report.

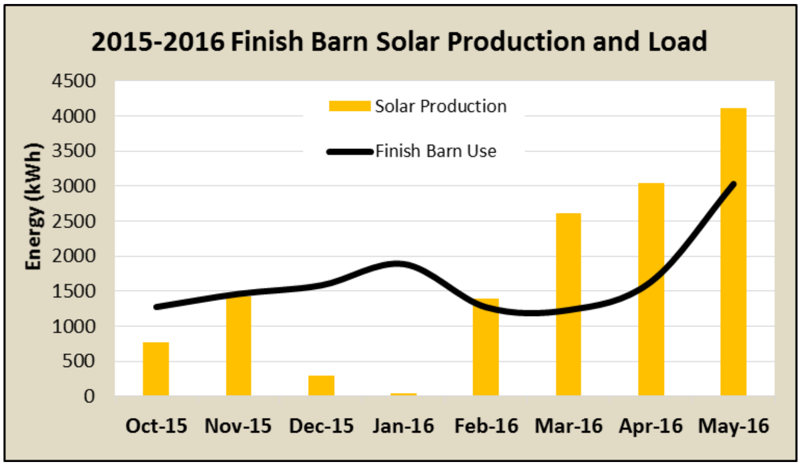
**Activity Status as of January 1, 2016:**
There were a few problems with the internet connection to the array inverters which prevented data collection until mid-September. The data is available and is stored in the utility meter that was installed during interconnection and will be retrieved from the utility. The chart below shows the system production so far



(minus the missing data) compared to the electricity actually used in the finish barn during the same time frame. The finish barn electrical usage is from a utility meter dedicated to the finish barn.

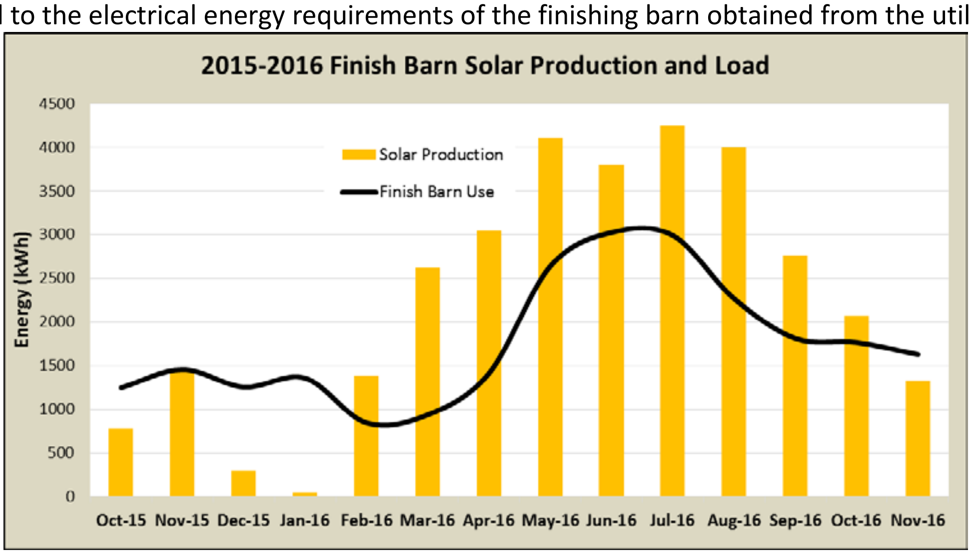
December typically produces the lowest solar energy output of the year and this December has been particularly cloudy. The panels have been covered in snow for a good part of the month as well. Pictures are being taken to document how quickly snow clears from the panels. So far it has taken about 5 days for the panels to clear after a snow fall and there have been several snowfalls this December. This will continue to be monitored and compared to other solar energy systems.

**Activity Status as of July 1, 2016:**
A summer intern was hired to collect data and evaluate production results from the 27 kW solar photovoltaic array installed on the roof of the WCROC finishing barn. The chart below shows the production from the array compared to the load in the finishing barn taken from the utility meter.




As it was predicted early on in the project, the solar array will produce the most energy during the summer months, when solar radiation is highest. The predicted increased production can be observed beginning earlier this spring and is well matched to the increasing load due to expanded use of ventilation fans to cool the pigs.

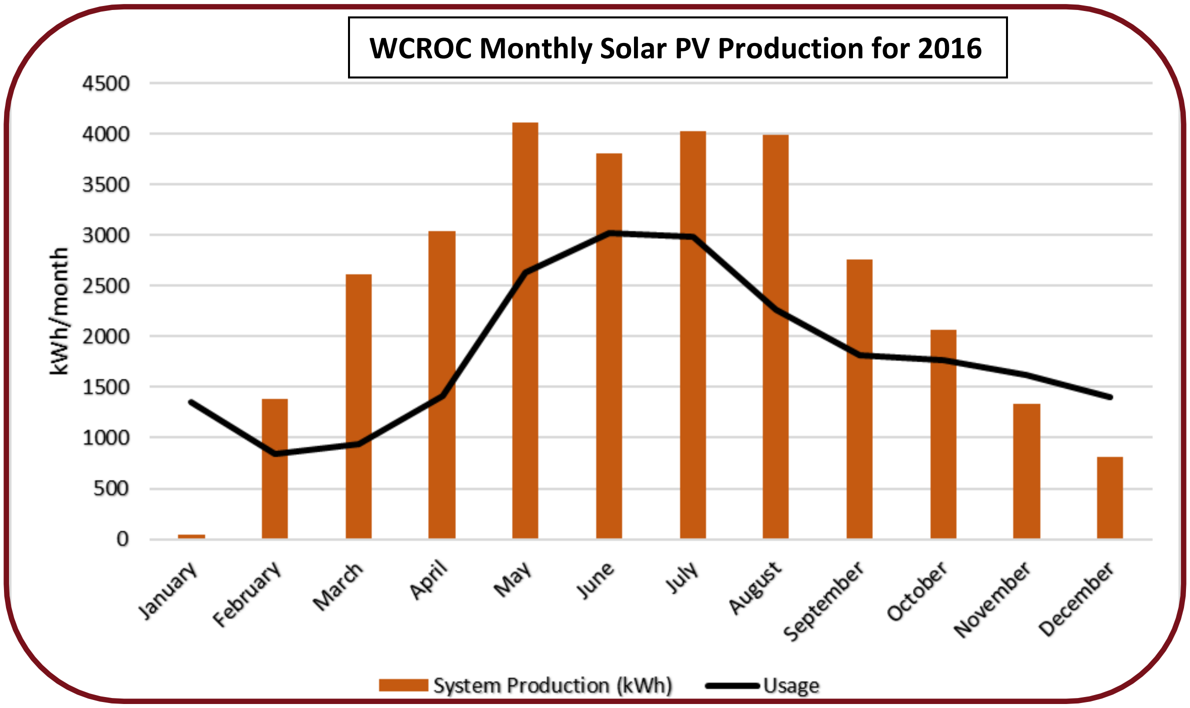
**Activity Status as of January 1, 2017:**
The intern hired during the summer of 2016 analyzed production results from the 27 kW PV array installed on the roof of the WCROC finishing barn. As a requirement of the internship, a research paper was completed and a public presentation was given in August, 2016. The chart below displays the updated production from the PV array compared to the electrical energy requirements of the finishing barn obtained from the utility meter.



As can be seen in the chart, the production from the solar array remains consistent with predicted production. During the summer, the finishing barn required more energy due to an increased use in ventilation fans. During this time when solar energy was more available, production of the solar array exceeded the requirements of the entire barn. As the days become shorter, solar production is predicted to decrease as can be seen above. The array will be monitored for snow cover this winter to document how quickly snow clears from the panels.

**Final Report Summary:**

The focus of Activity 2 was to begin the process towards improving swine energy systems and the first step was to install and test a solar PV system on the WCROC swine finishing facility.  A 26.9 kW DC array was installed in June 2015.  The system utilized 96 Heliene model 60M 280 modules.  Heliene qualifies as “Made-in-Minnesota” and this designation could be utilized by some Minnesota swine producers for additional incentives from Xcel Energy.  Each module provides 280 watts and has an efficiency of 17.4%.  Three SolarEdge SD9k inverters were also installed.  SolarEdge power optimizers were also on each module.  One full year of data is presented in the graph below.  An important question is addressed with this graph.   Is there adequate roof space on swine facilities to produce all the power required within the facility?  The graph shows that more power is produced on an annual basis than what is consumed in this particular case.  On a monthly basis, energy generation is higher than load in most months except during winter.  Insolation is lower in winter months but snow build up also occurred at various times during the winter. Mounting solar PV systems on the ground will allow for easier access to remove snow.  If space is limited and roof top installation is required, some losses may need to be included in financial modeling for days that snow covers panels.



A basic economic evaluation was performed on the WCROC solar PV system. Annual production from the system was approximately 30,000 kWh per year over the course of two years. Annual value of electricity sold equaled $3,000 (at $0.10 /kWh). The capital cost of the system was $86,000 or $3.18 / watt. Without state and federal incentives, this resulted in a 28.7 year simple pay back. If the 30% federal investment tax credit was added, a 20 year simple payback would be achieved. Adding the Made-in-Minnesota incentive for 10 years at $0.15 / kWh would result in an 11.5 year simple pay back.

Finally, a case study and financial model were developed using various system sizes and incentives. The table below indicates the system size and whether a specific incentive was included in the model. This table can be used by livestock producers to get a general idea if a solar PV system may work for them. However, each location and farm has unique variables so it is necessary to evaluate on an individual basis.

