M.L 2016, Chp. 186, Sec. 2 Subd. 07e Project Abstract
For the Period Ending June 30, 2019

PROJECT TITLE: Solar Energy Utilization for Minnesota Swine Farms – Phase II
PROJECT MANAGER: Lee Johnston
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2016, Chp. 186, Sec. 2, Subd. 07e

APPROPRIATION AMOUNT: $475,000
AMOUNT SPENT: $460,772
AMOUNT REMAINING: $14,228

Sound bite of Project Outcomes and Results
Our project demonstrated that solar-generated electricity used to power a sow cooling system in a swine farrowing system can effectively improve the comfort of sows and reduce the carbon footprint of commercial pork production.

Overall Project Outcome and Results
American pork producers are trying to improve the environmental footprint of their production systems by reducing their reliance on fossil fuels. Keeping sows and pigs in their ideal temperature range during hot seasons is one way to improve animal performance and the carbon footprint of their production system. Use of solar-generated electricity is another approach for pig farmers to reduce their reliance on fossil fuels. We designed and installed a solar-powered system to cool heat-stressed sows during the farrowing and lactation periods. After installation and commissioning, we studied 84 sows and litters over two summer seasons in three contemporary groups of sows. The 20 kW solar array consistently provided enough electricity to operate the sow cooling system installed in a confinement farrowing barn. The sow cooling system studied in this project was able to significantly reduce heat stress and improve welfare of farrowing and lactating sows. Unfortunately, the reduced heat stress of sows did not support improvements in litter size at weaning or growth rate of suckling pigs. A basic economic analysis of the 20 kW solar PV system installed for this project suggested the system would breakeven after 60 years on a straight cash basis (revenues minus expenses). When tax incentives are added and fully utilized, the breakeven point is between 8 and 12 years but can depend on the utility provider in the area. A Life Cycle Assessment (LCA) of the carbon and energy footprints of the sow cooling system was completed. Because there was no increased output (number or weight of weaned pigs) as a result of the cooling system, neither the carbon footprint nor the energy footprint of the farrowing operation were improved by the cooling system. However, using electricity generated by the solar PV system did substantially reduce the carbon footprint and also significantly reduced the consumption of energy derived from fossil fuels for the swine farrowing operation. Solar-generated electricity can play an important part in reducing carbon emissions from Minnesota pork production.

Project Results Use and Dissemination
Information related to this project has been disseminated to many different audiences in a variety of formats. The target audiences for these publications include: pig farmers, engineers and builders of swine production barns, swine industry consultants, and consumers. Publications related to this project include: a video about the project (Cooling Sows and Heating Piglets with Solar Energy) and two factsheets (WCROC Farrowing Barn Heating and Cooling System and Lactating Sow Performance with Solar-Powered Cooling). Multiple conference presentations and posters were made for industry and professional audiences, and many articles were printed in

newsletters and popular press, including the West Central Research and Outreach Center Newsletter, *Land Magazine*, *Morris Star Tribune Ag Supplement*, *The Farmer Magazine*, and *Minnesota Pork Congress Magazine.* Any of these publications are available upon request from the project manager. More publications are anticipated in the future.

Environment and Natural Resources Trust Fund (ENRTF) M.L. 2016 Work Plan – Final Report

Date of Report: September 30, 2019

Final Report

Date of Work Plan Approval: June 7, 2016

Project Completion Date: June 30, 2019

PROJECT TITLE: Solar Energy Utilization for Minnesota Swine Farms – Phase II

Project Manager: Lee Johnston

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Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$475,000**
	Amount Spent:	**$460,772**
	Balance:	**$14,228**

Legal Citation: M.L. 2016, Chp. 186, Sec. 2, Subd. 07e

Appropriation Language: (h) Solar Energy Utilization for Minnesota Swine Farms – Phase 2
$475,000 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 continue to develop and evaluate the utilization of solar photovoltaic systems at swine facilities to improve energy and economic performance, reduce fossil fuel usage and emissions, and optimize water usage. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Solar Energy Utilization for Minnesota Swine Farms—Phase 2

II. PROJECT STATEMENT:

This project addresses an important question facing American pork producers, namely how to lower fossil energy use and reduce the carbon and environmental footprint of swine production systems. Minnesota has been a leader in addressing competing challenges within the nexus of food, environment, and energy. Pork producers need innovative housing systems that help address environmental and energy concerns while remaining competitive in the global market for pork. Minnesota is a major pork producing state (3rd nationally). The Midwestern climate dictates considerable indoor environmental (temperature) control of production facilities to ensure efficient production and comfort of pigs and workers. This environmental control includes heating (fossil fuels) during cold conditions and cooling (electricity) during warm/hot weather for all phases of pig production. Producers are seeking solutions to their energy use challenges. Helping producers find solutions to these challenges fits well with the ten-year goal of the Univ. of MN's West Central Research and Outreach Center (WCROC). That goal is to reduce fossil energy consumption and reduce the carbon and environmental footprint of Minnesota farms. This goal was established as part of a strategic planning process that identified rising energy costs and changing market demands for low carbon footprint agricultural products as key agricultural issues in the next decade. In applying this strategic goal to the problem facing the Minnesota pork industry, the research team identified two innovative methods to cool pigs that will lower ventilation rates and thus emissions of odor, greenhouse gases, and dust in exhaust air, reduce water usage, and lower the carbon and environmental footprint of Minnesota-produced pork. The first cooling system uses liquid-cooled pads located in farrowing stalls to cool the sows while they nurse their piglets during summer. Sows will lie on the pads and heat will be transferred from their body to the liquid contained within the pad. The second cooling system will provide chilled drinking water (55 °F) to sows in a farrowing facility. Sows provided cooled water drink less water, and are physically cooled by intake of the chilled water. Water cooling will be provided by a chiller or an air-source heat pump powered by solar PV collectors mounted on the roof of the sow facility. This project complements other ongoing state- and commodity-funded projects at WCROC that are investigating clean energy agricultural production systems.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of: January 1, 2017

We are in the initial phases of this project and making good progress toward our objectives. We have identified and ordered the solar PV system; identified and ordered the cooling floor inserts; contracted with an engineering firm to develop specifications for installation of the cooling systems; and drafted a preliminary protocol that directs the study of sow performance under the cooling systems to be deployed.

Project Status as of: July 1, 2017

Report not submitted as per directions from LCCMR staff.

Project Status as of: January 1, 2018

This project is progressing nicely. We have installed the sow cooling floors and solar PV system. The cooling systems for sow floors and drinking water have been designed and installed. One group of sows have used the cooling systems in a preliminary test of the systems and data collection procedures. A second group of sows have used the systems for collection of animal and system performance data. We have shared details of this project with interested people at the Midwest Farm Energy Conference and through limited media outlets.

Project Status as of: July 1, 2018

This project is progressing as planned. We have assigned a second group of sows to use the system and have completed data collection for this second group. Summaries of data collection for this second group is underway. We will begin work on statistical analysis and interpretation of animal performance data and energy use data soon. We have shared information about this project with listeners on the Linder Farm Network (syndicated radio network based in Owatonna, MN) and subscribers to the multistate (Minnesota included) SowBridge educational series.

Project Status as of: January 1, 2019

This project is progressing as planned. We have completed data collection on three groups of sows for this experiment, one group more than originally proposed. Biological performance data has been summarized. We are in the midst of summarizing data on room conditions (temperatures, gas concentrations, humidity) and energy use within each experimental room. We have arranged for presentation of our results in several different venues in the coming months.

Amendment request as of July 19, 2019

We request extension of the date the final report is submitted from August 15 to September 30, 2019. This is being requested so we may more substantially complete and report on our dissemination outcomes, which includes publications of articles in industry and scientific journals that will occur after July 1. No funds will be spent after June 30, 2019. Amendment Approved by LCCMR 7/29/19.

Overall Project Outcomes and Results (September 30, 2019):

American pork producers are trying to improve the environmental footprint of their production systems by reducing their reliance on fossil fuels. Keeping sows and pigs in their ideal temperature range during hot seasons is one way to improve animal performance and the carbon footprint of their production system. Use of solar-generated electricity is another approach for pig farmers to reduce their reliance on fossil fuels. We designed and installed a solar-powered system to cool heat-stressed sows during the farrowing and lactation periods. After installation and commissioning, we studied 84 sows and litters over two summer seasons in three contemporary groups of sows. The 20 kW solar array consistently provided enough electricity to operate the sow cooling system installed in a confinement farrowing barn. The sow cooling system studied in this project was able to significantly reduce heat stress and improve welfare of farrowing and lactating sows. Unfortunately, the reduced heat stress of sows did not support improvements in litter size at weaning or growth rate of suckling pigs. A basic economic analysis of the 20 kW solar PV system installed for this project suggested the system would breakeven after 60 years on a straight cash basis (revenues minus expenses). When tax incentives are added and fully utilized, the breakeven point is between 8 and 12 years but can depend on the utility provider in the area. A Life Cycle Assessment (LCA) of the carbon and energy footprints of the sow cooling system was completed. Because there was no increased output (number or weight of weaned pigs) as a result of the cooling system, neither the carbon footprint nor the energy footprint of the farrowing operation were improved by the cooling system. However, using electricity generated by the solar PV system did substantially reduce the carbon footprint and also significantly reduced the consumption of energy derived from fossil fuels for the swine farrowing operation. Solar-generated electricity can play an important part in reducing carbon emissions from Minnesota pork production.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Design, install, and evaluate a solar PV system and sow cooling pads in the farrowing facility

Description: The team will install a 20 kW solar PV collector and research the effective cooling of farrowing sows. Performance testing will be conducted over the course of Years 2 and 3. The electric energy generated from the solar PV system will be used primarily to power a water chiller / heat pump. The use of chilled water will be evaluated as a means to cool sows using water jacketed floor pads that the sows lay upon. The solar powered cooling system will be designed using a combination of internal expertise and an external engineering firm. Commercially available floor pads will be installed in a farrowing room at the WCROC facilities and be connected to the water cooling system. Evaluation of the cooling pad system will be completed to determine improvements in performance and comfort of sows and their piglets in research over 2 summers. An engineering firm will assist the project team to model and design energy-efficient cooling systems that can be retrofitted into conventional swine facilities. Most of the swine facilities located in Minnesota have standardized design and construction. Therefore, retrofit designs can be utilized extensively across the state. The intent is to use an electric powered chiller / air-source heat pump to provide chilled liquid for the cooling systems. Heat pumps, especially air-source heat pumps, can be retrofitted to existing swine facilities. Heat pumps have a coefficient of performance of 2.5 meaning for every unit of energy put into the system, 2.5 units are available for use. Therefore, heat pumps could be a novel, energy saving feature for swine facilities. Cooling systems will be utilized that can also be incorporated into existing facilities. Interface control systems will be developed to effectively manage the novel cooling systems.

In the WCROC farrowing building, the project team will use either commercially-available or custom fabricated floor pad coolers within sow farrowing stalls and heat pumps to provide the cool, circulating fluid. Farrowing stalls are challenging to maintain proper temperature as a producer wants to keep the sows cool (about 60 °F) while keeping the piglets warm and dry (about 86 °F). Pad coolers utilize plates of steel with cooling loops attached to the underside which allow liquid to circulate. The pads are placed in the sow's stall and cool liquid is pumped through the cooling loops. Pad coolers will cool the sows through direct contact as the sow will lay across the pad and allow the piglets to remain warm in a separate, adjacent area. The liquid can then return to the heat pump where there is a transfer of the heat to the exterior air. The pad cooler covers about 30 to 50% of the sow's lying area and body. The farrowing building has two rooms with each containing sixteen individual sow farrowing stalls. Within one room, each sow will be cooled with a pad cooler and heat pump(s). The other room will be operated as the Control Treatment using conventional, forced-air ventilation cooling.

The project team will begin field testing by commissioning the systems without pigs in the rooms. In months 1 through 10, the cooling pads and chiller will be ordered and installed. Following installation, the system will be commissioned over the course of two months to insure proper performance during the sow trial. The commissioning process will include:

- Calibrating and refining controls
- Measuring liquid cooling temperatures
- Modeling heat transfer performance
- Troubleshooting

Once the system and controls are fine-tuned, pigs will be added to the buildings. Testing with pigs is anticipated to begin in the second year of the project.

In the farrowing building, sows will be allotted randomly to one of the two treatments: forced air ventilation cooling (Control Treatment - Room 1) or chiller / heat pump with pad cooler (Pad Cooling Treatment - Room 2). Animal performance variables measured will include: individual sow body temperature, sow feed intake, changes in sow weight and backfat depth, piglet and litter weight gains, and number of days from farrowing (birthing) to re-breeding. Amount of feed consumed daily by each sow will be recorded. Initial and ending (weaning date) sow weights will be recorded. Body temperature and respiration rates of the sows will be measured and utilized as an indicator of heat stress experienced by the sow. Following completion of the initial testing period, the study will be replicated at least once (if appropriate weather conditions allow) with a second set of sows to increase statistical confidence. Mechanical performance measures will include electrical energy consumption including power consumed by the heat pumps and ventilation fans which will be measured along with the outdoor, room, and cooling loop (fluid) temperatures. Air temperature and quality will be important metrics so variables measured will include: room temperatures, responsiveness of cooling systems in maintaining setpoint temperatures, humidity levels, and concentrations of ammonia, hydrogen sulfide, carbon dioxide, methane, and nitrous oxide.