**Case Study of Solar PV with Various Sizes and Incentives**

| Size (Name-plate KW) | Capital Costs ($) | 1st Year Production (KWh) | 1st Year Revenue ($) | ITC | MACRS Depre-ciation | Grants | Xcel Solar Rewards | MiM | Simple Payback (Years) |
|---|---|---|---|---|---|---|---|---|---|
| **20 kW** | $60,000 | 28,000 | $2,800 | ● | ● | | | | 18 |
| **20 kW** | $42,000 | 28,000 | $2,800 | ● | ● | ● | | | 9 |
| **20 kW** | $60,000 | 28,000 | $5,040 | ● | ● | | ● | | 10 |
| **20 kW** | $60,000 | 28,000 | $5,880 | ● | ● | | | ● | **8** |
| **20 kW** | $60,000 | 28,000 | $5,040 | ● | ● | ● | ● | | **4** |
| **20 kW** | $60,000 | 28,000 | $5,880 | ● | ● | ● | | ● | **3.5** |
| **40 kW** | $120,000 | 55,073 | $5,507 | ● | ● | | | | 18 |
| **40 kW** | $84,000 | 55,073 | $5,507 | ● | ● | ● | | | **9** |
| **40 kW** | $120,000 | 55,073 | $11,565 | ● | ● | | | ● | **8** |
| **40 kW** | $84,000 | 55,073 | $11,565 | ● | ● | ● | | ● | **4** |
| **65 kW** | $195,000 | 85,028 | $8,503 | ● | ● | | | | 18 |
| **65 kW** | $136,500 | 85,028 | $8,503 | ● | ● | ● | | | **9** |

Another task within this activity was to install upgraded control systems and test various control strategies. The solar PV system was operated continuously after installation to obtain production data. Upgraded controls were installed in the swine facilities. These controls allow for automated control of HVAC systems. Initial testing was conducted to refine operation parameters. Control strategies will be further evaluated in the second phase of this study which is currently in progress. The second phase brings in additional optimized energy measures which may allow for dynamic strategies.

**ACTIVITY 3: Perform a life cycle assessment**

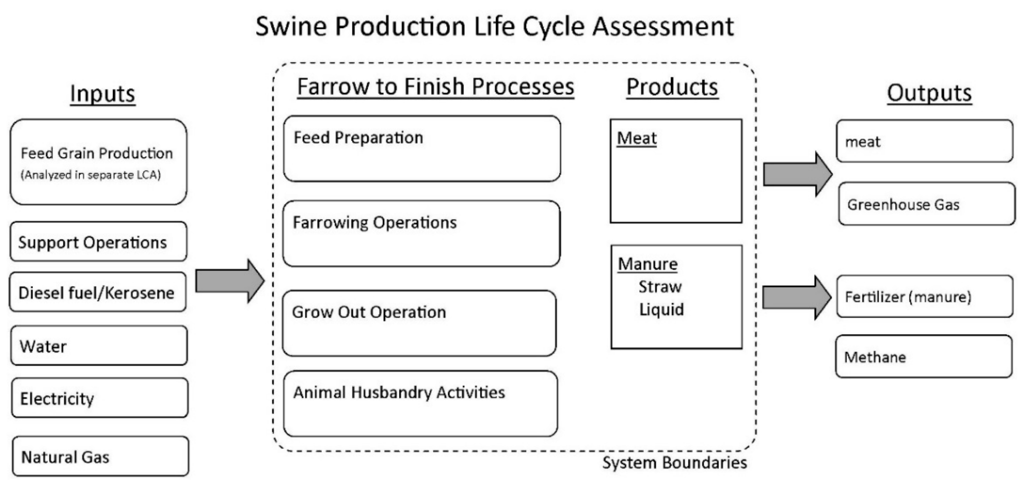
**Description:** A life cycle analysis will be performed on the WCROC swine nursery comparing conventional with the clean energy systems. This study will use life cycle assessment (LCA) to quantify the potential for energy conservation in swine production. Life cycle assessment is an accounting method used to track inputs and outputs in complex production and manufacturing systems. This work will build upon ongoing studies of the baseline energy consumption in swine, dairy, and cropping systems being researched at WCROC. In that work, the standard amount of energy used for producing pork, milk, and grain is also being analyzed using LCA methodology. This project will further refine the baseline fossil energy used in producing pork, and then assess the energy and greenhouse gas emission impacts of introducing energy-saving technologies into the swine production system. Technologies being investigated include adding solar PV panels to the facilities, bringing in more efficient ventilation systems, and possibly adding heat pumps. Each of these technologies will be selected based on the costs of retrofitting existing hog facilities, ease of use by producers, and potential to save energy.

For this project, the LCA methodology involves first identifying all inputs and outputs associated with producing hogs. This work will be done using WCROC's swine production research facilities as an energy test bed. An analysis will be conducted to identify high energy inputs such as heating and cooling facilities, feeding animals, construction/operation of the farm buildings and equipment, and all activities related to manure management. Seemingly smaller inputs into the system (like water, medications, and office facilities for staff) will also be documented. Each of these inputs is analyzed in terms of how much fossil energy was needed to incorporate the specific input into the swine production system. The next step is to examine the outputs from the system; in this case the main outputs will be live pigs leaving the facility and manures which will be used as fertilizer.

Using specifically designed LCA software, these inputs and outputs will be linked together in a complex model that ties the amount of inputs (i.e. BTUs of fossil energy) to the units of output (lbs of live pig). The final analysis will examine how many BTUs of fossil energy are needed to produce 1 pound of live pig leaving the facility. This energy input data will be used for a calculation of how much greenhouse gas is emitted in the production of 1 pound of live pig.

The LCA will be performed with appropriate ISO standards and the National Pork Board Lifecycle Assessment Study as guides for data collection and analysis. The LCA will focus on activities directly related to swine husbandry using per pound pork as a functional unit (see Figure 1).

Figure 1. Swine production life cycle assessment schematic




This LCA sets the production boundary at the farm gate and does not consider transportation/manufacture/or marketing of pork products. LCA data for inputs not inside the pork production system, such as grain production, will use both standard literature reference values and data from our separate LCA of WCROC's agronomic activities. One challenge in this system is estimating the impact of swine production system size (scale) on energy savings from particular technologies. Energy and GHG impacts from implementing conservation measures at large farms will likely be different than at smaller farms. Using our fairly modest production system, we will be able to look at the savings at smaller operations. However, scaling factors may need to be developed that can estimate how larger or smaller operations will benefit from these technologies.

**Summary Budget Information for Activity 3:** **ENRTF Budget: $ 61,655**
**Amount Spent: $ 55,854**
**Balance: $ 5,801**

**Activity Completion Date:** April 1, 2017

| Outcome | Completion Date | Budget |
|---|---|---|

| | | |
|---|---|---|
| **1.** *Complete a life cycle assessment of the WCROC conventional swine facilities using field data and literature values* | 4/1/2017 | $61,655 |

**Activity Status as of January 1, 2015:**
The LCA team is beginning to build the LCA model of the swine system. Early work includes incorporating information about the livestock housing, feeding, heating, cooling, and water into the model. In addition, the operation of tractors, trucks, and other infrastructure used in the swine operation is being documented. Data will be continually added to strengthen the modelling as the project progresses. Renewable energy inputs will be modeled once those systems are installed and energy data is available.

**Activity Status as of July 1, 2015:**
LCA work of the swine system is currently focusing on feed inputs (corn, soybeans, and other feed ingredients) and the energy needed and carbon emitted in producing feed. The model will include the ability to select between the regional specific data from feed cropping systems at the WCROC and national LCA estimates for the US. As energy and other data becomes available from other activities of this project, it will be incorporated into the model.

**Activity Status as of January 1, 2016:**
Work on LCA modeling for the project is progressing. The basic model of the swine production system is nearing functional use. In order to complete it, specific energy data will be added. The first years' worth of energy data has been collected and is being converted to the functional units needed for inclusion in the LCA. WCROC Cropping data for organic and non-organic data production systems will be added shortly. Additionally, it will need updating with manure and water data to be reasonably accurate. This work will continue over the next year.

**Activity Status as of July 1, 2016:**
Cropping data needed for swine feed production has been added to swine LCA modeling. Additional work on the swine feed system will look at mineral, nutrient, and growth supplements. Analysis has begun to evaluate changes needed to accommodate on-site energy production for WCROC systems. Initial examinations of energy consumption and production data from both on-farm and WCROC found that data patterns should be further analyzed before its use in the final models. As the energy auditing team provides additional information and explanations, the data will be further examined in the model.

**Activity Status as of January 1, 2017:**
During the last reporting period, the swine production life cycle assessment (LCA) model was revised with new cropping data and new model pathways for feed ingredients. The cropping data added included the revised 2013 to 2015 data for corn and soybeans. 2016 crop data is still being analyzed and should be added in before the final report. In addition, more information was added about secondary feed ingredients such as calcium, whey, and important amino acids. The feed production pathways were expanded to allow data from crops produced at the West Central Research and Outreach Center, as well as other national crop production datasets found in lifecycle assessment databases. Data from the energy audits of the WCROC farm and off-site commercial farms is being examined to see how it can be best integrated into the model. Currently, the LCA model has a simplistic system that adds the total energy used during production into the lifecycle assessment. As the energy data is compiled and analyzed, more complex model pathways are being planned that will separate out each area of energy use and the technologies used to reduce energy use. This will allow for testing different assumptions about the energy efficiency of swine production buildings constructed with different technologies and equipment. Currently, we are planning to examine the following technology scenarios using our data; WCROC conventional current technologies, WCROC alternative housing systems, commercial farm average technologies, commercial farm best technologies, WCROC best technologies, and commercial theoretical technologies.

**Final Report Summary:**

During the last reporting period, Life cycle assessment work for activity 3 was completed. Results from the model were analyzed and a summary LCA report was written (attached as APPENDIX). The following is an abridged version of the main report methods and findings:

During the last reporting period, Life cycle assessment work for activity 3 was completed. Results from the model were analyzed and a summary LCA report was written (submitted in supporting documents). The following is an abridged version of the main report methods and findings:

*Background*

The study employed lifecycle assessment (LCA) methodology to track resource inputs and outputs of the system and to analyze the amount of fossil energy used by and carbon dioxide (GWP) emitted during the swine production cycle. LCA methodology is essentially an organized method of tracking inputs and outputs into the swine production system and assigning impacts to them. The LCA work done for this project was done using ISO 14000 standard methodology as a general guide. SimaPro (7.2) software was used for modeling swine systems and calculating result data.

In addition to energy data, cropping system data was used from the WCROC research farm which is a supplier of feed ingredients to the swine system at WCROC. It also relied on data found in databases and literature when data was not available from WCROC or on-farm studies. Background databases used in conjunction with the SimaPro work included Ecoinvent (2.0), US LCI, and Agri-footprint. For global warming calculations, GWP 100a (IPCC 2013) was used to calculate impacts. Fossil energy impacts were calculated using the CED 1.08 method with the addition of United States based fossil energy sources.

To evaluate a variety of swine systems, different sets of data were used to look at the specific systems used at WCROC and hypothetical systems designed based on data from commercial farms. It was intended that using the different data would allow us to assess high performing and lower performing systems from the sustainability standpoint. The data was used to both look at impacts on individual growth stages and as for a complete cradle to gate modeled swine production systems,

*Results*

The initial LCA model develop as part of this project has been continually updated with new data on growth stages, inputs, and outputs as the data has become available. The current model includes data on all major inputs and outputs including; feed systems, building systems, and manure systems. By its nature, LCA models are designed to allow continual improvements and refinements. With the model that we have developed, we plan to examine individual heating, cooling, and ventilation system changes in newly funded grant projects. In addition, there are a number of improvements that we hope to make in the model as new data becomes available. Therefore, this model will continue to be used for swine production energy and GWP research into the future.

In terms of fossil energy sources used for the entire swine production system (base on WCROC data), natural gas and crude oil and lignite coal were the most used primary energy sources (Figure 2). In addition to being used in the grain production system (for grain drying), natural gas was used for electricity generation, building heat, and hot water. Much of the crude oil was used for vehicles and tractors for growing and transporting feed. Lignite coal was used in production of electricity, with the Minnesota based grid supplying more than 50% coal-based electricity. Commercial swine operations were slightly different in terms of natural gas use as rural farms are often not connected to a natural gas utility. These farms typically use propane as a heating source and for grain drying.

*Energy*

The total fossil energy for the modeled production systems is shown in Figure 4A, which is expressed in terms of the energy used for producing one market hog when combining all of the swine growth stages (Figure 3). The large impact that feed production has on the overall system is visible in the systems shown. Unfortunately, swine producers can't directly reduce the majority cropping energy impacts. A more detailed assessment of the energy needed specifically for housing or building systems (Figure 4B) shows that there are large differences in the amount of fossil energy needed between the different production systems. This figure also shows how the use of renewable electricity can decrease the amount of fossil energy needed. Depending how much fossil based electricity was used in the swine production building system, solar PV electricity reduced the fossil energy demand by between 42% (alternative) and 68% (commercial best).

*Global Warming Potential*

The analysis showed a similar situation in management of swine GWP as with swine fossil energy use, very little of the GWP emissions are able to be directly controlled by swine producers. The major areas of GWP impacts are feed production and manure management (Figure 5A). Though there are some methods of reducing manure emissions with feed additives, these are not economically feasible and are not all that effective. As with fossil energy, carbon emissions in feed ingredient production are also difficult for swine producers to influence. This leaves the building system part of swine production as the major area for pork producers to manage for GWP reduction. Unfortunately, it accounts for only about 10% of the total GWP impacts. However, our work with renewable energy does show that greenhouse gases can be significantly reduced in the building systems area (Figure 5B).

*Implications*

The findings of this work indicate that there are some areas that could be more heavily target by producers wishing to reduce their environmental impacts. On-farm activities of swine operations are within their control and can be impacted by farm management decisions. Unfortunately, because grain and feed ingredient production is such a large part of the impacts, it is difficult for swine producers to directly reduce the majority system sustainability impacts.

*Future Work and Areas for Refining LCA*

The swine life cycle model was designed as a tool to investigate a wide variety of issues related to the sustainability of pork production. It is able to be customized and expanded to meet many needs for swine sustainability research and is an important asset for Minnesota researchers. It was anticipated that the model would be used for new research efforts, and new funding has been secured to examine other swine production issues. As with all LCA models, the data collected on swine production is the key to making an accurate model. Going forward, we will continue to collect new data, both on the farm and off, to improve model results.

*Conclusions*

- A model was developed that can track energy use and greenhouse gas emissions though the swine production system at a moderate resolution, with the ability to be refined as more data becomes available. This model is designed and already committed for further research that examines questions regarding swine life cycle energy and carbon footprints with potential new technologies and organic production.
- Energy use and GWP emissions in the broader swine lifecycle were highest for feed production, which accounted for almost 60% percent of fossil energy and 50% of greenhouse gas emissions.

- The fossil energy portion of the production system that can be directly controlled by the hog growers is producer is roughly 25% of the energy of producing pork. On-farm renewable solar electricity can significantly lower the fossil energy use on the farm. However, replacements for natural gas/propane, diesel, and gasoline will be needed to further reduce fossil energy use.
- The fossil energy and GWP impacts for feed crop production and feed ingredients are an important area that must be addressed to continue reductions in environmental impacts of swine production systems.

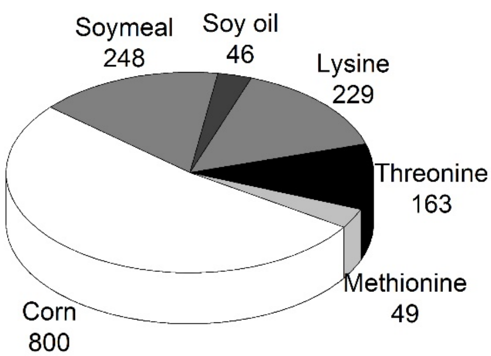



**Figure 1. Fossil Energy for Major Feed Ingredients.** Each of the feed ingredients is listed with the amount of fossil energy (in MJ) required to produce of the ingredients required to grow a single 120 kg market weight hog.

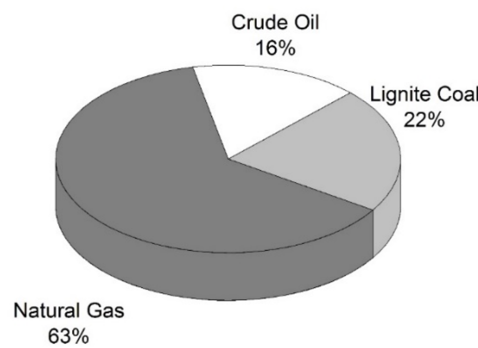



**Figure 2. Key Sources of Fossil Energy for The Swine Production System.** The primary energy sources for the production of pork and the relative percentage of each used.

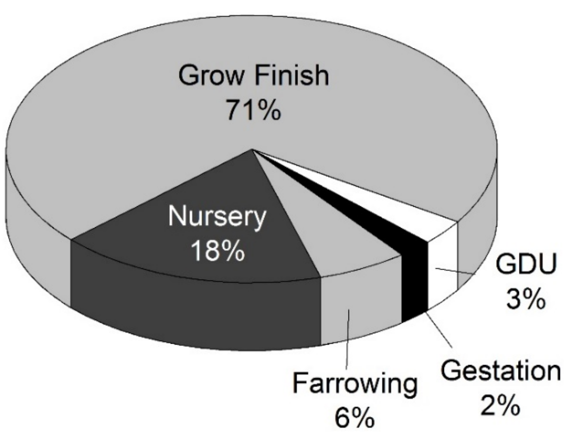
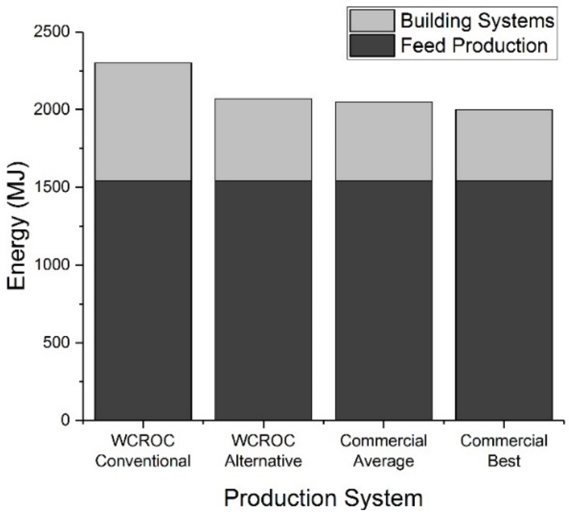



**Figure 3. Relative Fossil Energy Contribution of Each Growth Stage.** The relative contribution of the building system energy is shown for each stage is shown for the WCROC swine production system.