Outcomes will include information regarding energy savings and influences on pig performance. The information will then be used for the economic evaluation in Activity 3.

Reliability and durability of cooling systems are extremely important as equipment failure usually leads to compromised performance and in some situations could lead to death of a significant number of pigs. Swine production facilities are much harsher environments than office buildings with relatively high concentrations of dust, gases, and humidity, which increases the chances for physical damage to equipment. Typically, these undesirable components of air in the room are removed with exhaust air in a forced-air cooling system. Also, solar PV arrays may be exposed to harsher than normal conditions at a swine production facility. To characterize reliability of the solar PV and cooling systems, the project team will measure operational availability, hours of operation, energy production (solar PV), and maintenance and repair events. This information will be incorporated into an extension bulletin and be used to refine cooling system pre-designs for swine farrowing facilities (Activity 3).

Summary Budget Information for Activity 1:	**ENRTF Budget:**	**$ 272,860**
	Amount Spent:	**$ 270,516**
	Balance:	**$ 2,344**

Outcome	**Completion Date**
1. *Install solar PV collectors (20 kW) on the farrowing facility*	10/1/2016
2. *Design and install sow cooling systems including water-cooled pads for sows, heat pumps, and water delivery*	4/1/2017
3. *Field test and evaluate floor pad cooling for farrowing groups*	4/1/2019

Activity Status as of: January 1, 2017

This activity has received the most attention in the first 6 months of the project. We identified a supplier of the floor inserts that will cool the sows. The PI visited the manufacturer of the floor inserts this summer to ensure the product would work for our application. We have developed the appropriate mounting brackets that allow us to remove the existing floors from our farrowing stalls and replace them with the cooling floor inserts. Subsequently, we have ordered the flooring inserts and expect delivery in January, 2017. We established bid specifications for the solar PV system, offered those specifications to manufacturers and have selected Zenergy, LLC to supply and install the 20 kW solar PV system needed for this project. We expect installation in Spring 2017. We have also contracted with an engineering firm (AKF Engineering) to design the cooling system and controls for the system. AKF has made one site visit to begin development of the system. We have developed an initial draft of the barn protocol that will govern the conduct of the sow lactation experiment.

Activity Status as of: July 1, 2017

Report not submitted as per directions from LCCMR staff.

Activity Status as of: January 1, 2018

The floor inserts for cooling sows were received and installed early in 2017. The engineering design for the solar powered, sow cooling system was completed in the first quarter of 2017. The 20 kW solar PV system was installed using a ground mount in the spring. The entire cooling system to supply circulating cool water under sows was installed in May and June. The system was commissioned in early June. Unfortunately, only a very brief test of the system functionality (1 week) was conducted before sows had to be moved into the facility before farrowing (birthing). Sows moved into the facility on June 12 with anticipated farrowing dates of June 14 to 16. Sows remained in the facility until July 14. We planned to test the efficacy of the sow cooling system with this group of sows. However, two important factors subverted this objective. First, environmental temperatures during this period were not as hot as expected. Consequently, sows were not consistently heat stressed which prevented a true test of the cooling system. Second, there were intermittent disruptions in operation of the cooling system for a variety of reasons. Consequently, we used this sow group as a preliminary test of the cooling system and data collection systems.

From August 23 to September 22, we conducted a second trial. The cooling system worked much more reliably. To ensure heat stress of sows, we turned on furnaces in the farrowing facility to target a daytime temperature of about 85 degrees F and a nighttime temperature of about 70 degrees F. This approach ensured that sows were under consistent heat stress which enabled evaluation of the cooling system. The cooling system performed consistently with only a few minor glitches. We plan to repeat this trial and approach in spring and/or summer of 2018.

Activity Status as of: July 1, 2018

From May 29 through June 29, we conducted a third trial. The cooling system worked quite well and was much more reliable than in previous trials. Once again, we used the in-room furnaces to ensure that sows experienced heat stress so that we could effectively test the cooling potential of the system. The data collection portion of this third trial ended on June 29, 2018. In the coming weeks and months, we will summarize the animal performance, room conditions, and energy use data. After the data are summarized, we will begin preliminary statistical analysis and interpretation of the results.

Activity Status as of: January 1, 2019

From August 13 through September 7, we conducted a fourth trial of the solar-powered cooling system. The cooling system worked reliably and we used in-room heaters to ensure sows experienced heat stress during the lactation period. The artificial imposition of heat stress on sows allowed us to test the effectiveness of the cooling system. With completion of this fourth trial, we have three complete cohorts of data on which we can base our conclusions. In our original proposal, we planned to conduct this study with two groups of sows. But, we added a third group of sows so we have a more robust dataset for analysis. We have summarized data on the biological performance of the sows and are currently working on summarizing the rather large collection of raw data on energy use in the study rooms.

Final Report Summary (September 30, 2019):

Eighty-four sows and litters in three farrowing groups were studied to evaluate efficacy of the solar-powered cooling system. We consistently imposed heat stress on sows during farrowing and lactation periods to ensure an adequate test of the cooled floors. After an initial commissioning process, the floor cooling system functioned properly. Temperature of the floors that sows laid on in the Cool room were 5.7 °F cooler than similar floors in the Control (uncooled) room. Electricity use in the Cooled room was 160% to 260% of that used in the Control room. Most of this greater electricity use was attributable to operations of the heat pump, fan coil unit and pumps used to circulate cooled water through the system. The solar array produced enough electricity to meet the increased consumption of electricity in the Cooled room. The cooled floors (in combination with the cooled drinking water, see below) did alleviate a meaningful portion of heat stress experienced by sows. Rectal temperature of sows in the Cool room was significantly lower than body temperature of sows in the Control room. Furthermore, respiration rates of sows in the Cool room averaged 59 breaths per minute while sows in the Control room averaged 91 breaths per minute. Respiration rate is a very sensitive measure of heat stress in sows and would be about 30 breaths per minute when sows are housed in their most comfortable temperature range. Even though sows were more comfortable in the Cool room, there were no differences in the farrowing or postural behaviors of sows across rooms. Sows in the Cool room consumed more feed during lactation because they were more comfortable compared to sows in the Control room. However, the increased comfort and feed intake of sows in the Cool room did not improve sow or litter performance. Litter size weaned (11.2 vs. 11.4 pigs) and weight of litters at weaning (157.7 vs. 163.6 lbs) were not different statistically for Control and Cooled sows, respectively.