A) Total Swine System Fossil Energy




B) Building Energy With Renewable Production

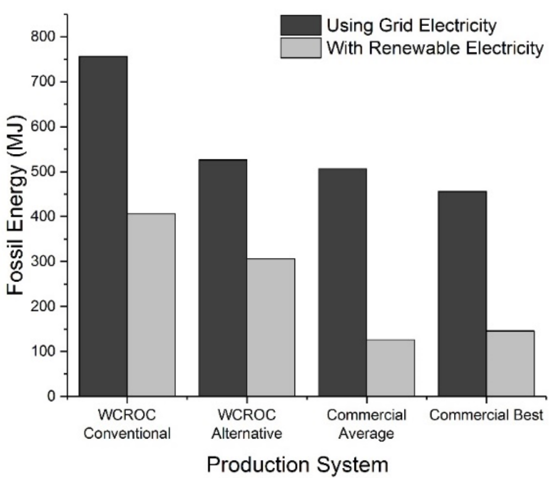
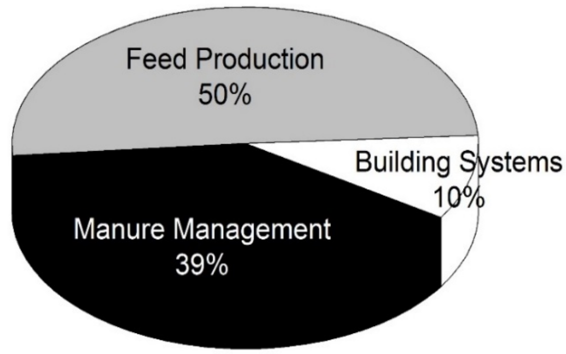



**Figure 4. Fossil Energy For Swine Production Systems.** These figures show the fossil energy needed for A) the entire swine production system and B) building system. Data is based on the energy needed for one market weight hog (120kg)

A) GWP Emissions from Swine System Components




B) GWP Emissions With Renewable Energy

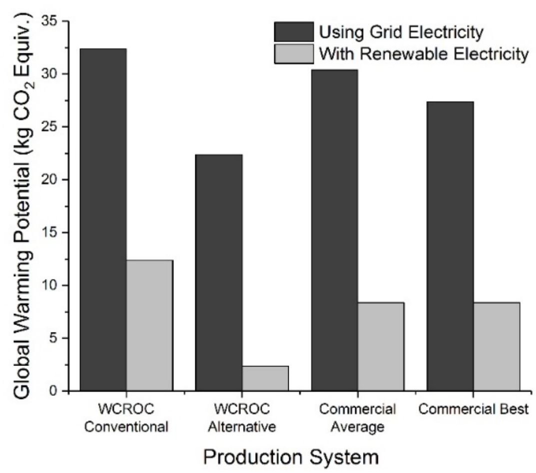



**Figure 5. Global Warming Potential for the Swine Production System.** The Global Warming Potential (kg of $CO_2$ Equivalents) for the system is shown A) as a comparison of the major GWP emitters and B) by the potential reduction using renewable energy.

**Activity 4: Educate farmers and students about clean energy strategies for Minnesota farms**

**Description:** Perhaps the most effective approach to change the way energy is used in crop and livestock systems is to educate agricultural students about clean energy technologies. Based on the research results and literature review, curriculum will be developed for secondary and technical students. Agricultural producers and other key stakeholders will be provided with educational opportunities including an agricultural energy conference and tour, two regional agricultural energy workshops across the State, and the completion of a bulletin entitled "Energy Strategies for Minnesota Swine Facilities".

The information developed as a result of this project will be transferred to producers through several outreach efforts. The primary method will be through a statewide conference and tour at the West Central Research and Outreach Center. The conference will provide producers actionable information they can use to improve energy utilization in swine facilities. Producers appreciate experiencing first-hand new systems and technology, so a bus tour will be held in conjunction with the workshop. Producers will tour the renewable energy systems at the WCROC (and other systems within close proximity) including solar thermal, solar PV, large and small scale wind, geothermal heat pumps, and energy efficient systems and controls. Two regional workshops will be presented in regions with high concentrations of swine producers (south central and southwest Minnesota). The workshops will present practical information that swine producers can use in their swine facilities including results from this project. Though not a deliverable of this project, the results are likely to be published in peer-reviewed swine production journals as well as industry magazines. The information generated as a result of this project will also be included on the WCROC Renewable Energy Program website.

| | | |
|---|---|---|
| **Summary Budget Information for Activity 4:** | **ENRTF Budget:** | **$ 48,812** |
| | **Amount Spent:** | **$ 42,739** |
| | **Balance:** | **$ 6,073** |

**Activity Completion Date:** June 30, 2017

| Outcome | Completion Date | Budget |
|---|---|---|
| **1.** *Develop agricultural energy curriculum for secondary and technical students* | 8/1/2016 | $11,455 |
| **2.** *Host an agricultural energy conference and tour to showcase clean energy systems* | 6/30/2017 | $11,313 |
| **3.** *Conduct two regional agricultural energy workshops in southern Minnesota* | 4/15/2017 | $7,371 |
| **4.** Complete a "Energy Strategies for Minnesota Swine Facilities" bulletin | 6/15/2017 | $14,320 |
| **5.** Submit semi-annual reports and a comprehensive final report | 6/30/2017 | $4,353 |

**Activity Status as of January 1, 2015:**
This activity will start once data from the previous activities are available.

**Activity Status as of July 1, 2015:**
This activity will start once data from the previous activities are available.

**Activity Status as of January 1, 2016:**
A preliminary outline has been prepared showing the proposed topics of instruction for the secondary/technical school curriculum and is shown below. The outline provides a framework to organize project results as they become available and will continue to be updated and modified as the project progresses.

**Activity Status as of July 1, 2016:**
Curriculum development is underway. Curriculum is being formatted in a way that will provide several short "modules" for secondary and technical instructors to use. Examples of topics to include range from human-induced climate change to renewable energy in agriculture. Hands-on laboratory/field experience is another valuable aspect that will be included in these modules. Several resources have been identified to help with the planning process including individuals and graduation standards.

**Activity Status as of January 1, 2017:**
Course curriculum for secondary and technical students is being developed in the form of PowerPoint presentations. The "Agricultural Energy Curriculum" will follow requirements for Minnesota Academic Standards in science and mathematics, targeting three standards in each of the presentations. The presentations will cover main topics such as introduction of energy in agricultural systems, energy conservation and efficiency in

agriculture, energy conservation and efficiency in livestock systems, and renewable energy in agriculture. Results from this study will be included in the curriculum.

**Final Report Summary:**
Task 4 activities involved the dissemination of results to various audiences but were primarily focused to swine producers and professionals. The Midwest Farm Energy Conference was hosted at the WCROC on June 13 and 14th, 2017. Approximately 90 attendees participated in tours and presentations over the two day conference. The second day of the conference focused exclusively on swine energy systems and detailed the results of this study as well as provided tours to see the swine energy systems. Conference planning was aided by swine producer and energy professional volunteers including representatives from Christensen Farms (largest swine producer in Minnesota), Dr. Mike Brumm (Brumm Swine Consultancy), Clean Energy Resource Teams (CERTS) representatives, Runestone Electric, Kandiyohi Power, Great River Energy, and other University experts. Videos of the conference presentations as well as the Power Point presentations can be viewed at https://wcroc.cfans.umn.edu/events-education/2017-midwest-farm-energy-conference. Swine producers at the conference represented about 2.2 million pigs marketed per year.

In addition to the conference, the project team provided outreach in the form of shorter workshops geared towards swine producers. The first workshop was presented by Johnston and Reese during the Minnesota Pork Congress on January 18, 2017 at the Minneapolis Convention Center. A second workshop was presented at two locations (Jackson and Sleepy Eye, MN) on May 31, 2017. The producers attending the workshop represented about 1.9 million pigs marketed per year.

Several presentation of results have been made at local, regional, and national swine producer and professional meetings and conferences. Professor Lee Johnston gave a presentation titled "*Reducing fossil fuel use in swine - one piece at a time" at the* National Pork Board Swine Educators Conference in St. Louis, MO on September 27, 2016. This presentation in particular was impactful as over one hundred swine educators from across the nation attended.

Agriculture energy systems curriculum was developed for use by educators who teach agriculture and science secondary and post-secondary technical students. The curriculum incorporates research results from this study. Teachers from across the state have been contacted regarding the curriculum and its availability. The curriculum is included in the supporting documents. Finally, several informational bulletins have been developed and are updated as new results and information becomes available.

**V. DISSEMINATION:**

**Description:** The dissemination of the information generated in this project is described in Activity 4. The project team will develop curriculum for secondary and technical students. A statewide agricultural energy conference and tour will be held at the WCROC in Morris to showcase clean energy systems. Two regional workshops will be held in key swine production areas within the state. A bulletin will be developed titled "Energy Strategies for Minnesota Swine Facilities". The bulletin will be made available both in paper and electronic formats. The information generated as a result of the project will be placed on the WCROC Renewable Energy Program website at wcroc.cfans.umn.edu/RenewableEnergy and other groups such as the Clean Energy Resource Teams (CERTS) and swine producer organizations will be encouraged to link to the site.

**Status as of January 1, 2015:**
A Midwest Farm Energy Conference is being planned for June 17-19, 2015. Although not funded as part of this project, the conference will showcase research and results from this sponsored project.

**Status as of July 1, 2015:**

The Midwest Farm Energy Conference was held at the WCROC from June 17th through June 19th. Preliminary data from the swine barn energy monitoring protocol was presented and the solar PV system was included on a tour of AG energy systems.

**Status as of January 1, 2016:**
Current efforts on information dissemination are focusing on development of secondary and technical student curriculum. The project has been presented to several producer groups and organizations. At this time, more data and analysis is required to report results to producers.

**Status as of July 1, 2016:**
Planning is underway for the next Midwest Farm Energy Conference to be held during the summer of 2017. A planning committee is being formed to begin more rigorous planning, focusing on the topic of energy in pork production systems. The committee is made up of a cross section of University and utility experts. "Save the Date" cards are being formatted to handout at various events.

**Status as of January 1, 2017:**
The Midwest Farm Energy Conference committee continues to meet and plan for the 2017 conference. The committee includes representatives from two rural electric co-ops, a large swine producer, a private swine consultant, Clean Energy Resource Teams (CERTS), U of MN Department of Bioproducts and Bioengineering, and U of MN WCROC staff. The conference is being planned for June 13th and June 14th, 2017. "Save the Date" cards and brochures have been created to hand out at various events. Brochures are being distributed at major regional swine industry conferences. A pdf of the brochure is attached. A draft program agenda has been created and keynote and conference speakers have been confirmed. The speakers include University faculty and staff, utility and production specialists, and financial experts. There will be a heavy focus on energy use in swine production systems with tours and presentations included. A conference communication plan has been developed and includes submitting press releases to several local and regional newspapers and industry publications.

Several presentation of initial results have been made at local, regional, and national swine producer and professional meetings and conferences. Professor Lee Johnston gave a presentation titled "*Reducing fossil fuel use in swine - one piece at a time" at the* National Pork Board Swine Educators Conference in St. Louis, MO on September 27, 2016. A workshop will be presented by Johnston and Reese during the Minnesota Pork Congress on January 18, 2017 at the Minneapolis Convention Center. A second workshop is being planned for southern Minnesota in early spring 2017.

Curriculum continues to be developed for secondary and technical students, incorporating results from this study. In order to better disseminate the curriculum, science and agriculture teachers will be targeted for Midwest Farm Energy Conference invitations and will include a discounted participation fee.

**Final Report Summary:**
Task 4 activities involved the dissemination of results to various audiences but were primarily focused to swine producers and professionals. The Midwest Farm Energy Conference was hosted at the WCROC on June 13 and 14th, 2017. Approximately 90 attendees participated in tours and presentations over the two day conference. The second day of the conference focused exclusively on swine energy systems and detailed the results of this study as well as provided tours to see the swine energy systems. Conference planning was aided by swine producer and energy professional volunteers including representatives from Christensen Farms (largest swine producer in Minnesota), Dr. Mike Brumm (Brumm Swine Consultancy), Clean Energy Resource Teams (CERTS) representatives, Runestone Electric, Kandiyohi Power, Great River Energy, and other University experts. Videos of the conference presentations as well as the Power Point presentations can be viewed at https://wcroc.cfans.umn.edu/events-education/2017-midwest-farm-energy-conference. Swine producers at the conference represented about 2.2 million pigs marketed per year.

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**VI. PROJECT BUDGET SUMMARY:**

**A. ENRTF Budget Overview:**

| Budget Category | $ Amount Spent | Explanation |
|---|---|---|
| Personnel: | $ 220,001 | 1 project coordinator at 20%, 40%, 20% FTE in years 1,2, and 3 respectively; 1 life cycle analysis researcher at 5% FTE for 3 years; 1 junior scientist at 100% FTE for 2.5 years; and 1 undergraduate student intern for two years during summer term |
| Professional/Technical/Service Contracts: | $ 102,521 | 1 contract with AKF Engineering or equivalent firm for modeling, pre-design, design, and commissioning; Up to 6 contracts with swine producers for stipends to participate in baseline energy auditing study, 1 contract with a general contractor for the installation of the solar PV system; and 1 contract with a mechanical contractor for installation of control systems and meters |
| Equipment/Tools/Supplies: | $ 11,111 | Energy meters and data loggers for the swine facilities. |
| Capital Expenditures over $5,000: | $ 86,006 | 27 kW solar PV system at the WCROC swine facilities; control systems for the WCROC swine building(s) |
| Printing: | $ 2,545 | Publication and printing of curriculum, Ag Energy Conference materials, regional workshop materials, and extension bulletins |
| Travel Expenses in MN: | $ 4,173 | Mileage, lodging, meals |
| Other: | $ 2,655 | One bus and postage for the Ag Energy Conference; software for life cycle analysis |
| **TOTAL ENRTF BUDGET:** | **$429,012** | |
| | | |

**Explanation of Use of Classified Staff:** Not Applicable

**Explanation of Capital Expenditures Greater Than $5,000:** One solar photovoltaic system is being purchased and installed at the University of Minnesota West Central Research and Outreach Center. The system will be performance tested with results added to the models for optimizing commercial swine facilities. In addition, a control system will be purchased for the WCROC swine nursery which will enable data acquisition and assist with field testing and modeling integration of energy systems. Following the project, the WCROC will continue to use the equipment on similar projects for its expected serviceable life. If the equipment is sold prior to the end of its serviceable life, the proceeds will be paid back to the Environment and Natural Resources Trust Fund.

**Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation:** ~4.0 (~1.33 FTEs for three years)

**Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation:** Not applicable. The contracts are for professional engineering services and equipment installation.

**B. Other Funds:**

| Source of Funds | $ Amount Proposed | $ Amount Spent | Use of Other Funds |
|---|---|---|---|
| **Non-state** | | | |
| University of Minnesota – Unrecovered Indirect Costs (ICR) used as in-kind match. | $155,296 | $133,247 | Indirect costs – Reduced amount reflects amount of direct expenditures. |
| **State** | | | |
| | $ | $ | |
| **TOTAL OTHER FUNDS:** | **$155,296** | **$133,247** | |

**VII. PROJECT STRATEGY:**

**A. Project Partners:** Michael Reese, U of MN WCROC Renewable Energy Director, will serve as the principle investigator and project manager. He will be responsible for all reports and deliverables. Dr. Lee Johnston (U of MN Swine Scientist) will be a co-principle investigator managing the activities within the WCROC swine facilities and assisting in interfacing with the collaborating swine producers. Dr. Larry Jacobson (U of MN Agricultural Engineer) and Dr. Brad Heins (U of MN Dairy Scientist) will be co-investigators and provide guidance on clean energy designs and testing in livestock facilities. They will also participate in the outreach activities. Dr. Joel Tallaksen (WCROC Renewable Energy Scientist) will serve as a co-investigator and be responsible for the life cycle analysis and oversee the basic economic evaluation. Eric Buchanan (WCROC Renewable Energy Scientist and Engineer) will be the project coordinator assisting in the design, installation, testing, and control strategies of the clean energy technologies. He will also assist with the outreach and dissemination of results. AKF Engineering (Minneapolis) or equivalent will provide consulting services for clean energy modeling, designing, commissioning, and control strategies.

**B. Project Impact and Long-term Strategy:** There are approximately 7.8 million pigs in Minnesota. Past research at the WCROC has shown significant energy and cost savings with off-the-shelf technologies. Proven energy optimized systems have the potential to significantly lower the energy consumed in swine facilities and begin the transition to locally-produced, clean energy. The WCROC has a 10-year strategic plan to reduce fossil energy consumption and the carbon footprint within production agriculture. This proposal will leverage and build upon current projects. Funding has been received through the U of MN Initiative for Renewable Energy and the Environment ($350k) to measure energy consumption within a model dairy and test clean thermal energy systems. The funded project will also evaluate greenhouse gas emissions within portions of crop and dairy production. Long-term funding will be sought to research alternatives to fossil energy within all agricultural crop and livestock enterprises.

**C. Spending History:**

| **Funding Source** | **M.L. 2008 or FY09** | **M.L. 2009 or FY10** | **M.L. 2010 or FY11** | **M.L. 2011 or FY12-13** | **M.L. 2013 or FY14** |
|---|---|---|---|---|---|
| U of MN IREE (Crops and Dairy) | | | | $350,000 | |
| U of MN RARF (Dairy and Swine) – The swine portion of this project is related to diurnal control of temperature or lowering the temperature during evening hours to conserve energy. | | | | $167,061 | |
| Xcel RDF Pending PUC Approval (Dairy facilities only – If approved, the project will add small wind and solar system to the WCROC dairy parlor) | | | | | $982,408 |