A comprehensive technical report has been submitted as an addendum to this final progress report. This technical report describes the conduct of the experiment and results in great detail.

ACTIVITY 2: Design, install and evaluate chilled drinking water system for pigs

Description: A second option to cool sows is to provide cool drinking water. Even though this seems to be obvious, initial testing has shown that drinking water in conventional farrowing facilities can warm up significantly and contribute to overheating animals. So chilling and recirculating the drinking water may be an effective approach to maintaining sows within their thermal neutral comfort zone. When sow body temperatures climb above the thermal neutral comfort zone, feed efficiency, reproductive performance, and litter performance can decline significantly.

In this activity, a cooling system that supplies chilled drinking water to sows will be designed by the project team and external consulting engineers. The team anticipates using the same chiller / heat pump used in Activity 1 to chill the drinking water. The system will be installed and evaluated in the farrowing building at WCROC. The system will be evaluated for its ability to provide chilled water consistently and reliably to sows over the two years of the project. Economic feasibility of the system will be determined considering costs of equipment, installation (including insulating water lines), maintenance, operation, and performance of sows. Electricity from the solar PV array will be used to power the system. Sows will be allotted randomly to one of the two treatments: conventional drinking water (Control Treatment - Room 1) or chilled drinking water (Chilled Water Treatment - Room 2). Animal performance variables measured will include: individual sow body temperature, sow feed intake, changes in sow weight and backfat depth, piglet and litter weight gains, and number of days from farrowing (birthing) to re-breeding. Amount of feed consumed daily by each sow will be recorded. Initial and ending (weaning date) sow weights will be recorded. Body temperature and respiration rates of the sows will be measured and utilized as sensitive indicators of heat stress experienced by the sow. Following completion of the initial testing period, the study will be replicated at least once (if appropriate weather conditions allow) with a second set of sows to increase statistical confidence. Water temperature of the system will be measured for both the control and chilled water treatments. Temperature of the drinking water will be measured as it enters the building, after chilling (chilled water treatment), and at various points within the farrowing room. Energy consumed in chilling the drinking water will be measured.

Summary Budget Information for Activity 2: **ENRTF Budget: $139,434**
Amount Spent: $134,689
Balance: $ 4,745

Outcome	Completion Date
1. *Design and install a chilled drinking water system in the sow farrowing facility*	4/1/2017
2. *Field test and evaluate the chilled drinking water system in the sow farrowing facility*	4/1/2019

Activity Status as of: January 1, 2017

Much of the work completed in Activity 1 also applies to this Activity. Selection of a solar PV supplier and engineering firm for design work applies to this activity as well. In addition, we have investigated equipment to allow remote, continuous monitoring of sow body temperatures during the sow lactation experiment.

Activity Status as of: July 1, 2017

Report not submitted as per directions from LCCMR staff.

Activity Status as of: January 1, 2018

Much of the work completed in Activity 1 also applies to this Activity. The cooling system for drinking water was designed by the same engineering firm used for Activity 1. The cooled drinking water system was installed at the same time as the cooling system for flooring. The first group of sows through the facility was used as a preliminary test as described in Activity 1. The second group of sows was used for full data collection under heat stress conditions. We used the continuous body temperature monitoring system in sows of both groups with limited success. There was not good retention of body temperature sensors in large sows.

Activity Status as of: July 1, 2018

Much of the work completed in Activity 1 also applies to this Activity. The cooled drinking water system worked reliably during the third trial of this project. Once again, we used a system to continuously measure internal body temperature of sows over selected 2-day periods as we did in the previous trial. This time, we achieved excellent retention of the sensors in sows during the first week of lactation. During the last week of lactation when suckling pigs were larger and more active, retention of the sensors was not as good; but still better than the comparable period in the last trial.

Activity Status as of: January 1, 2019

As in previous reports, much of the work described in Activity 1 also applies to this Activity. As mentioned previously, we conducted the study on a third group of sows. However, we did not use the continuous internal body temperature sensor system in sows of this last group. Because of our previous difficulties with retention of sensors, we opted not to use the continuous body temperature monitors in this last group of sows.

Final Report Summary (September 30, 2019):

As noted previously, much of the work related to Activity 2 was related closely to the work in Activity 1. The system to supply cool drinking water to sows functioned properly throughout all three farrowing groups. Temperature of drinking water ranged from 58 °F to 74 °F in the Cool room (average = 63.3 °F) and 64 °F to 106 °F in the Control room (average = 82.9 °F). This significant reduction in drinking water temperatures for sows in the Cool room is partially responsible for the increased comfort and feed intake of sows in the Cool room compared to the Control room (see Activity 1 above). However, providing cooled drinking water to sows did not have a statistically significant influence on drinking behavior of sows during the short observation periods of this experiment. We believe cool drinking water may increase drinking time of sows but we might have to observe sows for much longer periods of time (e.g. 12 to 24 hours) to detect this difference in behaviors. Providing cooled drinking water to sows may be a more practical, cost-effective approach to cooling heat-stressed sows compared with installing cooled flooring for sows.

A comprehensive technical report has been submitted as an addendum to this final progress report. This technical report describes the conduct of the experiment and results in great detail.

ACTIVITY 3: Perform economic analysis and disseminate results of system evaluations

Description: A basic cost-benefit analysis will be developed comparing the conventional and energy-optimized systems. Basic economics will be evaluated in terms of capital expense, operational and maintenance costs, pig performance, and energy savings. A closeout spreadsheet model will be developed for the farrowing treatments. The spreadsheet will include the capital and operating costs from each system and will project simple payback using performance information observed during the farrowing facility trials. A spreadsheet will be developed for swine producers so they can model their own potential return on investment for the energy-efficient cooling system retrofits. The results of the study will be transferred to swine producers through a variety of methods including presentations and tours at the Midwest Farm Energy Conference in Summer 2017 focusing on swine production facilities, development of an extension bulletin, a dedicated web page, news articles in agricultural magazines, summaries on the University of Minnesota Extension Swine webpage, peer-reviewed publications, and through presentations to swine producers at industry meetings. The information will be incorporated into an extension bulletin and be used to refine cooling system pre-designs for swine farrowing facilities.