**VIII. ACQUISITION/RESTORATION LIST:** Not applicable

**IX. VISUAL ELEMENT or MAP(S):** Please see the end of this document for the visual elements

**X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET:** Not applicable

**XI. RESEARCH ADDENDUM:** As detailed in the activity sections

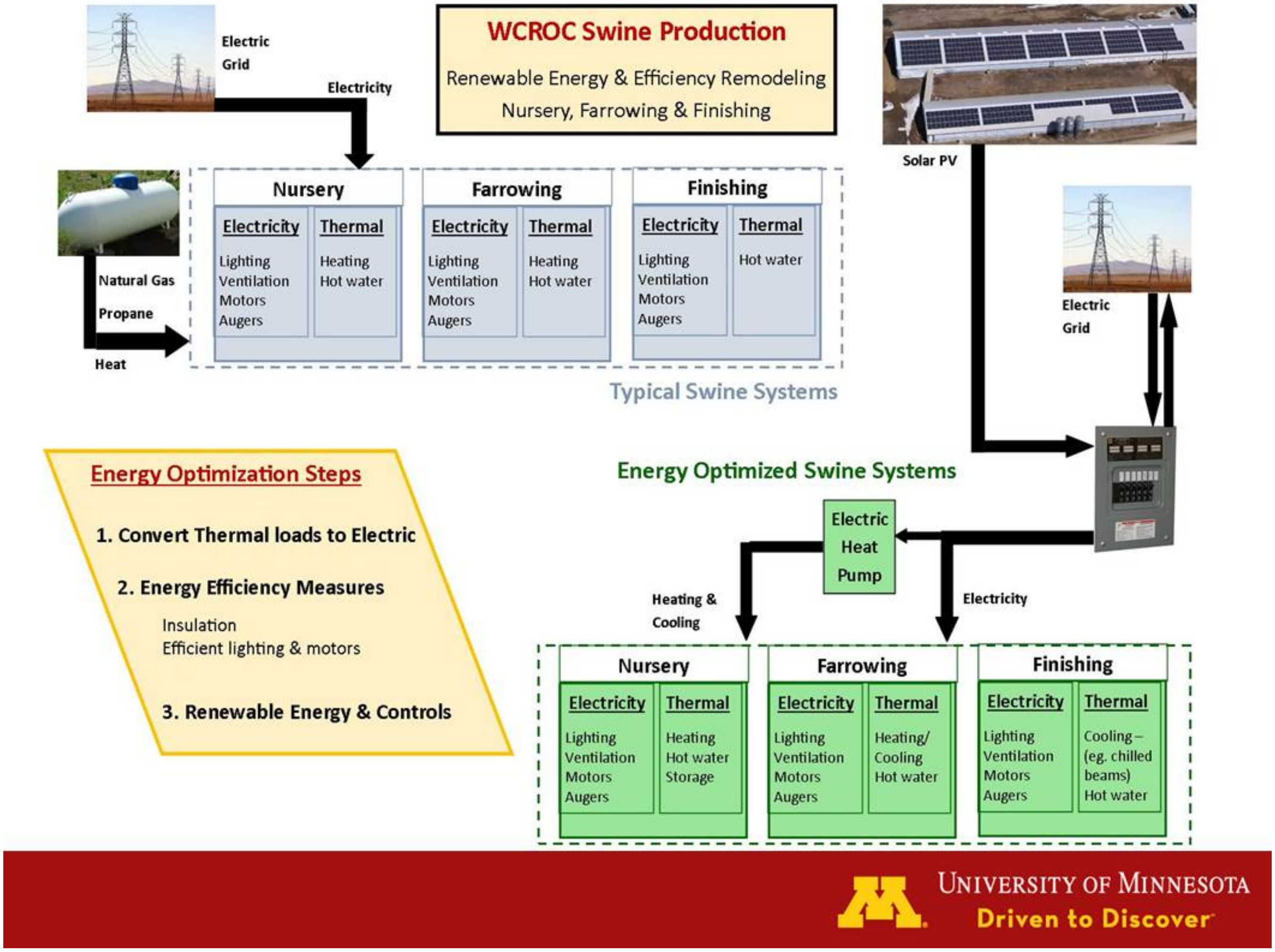
**XII. REPORTING REQUIREMENTS:**
Periodic work plan status update reports will be submitted no later than January 1, 2015; July 1, 2015; January 1, 2016; July 1, 2016; and January 1, 2017. A final report and associated products will be submitted between June 30 and August 15, 2017.

**Literature Cited**

Lammers, P. J., M. S. Honeyman, J. D. Harmon, and M. J. Helmers. 2010. Energy and carbon inventory of Iowa swine production facilities. Agric. Systems 103:551-561.

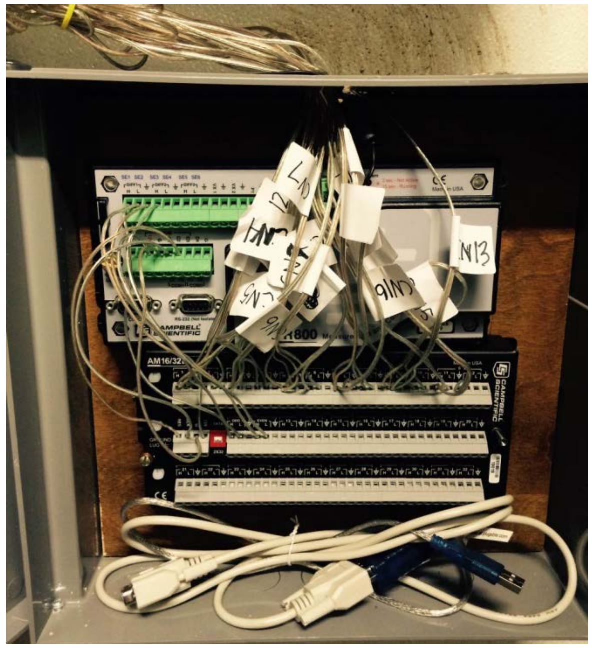
Lammers, P. J., M. D. Kenealy, J. B. Kliebenstein, J. D. Harmon, M. J. Helmers, and M. S. Honeyman. 2012. Energy use in pig production: An examination of current Iowa systems. J. Anim. Sci. 90:1056-1068.

**Visual Element**: Basic Schematic of Conventional and Optimized Energy Systems for Swine Facilities


WCROC Swine Production
Renewable Energy & Efficiency Remodeling
Nursery, Farrowing & Finishing
Electric Grid
Electricity
Natural Gas
Propane
Heat
Nursery
Electricity
Lighting
Ventilation
Motors
Augers
Thermal
Heating
Hot water
Farrowing
Electricity
Lighting
Ventilation
Motors
Augers
Thermal
Heating
Hot water
Finishing
Electricity
Lighting
Ventilation
Motors
Augers
Thermal
Hot water
Typical Swine Systems
Solar PV
Electric Grid
Energy Optimization Steps
1. Convert Thermal loads to Electric
2. Energy Efficiency Measures
Insulation
Efficient lighting & motors
3. Renewable Energy & Controls
Energy Optimized Swine Systems
Electric Heat Pump
Heating & Cooling
Electricity
Nursery
Electricity
Lighting
Ventilation
Motors
Augers
Thermal
Heating
Hot water
Storage
Farrowing
Electricity
Lighting
Ventilation
Motors
Augers
Thermal
Heating/
Cooling
Hot water
Finishing
Electricity
Lighting
Ventilation
Motors
Augers
Thermal
Cooling –
(eg. chilled
beams)
Hot water
UNIVERSITY OF MINNESOTA
Driven to Discover

**Attachments: January 1, 2015**

Picture 1. Data loggers being installed in circuit breaker box at a commercial finishing barn




Picture 2. Data logger in WCROC farrowing barn

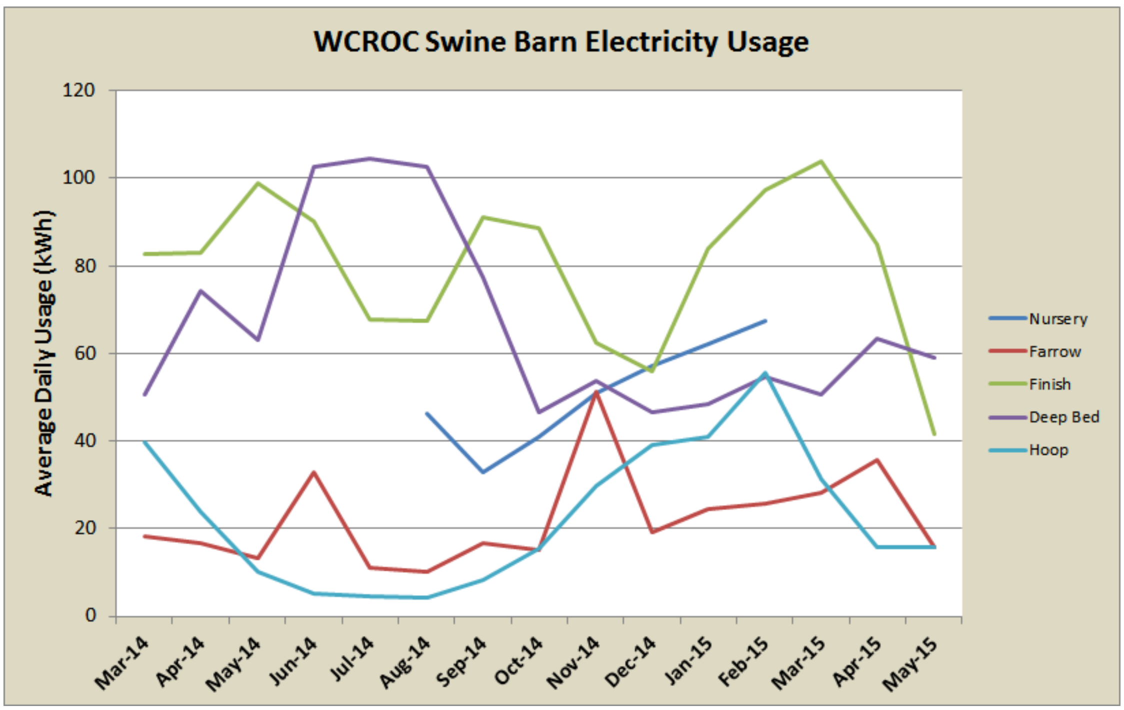



**Figure 6. WCROC swine facility electrical energy consumption compiled from utility meter**

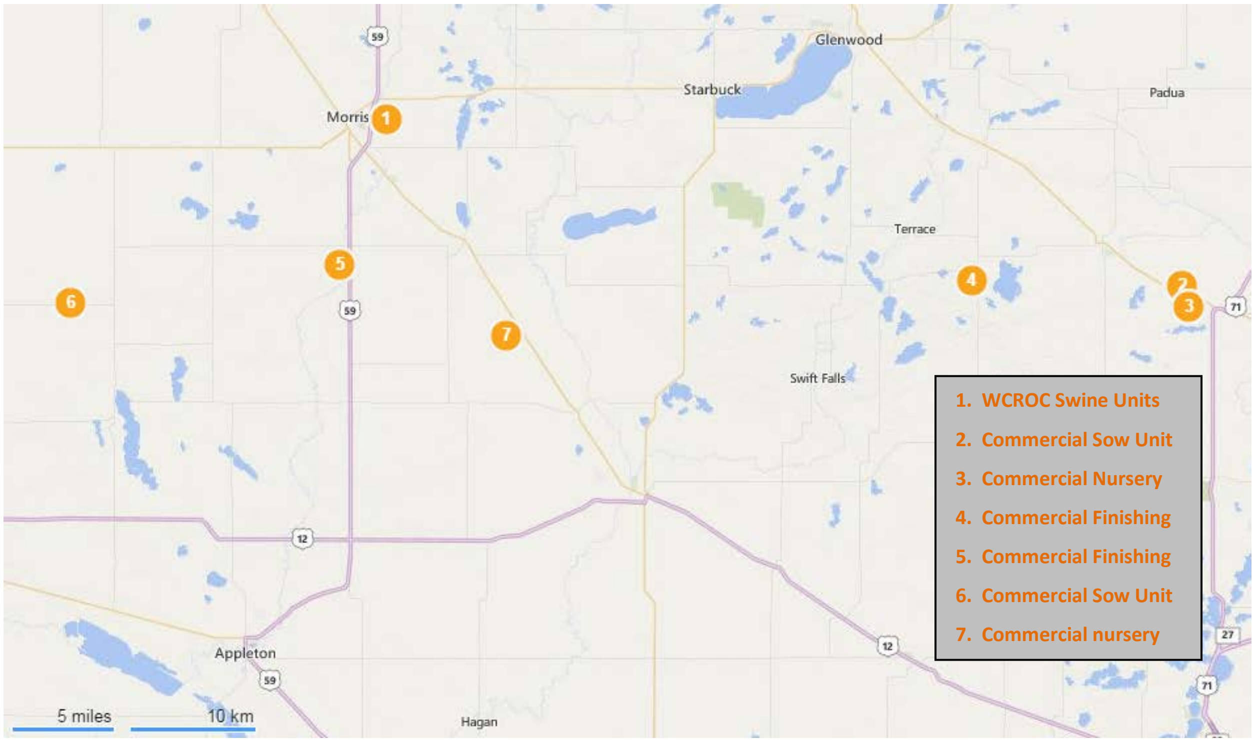



**Figure 7. Map indicating location of swine facility monitoring**

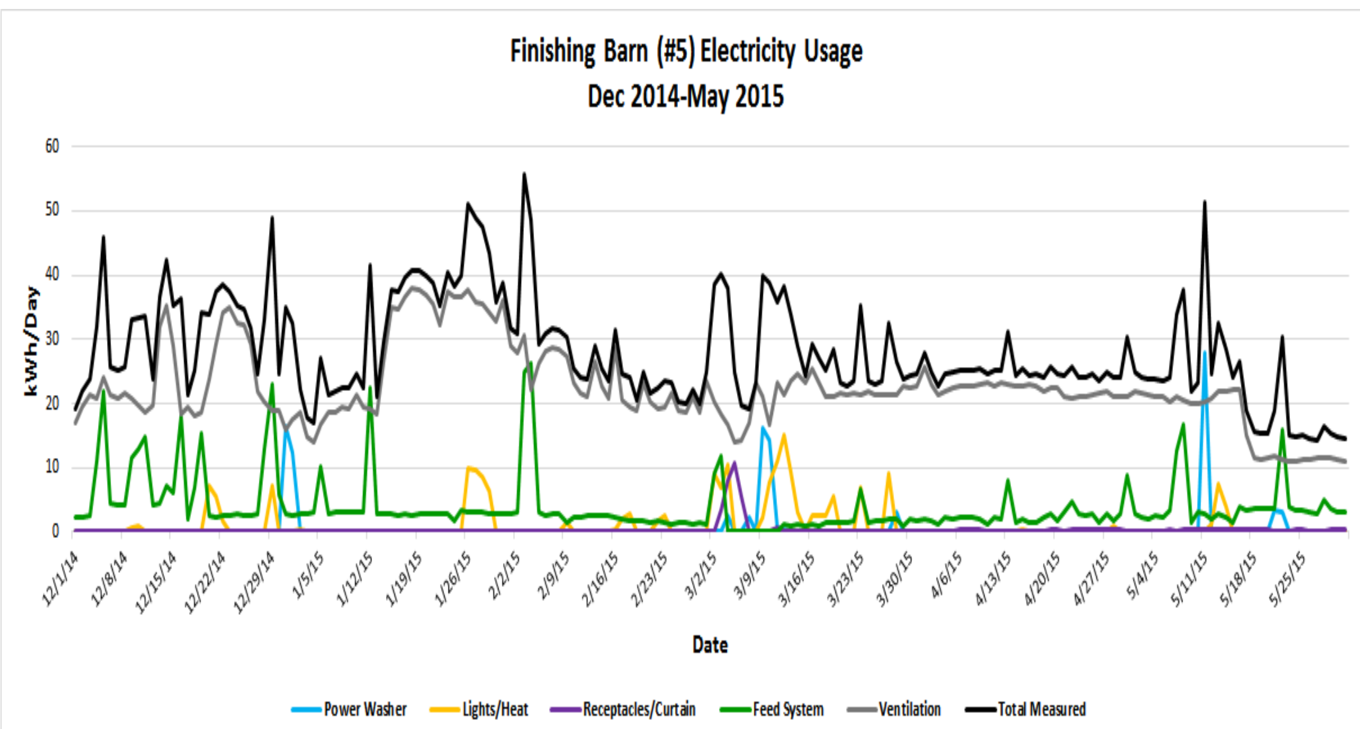



**Figure 8 Example of weekly energy usage data from a cooperator swine facility**

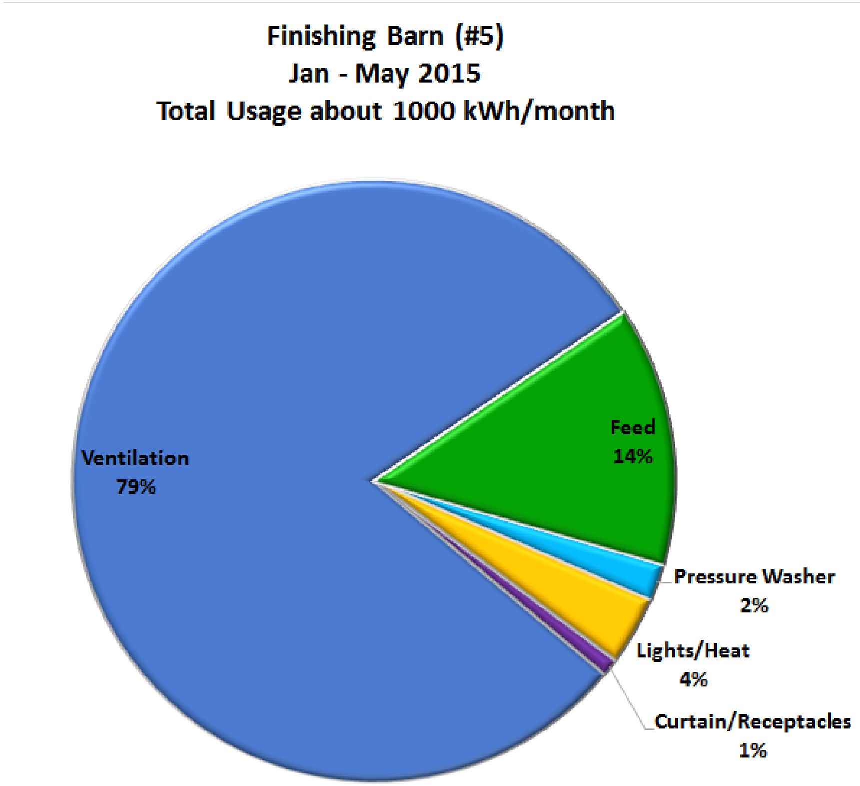



**Figure 9. Example breakdown of energy used for processes within a cooperator swine facility**

**Picture 3. 27 kW Solar PV System on WCROC Swine Facility – West Side**

**Picture 4. 27 kW Solar PV System on WCROC Swine Facility – East Side**

**Attachments: January 1, 2017**

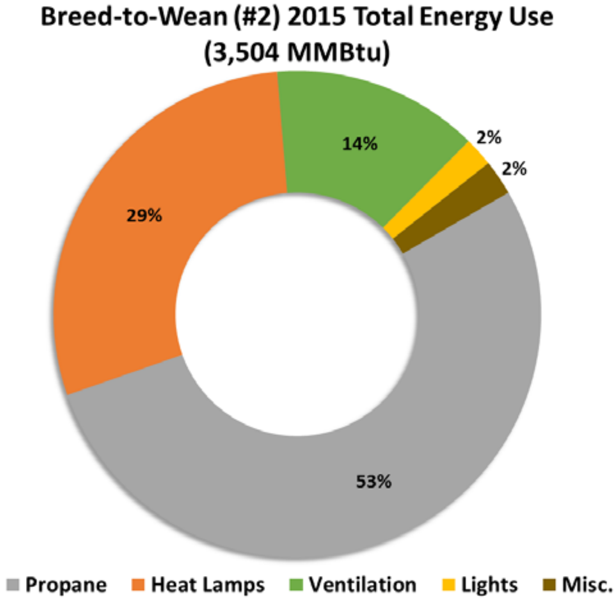



**Figure 5. Total energy use in 2015 of propane and electrical categories in commercial Breed-to-Wean Barn #2.**

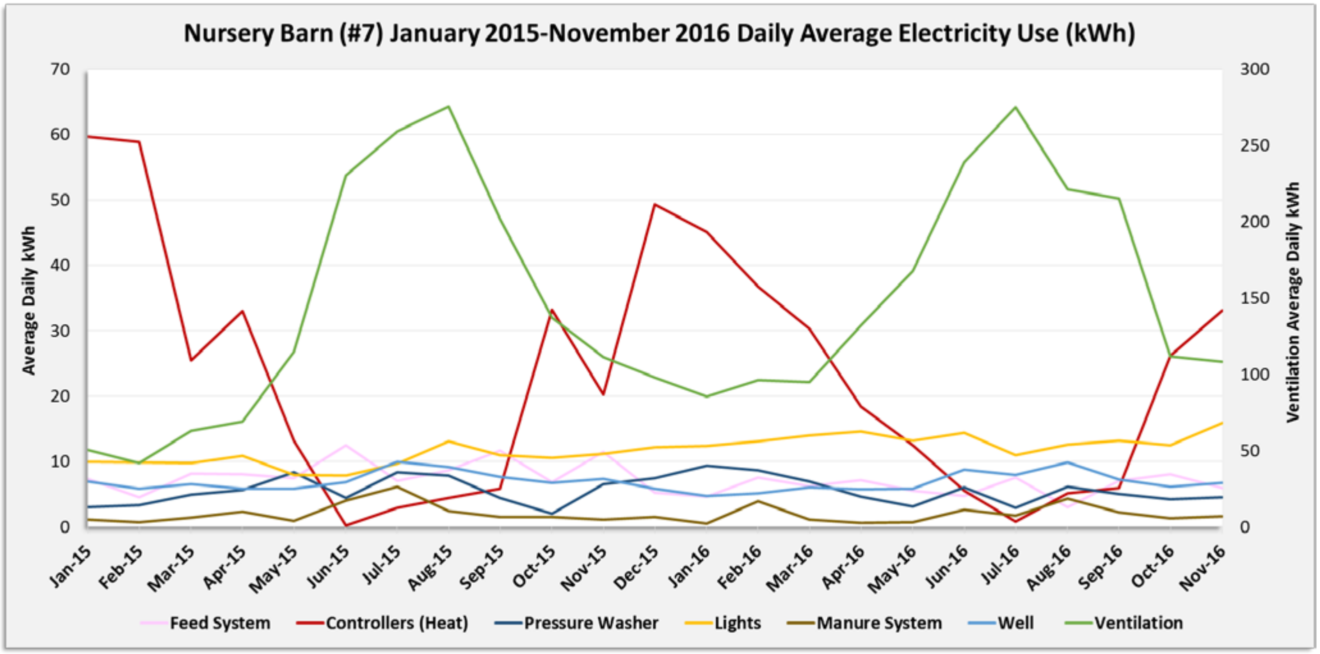



**Figure 6. Average daily electricity use of electrical loads in Nursery Barn #7.**

**Picture 5. Photo of West Finishing Barn solar panels taken on 12/22/16, 6 days after a large snowstorm.**

**Picture 6. Photo of East Finishing Barn solar panels taken on 12/22/16, 6 days after a large snowstorm.**

**2017 Midwest Farm Energy Conference Brochure (Page 1 and 2 of a trifold):**


**A report by AKF Engineers titled "Swine Barn Energy Modeling Narrative" has been attached in a second file. The report is a deliverable of Activity 1.**

**August 11, 2017 Report Pictures and Documents will be sent and uploaded as supporting documentation.**

**Environment and Natural Resources Trust Fund**
**M.L. 2014 Final Attachment A Project Budget**

**Project Title:** *Transitioning Minnesota Farms to Local Energy*
**Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 08d**
**Project Manager:** *Michael Reese*
**Organization:** *University of Minnesota West Central Research and Outreach Center*
**M.L. 2014 ENRTF Appropriation: $** *500,000*
**Project Length and Completion Date:** *3 Years, June 30, 2017*
**Date of Final Report:** August 11, 2017

| ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET | Revised Activity 1 Budget 08/16/2016 | Amount Spent | Activity 1 Balance | Revised Activity 2 Budget 08/16/2016 | Amount Spent | Activity 2 Balance | Activity 3 Budget | Amount Spent | Activity 3 Balance | Revised Activity 4 Budget 01/30/17 | Amount Spent | Activity 4 Balance | Revised TOTAL BUDGET 01/30/2017 | REVISED TOTAL BALANCE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **BUDGET ITEM** | | | | | | | ***Perform a life cycle assessment*** | | | | | | | |
| **Personnel (Wages and Benefits)** | $76,755 | $64,652 | $12,103 | $64,651 | $64,651 | $0 | $55,855 | $55,854 | $1 | $34,847 | $34,844 | $3 | $232,108 | $12,107 |
| Project Coordinator - Eric Buchanan (FTEs =20% Year 1, 40% Year 2, 20% Year 3) 36.8 % fringe rate | | | | | | | | | | | | | | |
| Life Cycle Analysis Researcher - Dr. Joel Tallaksen (5% FTE) 36.8 % fringe rate | | | | | | | | | | | | | | |
| Junior Scientist - Technician for data collection, system testing (100% FTE - 2.75 Yrs) 36.8 % fringe rate | | | | | | | | | | | | | | |