Summary Budget Information for Activity 3: **ENRTF Budget: $62,706**
Amount Spent: $ 55,567
Balance: $ 7,139

Outcome	Completion Date
1. *Perform a basic economic analysis on the solar PV and sow cooling systems.*	4/1/2019
2. *Develop an extension bulletin with results as well as pre-design examples for the solar PV and sow cooling systems that producers may use as guides. The extension bulletin will be printed and placed on-line.*	4/1/2019

3. *In each of the first two years of the project, the project and preliminary results will be discussed at 3 or more producer / professional meetings. In Year 3, the team will organize three informational meetings in key swine production areas of Minnesota.*	6/1/2019

Activity Status as of: January 1, 2017

There has been no progress on this activity because we need to have the system in place and operational before there are any data to evaluate or disseminate.

Activity Status as of: July 1, 2017

Report not submitted as per directions from LCCMR staff.

Activity Status as of: January 1, 2018

There has been no progress on this activity because we need to generate sufficient data to ensure the system is working properly and that we have adequately characterized the sows' responses to the cooling systems.

Activity Status as of: July 1, 2018

As mentioned in Activity 1, we are summarizing the animal performance data and energy use data. These summaries will inform the economic analysis of the system. A University of Minnesota undergraduate student in Economics is serving as a 2018 summer intern on this project. This student is working on summarizing the economic implications of this cooling system under the direction of the project team.

Activity Status as of: January 1, 2019

The undergraduate intern hired to work on this project determined that the economic returns generated from improved performance of sows was not sufficient to cover the cost of the sow cooling system within a reasonable period of time. So, we are delving further into the economic analysis to determine the impact of the sow cooling system on energy use within the farrowing rooms. Possibly, differences in energy use elicited by the sow cooling system may improve the economic returns to the system. We are currently summarizing the energy use data so that economic calculations can be applied.

Final Report Summary (September 30, 2019):

We divided our economic analysis into two categories: 1. costs associated with installation and operation of the sow cooling systems, and 2. Costs associated with installation of the solar array. The capital costs for the sow cooling system (cool floors and cooled water) totaled $178,865 to equip 16 farrowing stalls for a cost of $11,179 per stall. If one depreciates these capital costs over a 20-year period, the annual per stall capital cost is $559 per stall. These "per stall" costs could be reduced substantially if a larger number of stalls were equipped with the cooling equipment so that the equipment costs could be spread over more stalls. The engineering design firm for the sow cooling system estimated annual operation and maintenance costs of the cooling system equipment would be about 0.5% of the equipment cost ($148,865) which amounts to $744 per year.

The 20 kW solar PV array was of sufficient size to produce electricity in excess of that needed to operate the cooling system during the hot summer months. The solar array also produced electricity during periods of the year when the sow cooling system was not needed. This excess electricity could be used other places on the farm to displace electricity purchased from the grid or sold back on the grid in certain situations. The National Renewable Energy Lab (NREL) aggregates and models solar PV costs using data from actual installations around the country and estimated operations and maintenance (O&M) costs at $13/kW/yr in 2018. A basic financial assessment of the 20 kW solar PV system installed at the WCROC was conducted. Electricity pricing and tariff fees were used from the bills submitted to the West Central Research and Outreach Center from Runestone Electric Association (REA). REA is a rural electric cooperative. Results of this economic analysis will vary significantly between rural electric cooperatives and investor owned utilities. Considering the capital costs, value of the power produced, and fees charged by the utility; the 20 kW solar PV system will breakeven after 60 years on a straight cash basis (revenues minus expenses). When tax incentives are added and fully utilized, the breakeven point is between 8 and 12 years. The tax incentives include an investment tax credit that currently is 30% in 2019 and will decline each year. The second tax advantage is accelerated depreciation which allows the system to be fully depreciated in either one year or five years. There are two key takeaway points and recommendations on financial viability of solar PV systems on farms. The first recommendation is to research the electricity pricing, incentives offered, and fees charged by the local utility. Again, these will all vary significantly across electricity utilities. The second, and perhaps most important recommendation, is to determine if available tax incentives can be fully utilized and the value completely realized by the individual or farming operation.

A Life Cycle Assessment (LCA) of the carbon and energy footprints of the sow cooling system was completed. Sow and litter performance were not improved by the sow cooling system. Consequently, there were no increases in output (number or weight of weaned pigs) of the farrowing system. Because there was no increased output as a result of the cooling system, neither the carbon footprint nor the energy footprint of the farrowing operation were improved by the cooling system. However, using electricity generated by the solar PV system did substantially reduce the carbon footprint and also significantly reduced the consumption of energy derived from fossil fuels. A complete technical report on the LCA methodology and results has been submitted as an addendum to this final report.

V. DISSEMINATION:

Description: Results of this project will be disseminated through several methods. In summer 2017, the West Central Research and Outreach Center will host the Midwest Farm Energy Conference. Attendees expect to include livestock producers, energy professionals, students and other stakeholders. At the conference, results of this project will be presented and there will be a tour of the solar energy systems at the WCROC Swine Research Unit (as long as biosecurity protocols can be met). Initial results will be discussed at three or more meetings with swine producers, swine industry professionals, or energy professionals in each of the first two years of the project. In Year Three, the project team will organize three informational meetings in key swine production areas of Minnesota. The meetings will focus on disseminating the results to swine producers and the professionals that consult with swine producers. The results will also be disseminated on-line on the WCROC website as well as the University of Minnesota Swine Extension Team website. An extension bulletin with the project results and retrofit pre-designs will be printed and provided to swine producers and other stakeholders. We also anticipate publishing results in academic journals, local and regional newspapers, and industry magazines.

Status as of: January 1, 2017

There has been no dissemination of data in the project because we are in the initial phases of developing the system. We have discussed this project with many stakeholders in related industries in numerous informal settings. A committee has been established and has met four times to plan the 2017 Midwest Farm Energy Conference (MFEC). The MFEC conference will be held June 13th and 14th. The June 14th session will include presentations about this research as well as tours.

Status as of: July 1, 2017

Report not submitted as per directions from LCCMR staff.

Status as of: January 1, 2018

The Midwest Farm Energy Conference was held at the West Central Research and Outreach Center on June 13 and 14, 2017. A tour of the farrowing facilities was included in the conference agenda. About 35 people participated in the tour. The sow cooling systems were in place and operating at the time of the conference. Sows were present in the farrowing facilities but they had not farrowed at the time of the tour. As a result of the conference tour, an article on the project appeared in *The Farmer* magazine in July, 2017. Furthermore, we wrote a short article entitled “Using sun to keep sows cool” that appeared in the August issue of the WCROC Newsletter and currently resides on the WCROC website.