| Undergrad Student Intern - Clean Energy Technology for MN Swine Facilities (2 Yrs) 7.44% Fringe Rate | | | | | | | | | | | | | | |
| **Professional/Technical/Service Contracts** | | | | | | | | | | | | | | |
| AKF Engineering (or equivalent firm) - Modeling, Pre-design, Design, Commissioning, and Control Optimization Engineering Professional Services | $62,000 | $57,153 | $4,848 | | | | | | | | | | $62,000 | $4,848 |
| Farmer Contracts - Funds for monitoring of on-farm systems | $24,000 | $24,000 | $0 | | | | | | | | | | $24,000 | $0 |
| General Contractor -Zenergy LLC - Installation of the solar PV system | | $0 | $0 | $28,154 | $17,599 | $10,555 | | | | | | | $28,154 | $10,555 |
| Mechanical Contractor(s) -Runestone Electric and Asmus Electric-Installation of energy meters / control systems | $2,550 | $1,884 | $666 | $7,650 | $1,884 | $5,766 | | | | | | | $10,200 | $6,431 |
| **Equipment/Tools/Supplies** | | | | | | | | | | | | | | |
| Energy Meters and Components for Swine Building(s) to measure energy consumption | $10,800 | $5,450 | $5,350 | | | | | | | | | | $10,800 | $5,350 |
| Data Loggers and Components for Swine Building(s) for data collection and acquisition | $9,600 | $5,661 | $3,939 | | | | | | | | | | $9,600 | $3,939 |
| **Capital Expenditures Over $5,000** | | | | | | | | | | | | | | |
| 20 kW solar photovotaic (electric) system | | | | $75,895 | $73,667 | $2,228 | | | | | | | $75,895 | $2,228 |
| Control system for WCROC Swine Facilities | | | | $26,000 | $12,339 | $13,661 | | | | | | | $26,000 | $13,661 |
| **Printing** Curriculum, Ag Energy Conference materials, regional workshop materials, and extension bulletin printing. | | | | | | | | | | $6,400 | $2,545 | $3,855 | $6,400 | $3,855 |
| **Travel expenses in Minnesota** Eight trips by Dr. Jacobson from Saint Paul to Morris, MN (330 miles @ $.56 / mi); Travel by project team to two regional workshops across the State (2 trips, 400 miles each, $.56 / mi); Lodging and meals for WCROC project team at two regional workshops (4 people / 2 nights @ $80 / room and $40 ea for meals); Travel, lodging and meals for Larry Jacobson at two regional workshops (400 miles and 2 trips @ .56, 2 nights @ $80 / room and $40 ea for meals); Travel, lodging, and meals for six ag energy conference speakers (6 @ 330 mi and $80 / room and $40 ea for meals) | $739 | $739 | $0 | $739 | $739 | $0 | | | | $3,765 | $2,695 | $1,070 | $5,243 | $1,070 |
| **Other** | | | | | | | | | | | | | | |
| Buses for the ag energy conference | | | | | | | | | | $2,000 | $1,425 | $575 | $2,000 | $575 |
| Postage for conference brochures and save-the date cards (5000 units *$.22 bulk rate for brochures and *$.14 bulk rate for postcards) (01/30/17) | | | | | | | | | | $1,800 | $1,230 | $570 | $1,800 | $570 |
| Life cycle analysis software to perform the study | | | | | | | $5,800 | $0 | $5,800 | | | $0 | $5,800 | $5,800 |
| **COLUMN TOTAL** | **$186,444** | **$159,539** | **$26,905** | **$203,089** | **$170,879** | **$32,210** | **$61,655** | **$55,854** | **$5,801** | **$48,812** | **$42,739** | **$6,073** | **$500,000** | **$70,988** |