Status as of: July 1, 2018

Without complete results, there was not much to share with stakeholders in the first half of 2018. Two members of the project team did a radio interview with Linda Brekke from the Linder Farm Network. The interview aired on the Linder Farm Network over the noon hour in January. The Linder Farm Network based in Owatonna, MN reaches farmers throughout Minnesota. In addition, the Project Director included information on this project as part of his presentation on the SowBridge educational series in May. SowBridge is an educational program targeted toward animal caretakers on sow farms throughout the U.S. Over the past several years, SowBridge subscribers have resided in 16 U.S. states (Minnesota included), Canada, and Ireland.

Status as of: January 1, 2019

We are working to complete analysis of results related to biological performance and energy use. With this complete summary and analysis, we can provide a complete picture of the results for pork producers and industry professionals to evaluate the utility of the solar sow cooling system. We will present our results at the 3rd Midwest Farm Energy Conference held at WCROC on July 10 and 11, 2019. In addition, we will submit an abstract for presentation at the Waste-to-Worth Conference held at the University of Minnesota (Minneapolis) in April, 2019. We also plan to present our results at the Minnesota Pork Congress (February, 2019) and at the annual meeting of the MinnKota Builders Association at a location yet to be determined (March, 2019). We will also prepare summaries for pork industry trade publications such as the National Hog Farmer magazine and a complete research paper for a peer-refereed scientific journal such as Applied Engineering in Agriculture.

Final Report Summary (September 30, 2019):

Information related to this project has been disseminated to many different audiences in a variety of formats. Below are listed the publications related to this project. Any of these publications are available upon request from the project PI. More publications are anticipated in the future.

Video:

Cooling Sows and Heating Piglets with Solar Energy.
https://www.youtube.com/watch?v=F8CwSZnyJq4&feature=youtu.be

Factsheets:

WCROC Farrowing Barn Heating and Cooling System. West Central Research and Outreach Center, Morris, MN. January 2019. https://z.umn.edu/4nv3

Lactating Sow Performance with Solar-Powered Cooling. West Central Research and Outreach Center, Morris, MN. September 2019. https://z.umn.edu/4nv4

Conference presentations and posters for industry and professional audiences:

Johnston, L. J. 2019. Cooling sows and heating piglets with solar energy. Midwest Farm Energy Conference, Morris, MN. July 11, 2019.

Lozinski, B. M., M. Reese, E. Buchanan, A. M. Hilbrands, K. A. Janni, E. Cortus, B. Hetchler, J. Tallaksen, Y. Li, and L. J. Johnston. 2019. Innovative solar energy utilization for Minnesota swine farms. Proceedings paper and poster for Waste-to-Worth Conference, Minneapolis, MN. April 24, 2019.

Lozinski, B., M. Reese, E. Buchanan, A. M. Hilbrands, K. A. Janni, E. Cortus, B. Hetchler, J. Tallaksen, Y. Li, and L. J. Johnston. Innovative use of solar energy to mitigate heat stress in sows. Univ. of Minnesota Department of Animal Science Showcase. St. Paul, MN. April 3, 2019.

Li, Y., M. Lou, M. Reese, E. Buchanan, and L. Johnston. 2019. Effects of cooled floor pads and cooled drinking water on behavior of lactating sows under heat stress. Midwest Section of American Society of Animal Science. Omaha, NE. March 12, 2019.

Johnston, L.J. 2019. Innovative Solar Energy Utilization for Minnesota Farms. Presented to Minnkota Builders Assoc. Mtg. Morris, MN. March 15, 2019.

Johnston, L. J. 2018. WCROC's Greening of Agriculture Project. USDA Roman L. Hruska Meat Animal Research Center, Clay Center, NE. September 6, 2018.

Johnston, L. J. and B. T. Richert. 2018. Heat Mitigation for Sows. SowBridge. May 2, 2018.

Articles in newsletters and popular press:

Johnston, L., M. Reese, E. Buchanan, Y. Li, K. Janni, E. Cortus, J. Tallaksen, and K. Sharpe. 2019. Cooling sows with solar power. West Central Research and Outreach Center Newsletter. August, 2019. https://wcroc.cfans.umn.edu/wcroc-news/cooling-sows

Johnston, L., B. Lozinski, M. Reese, E. Buchanan, Y. Li, A. Hilbrands, K. Janni, B. Hetchler, and E. Cortus. 2019. Can the sun cool sows? *Land Magazine*, Swine and U column. June 28, 2019.

Johnston, L., M. Reese, E. Buchanan, Y. Li, K. Janni, and K. Sharpe. 2018. Solar cooling of sows. *Morris Sun Tribune Ag Supplement*. March, 2018.

Morrison, L. 2017. Using the sun to keep sows cool: Morris research farm testing innovative energy practices in swine production. *The Farmer Magazine* – News Briefs. July, 2017. (Freelance article covering our project.)

Johnston, L. J. 2017. Reducing fossil fuel use in swine production – One piece at a time. MN Pork Congress. Minneapolis, MN. January 18, 2017.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Overview Explanation
Personnel:	$ 228,510	Staff to coordinate project, collect and organize data, and assist in disseminating results including: Project Coordinator at 0.4 FTE Yr 1 and 0.5 FTE Yr 2 and 3 ($97,232); 3 Student interns Yr 2 & 3 ($17,148); Junior Scientist Yr 2 ($52,137); Research Fellow 0.5 FTE Yr 1 and 0.24 FTE Yr 2 ($61,993)

Budget Category	$ Amount	Overview Explanation
Professional/Technical/Service Contracts:	$ 98,000	Contracts for engineering design and system installation including: $30,000 for engineering professional services, $35,000 for General Contracting of Cooling System installation, $20,000 for General Contracting of Solar PV installation, $3,000 for Mechanical Contractor for Energy Sensor and Meter installation, and $10,000 for Control System installation. These professional services will be bid through a RFP process following University of Minnesota purchasing policy.
Equipment/Tools/Supplies:	$ 9,000	Energy and temperature sensors for sow facilities and animals including the potential for approximately 32 electronic temperature sensors for sows, 64 water temperature sensors, 12 electrical current sensors and data loggers.
Capital Expenditures over $5,000:	$ 130,425	Chiller / air source heat pump to cool water ($50,000), 20 kW solar PV system and cooling systems for sow farrowing facilities ($60,425), Controls for sow and water cooling systems ($20,000)
Fee Title Acquisition:	$NA	
Easement Acquisition:	$NA	
Professional Services for Acquisition:	$NA	
Printing:	$ 3,600	Printing of an extension bulletin to disseminate to swine producers, their consultants, and energy professionals (300 copies @ $12 each)
Travel Expenses in MN:	$ 5,465	Travel from Saint Paul to Morris to setup experiments and to collect data (10 trips, 330 miles each, $.565/mi). Travel to regional, in-state swine producer meetings to disseminate results (At least nine total trips @ $400 each including mileage, room, and meals).
TOTAL ENRTF BUDGET:	**$ 475,000**	

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than $5,000:
The University of Minnesota West Central Research and Outreach will purchase a 20 kW solar photovoltaic system ($60,425) which will produce electricity for the on-site sow farrowing facility. Energy production, availability, and other variables important to economic feasibility will be measured. In addition, the solar PV system will be used to power sow cooling systems including a chiller / heat pump. The chiller / heat pump will be installed within the sow farrowing system and produce chilled water for the sow cooling pads and chilled drinking water. The cooling system will cost approximately $50,000. The sow cooling systems will need dynamic control capabilities to measure and adjust temperature so a control system will be purchased ($20,000). Funding for installation of these components is included in the Contract budget line.

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation:
Averages 1.2 FTE per year over three years. Cumulative FTE 3.64

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: Approximately 2.4 FTE total (year 1).

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
U of MN Indirect Cost Recovery / In-kind	$123,019	$	Indirect costs associated with normal operation of the University of Minnesota will be used as in-kind cost share.
State			
	$	$	
TOTAL OTHER FUNDS:	**$123,019**	**$**	

VII. PROJECT STRATEGY:

A. Project Partners:
Dr. Lee Johnston, U of MN WCROC Director of Operations and Swine Scientist, will serve as the principle investigator and project manager. He will be responsible for all reports and deliverables. Dr. Kevin Janni (U of MN Agricultural Engineer) will be a co-investigator and provide guidance on cooling system designs and testing in the swine facilities. He will also participate in the outreach activities. Mike Reese (WCROC Renewable Energy Director) will serve as a co-investigator and assist in the design, installation, testing, and control strategies of the solar energy portions of the cooling systems. He will also assist in coordinating with other ongoing energy projects at WCROC and help disseminate results. An engineering firm will be solicited through a RFP and will provide consulting services for designing, commissioning, and control strategies. An agricultural economist (yet to be named) will assist in the economic analysis of the solar systems.

B. Project Impact and Long-term Strategy:
The WCROC has a 10-year strategic plan to reduce consumption of fossil fuel and reduce the carbon and environmental footprint within production agriculture. This proposal builds upon current projects including 2014 ENTRF funding for the solar PV system on the WCROC grow-finish swine facility, energy audit, and modeling ($500,000). Long-term funding will continue to be sought to research alternatives to fossil energy within all agricultural crop and livestock enterprises through federal, state, and stakeholder groups.

C. Funding History:

Funding Source and Use of Funds	Funding Timeframe	$ Amount
2014 ENTRF – Phase 1 – "Transitioning Minnesota Farms to Clean Energy" to audit energy consumption in conventional swine production facilities, model optimal clean energy systems, and evaluate performance	July 2014 to June 2017	$500,000
University of Minnesota College of Food, Agricultural, and Natural Resource Sciences for additional research support to develop and evaluate clean energy systems for agricultural	July 1, 2013 to June 2015	$167,061

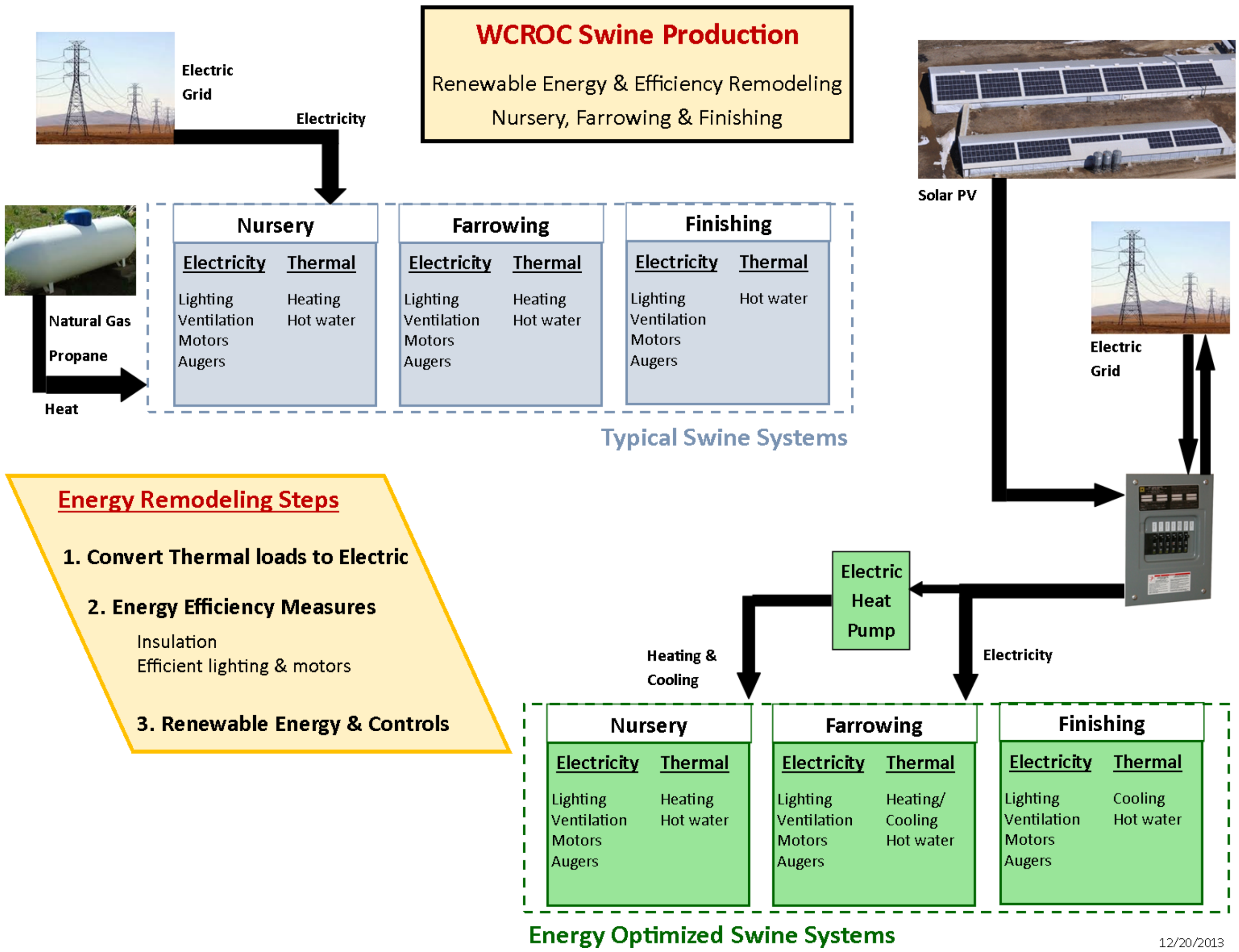
Funding Source and Use of Funds	Funding Timeframe	$ Amount
production systems including crop (feed), dairy, and swine production		
University of Minnesota Initiative for Renewable Energy and the Environment – Establishment of baseline energy consumption of dairy and crop / feed production systems	Through January 2016	$350,000

VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS: Not applicable

IX. VISUAL COMPONENT or MAP(S):

Environmental and Natural Resources Trust Fund
2016 Visual Graphics
Project Title: Solar Energy Utilization for Minnesota Swine Farms—Phase 2

Graphics 1. Schematic representation of the energy-optimized WCROC swine facilities



The project team has received past funding from the Environment and Natural Resources Trust Fund to audit energy consumption and install a 27 kW solar photo voltaic system for the WCROC swine facilities. Funding is being requested from LCCMR in this proposal to install a second 20 kW solar photo voltaic system. These two solar electric generation systems will provide electricity for their respective buildings. The primary purpose of this proposal is to develop effective uses for the solar power generated on swine farms. So therefore, additional funding is being requested to evaluate and optimize the local use of the solar energy on Minnesota swine farms by installing electric heating and cooling systems within the facilities. Using novel solar electric-powered heating and cooling systems will enable the increased utilization of locally-produced renewable energy and have the added potential to lower ventilation rates and thus emissions of odor, greenhouse gases, and dust in exhaust air, reduce water usage, and lower the carbon footprint of Minnesota-produced pork.

X. RESEARCH ADDENDUM: The following addenda are included with this report:

1. Factsheet: WCROC Farrowing Barn Heating and Cooling System
2. Factsheet: Lactating Sow Performance with Solar-Powered Cooling
3. Technical report: Effects of a Solar Cooling System on Sow Performance
4. Technical report: Life Cycle Assessment of Cooling Sows Using Solar Electricity

XI. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted no later than January 1, 2017; July 1, 2017; January 1, 2018; July 1, 2018; and January 1, 2019. A final report and associated products will be submitted between June 30 and September 30, 2019.

Project Length and Completion Date: 3 Years, June 30, 2019
Date of Report: September 30, 2019

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	$ Spent as of 6/30/19	Activity 1 Balance	Activity 2 Budget	$ Spent as of 6/30/19	Activity 2 Balance	Activity 3 Budget	$ Spent as of 6/30/19	Activity 3 Balance	TOTAL BUDGET	FINAL TOTAL BALANCE
BUDGET ITEM	*Install/ evaluate solar PV & sow cooling*			*Install/ evaluate chilled sow drinking water*			*Perform economic analysis & outreach*				
Personnel (Wages and Benefits)	**$86,502**	$86,502	$0	**$86,502**	$86,502	$0	$55,506	$53,023	$2,483	$228,510	$2,484
Eric Buchanan, Project Coordinator: $97,232 (.4 FTE Yr 1, .5 FTE Yrs 2 & 3) 72.6 % Salary and 27.4% Fringe Rate											
Junior Scientist, Technician for data collection, system testing: $52,137 (1 FTE Yr 2) 72.6 % Salary and 27.4% Fringe Rate											
Brian Hetchler, Research Fellow, Facilility data collection and testing: $61,993 (.5 FTE Yr 1, .24 FTE Yr 2) 72.6% salary and 27.4% Fringe Rate											
Undergrad Student Interns to evaluate Clean Energy Technology for MN Swine Farms as well as help with Economic Analysis: $17,148 (2 summer interns in Yr 2 & 1 summer intern in Yr 3) 100 % Salary and 0% Fringe Rate											
Professional/Technical/Service Contracts											
AKF Engineering (or equivalent firm) - Professional design and commissioning engineering services. AKF Engineering is working on past phases. Contracts will be bid /awarded based on U of MN purchasing policy.	**$22,000**	$21,824	$176	**$8,000**	$6,611	$1,389				$30,000	$1,564
General Contractor TBD - Installation of Cooling Systems. Contracts will be bid /awarded based on U of MN purchasing policy.	**$20,000**	$20,000	$0	**$15,000**	$12,094	$2,906				$35,000	$2,906
General Contractor TBD - Installation of Solar PV Systems Contracts will be bid /awarded based on U of MN purchasing policy.	**$20,000**	$20,000	$0							$20,000	$0
Mechanical Contractor TBD - Installation of energy and temp meters / sensors. Contracts will be bid /awarded based on U of MN purchasing policy.	**$1,500**	$1,500	$0	**$1,500**	$1,500	$0				$3,000	$0
Mechanical Contractor TBD - Installation of control systems in swine facilities. Contracts will be bid /awarded based on U of MN purchasing policy.	**$7,000**	$5,620	$1,380	**$3,000**	$3,000	$0				$10,000	$1,380
Equipment/Tools/Supplies											
Sensors and Meters - For measurement of energy consumption and temperature in swine facilities and in animals (temperature only).	**$4,500**	$4,500	$0	**$4,500**	$4,050	$450				$9,000	$450
Capital Expenditures Over $5,000											
Chillers / Air Source Heat Pump(s) and Cooling Pads for Swine Farrowing Facility	**$38,000**	$37,457	$543	**$12,000**	$12,000	$0				$50,000	$543
20 kW Solar Photovoltaic System for Swine Farrowing Facility	**$60,425**	$60,178	$247							$60,425	$247
Controls for Pad and Chilled Water Cooling Systems	**$12,000**	$12,000	$0	**$8,000**	$8,000	$0				$20,000	$0
Fee Title Acquisition											
Easement Acquisition											
Professional Services for Acquisition											
Printing											
Printing of outreach materials / extension bulletin for swine producers and energy / swine facility professionals (engineers, etc) - 300 @ $12 ea							$3,600	$978	$2,622	$3,600	$2,622
Travel expenses in Minnesota											
Ten trips by Janni / Hetchler from St. Paul to Morris (330 miles @ $.565 /mi	**$933**	$933	$0	**$932**	$932	$0				$1,865	$0
In-state travel by project team to regional outreach events and meetings (At least 3 events per year)							$3,600	$1,567	$2,033	$3,600	$2,033
Other											
									$0	$0	$0
COLUMN TOTAL	**$272,860**	**$270,516**	**$2,344**	**$139,434**	**$134,689**	**$4,745**	**$62,706**	**$55,567**	**$7,139**	**$475,000**	**$14,228**