Proposal No. __________

The Andersons Research Grant Program

Project Title: **Wireless Sensors for Quality Monitoring and Management of Stored Grain Inventories**

Project Contact (list one person to act as the primary contact):

Principal Investigator(s)/ Name:	Institution/Agency/Other
Dirk E. Maier	Iowa State University

(Attach an additional sheet if more space is needed.)

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Period of Proposed Project Dates:

Beginning: 3/1/2018 Ending: 2/29/2020

Amount Requested ($50,000):

Year 1: $25,000 Year 2: $25,000

PROBLEM IDENTIFICATION AND RELATED RESEARCH

The number of food insecure people in the world has been estimated at more than 870 million (FAO et al., 2012). With continued population growth, more food production will be required with lower resource inputs such as labor, fertilizer, water and land. This is a challenge that cannot be met by focusing exclusively on increasing food production. As a result, reducing post-harvest loss has been recognized as a vital tool for meeting global food and energy needs (FAO, 2014; World Bank et al., 2011).

The most significant sources of post-harvest loss are insect infestation and grain spoilage. These result in loss of product quality and quantity (shrink loss) as well as income loss due to discounts at the first point of sale. In order to minimize these types of loss, it is important to keep grain conditions consistently dry and cool. These conditions are achieved through drying and aerating processes. While these are not novel procedures, their success can be influenced by several factors such as airflow patterns through the grain mass and weather conditions affecting the stored grain ecosystem. Additionally, even grain that has been handled properly may develop adverse conditions due to insect infestations, moisture condensation, and weather effects. In order to ensure grain quality and food safety, monitoring grain conditions during aeration and storage is an important strategy to address overall stored grain quality.

The most common monitoring system currently used in stored grain bulks relies on temperature cables that are hung in a bin, silo, tank or building from the roof rafters. While temperature cables remain an important tool they have several limitations and disadvantages. For instance, temperature cables are limited by the number of sensors that can be mounted on them and by the number of cables that can be hung from the roof without jeopardizing load limits. As a result, the grain mass can be monitored only at a fixed number of locations. Also, temperature cables are not commonly placed near the side walls of the bin, limiting the ability to reliably monitor the perimeter of the silo where external solar radiation substantially influences grain temperature and moisture changes that can cause grain spoilage and wall caking. This limits the likelihood that potential grain storage problems will be detected in a timely manner. The grain mass surface and perimeter areas are also typically the first areas in the storage structure to be infested by insects. More recently, moisture sensing cables have been introduced that monitor temperature and relative humidity of the interstitial air at fixed locations and calculate the equilibrium moisture content of the surrounding grain mass. The actual sensors are visible as peanut-size knots on the cables and as a result cause substantially greater frictional loads on roofs than temperature cables. Thus, they have even greater constraints than temperature cables in terms of the number of locations that can be monitored in a stored grain mass.

Eliminating temperature and moisture cables from grain storage structures by providing an alternative grain monitoring system would therefore be beneficial for a number of reasons. Foremost, it reduces structural roof loads as cables would no longer be connected to roofs. Given increased storage bin sizes with diameters of up to 154 feet more and more expensive structurally engineered steel beams are required to account for the load cables exert on roofs as a result of frictional forces. A novel stored grain ecosystem monitoring technology[1] that allows for the monitoring of temperature, relative humidity, volatile organic compounds, and pressure within the stored grain porous media ***wirelessly*** is being developed by Amber Agriculture. Their technology consists of low-power wireless sensors that capture and transmit key quality

[1] https://www.engadget.com/2017/01/06/ambers-sensors-aim-to-save-farmers-grain-from-spoilage/

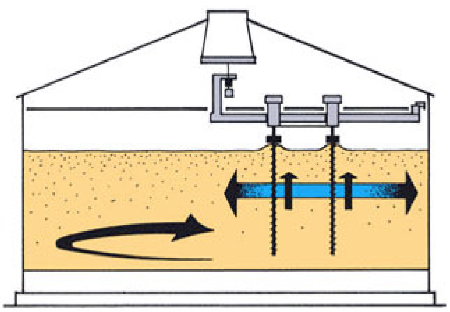
conditions throughout the storage season (Figure 1). These sensor pellets, distributed throughout the grain mass, will report real time grain conditions through a smart phone app and can control aeration fans to operate at optimum times to condition stored grain automatically throughout the year. The technical feat of the sensor is its low-power requirement and thus its capability to last through a full storage season (up to 14 months). Leveraging cloud-computing algorithms based on grain science principles, localized weather data from the attached weather hub (see Figure 1 top left) can condition stored grain to the right moisture content to minimize shrink loss by factoring in the operator's expected delivery date.

FIGURE 1
(Innovation and Value Proposition)

This new technology has great potential to improve stored grain quality and to aid in scientific investigations of the stored grain environment. However, there are a number of uncertainties that must be further researched before scale up and commercialization. Although highly promising, use of this new technology has not yet been demonstrated throughout a full grain storage season in combination with intermittent aeration. Additionally, while the sensor network can determine the vertical position of the sensor pellets in the grain mass, there is no current method to determine where the sensors self-position horizontally throughout the grain mass. Horizontal distribution of the sensor pellets is a function of vertical gravity flow of grain into the storage structure and speed of the horizontal flow along the grain surface. Determining the horizontal distribution tendencies of the Amber sensors is critically important in evaluating whether they can monitor grain conditions in a representative manner (including grain mass core and perimeter) equal or ideally better than temperature (and moisture) cables. Wireless sensors need to result in a competitive advantage over the existing cable technology in terms of sensor distribution, system costs, and ease of use (including recovery of the sensors during bin unloading). If wireless sensors were to accumulate in a particular location (e.g., within 10 ft of the core at any depth) the sensors may need to be redesigned in terms of shape and density to change their flow behavior within the vertical and horizontal grain stream during bin filling.

Another advantage of the Amber Agriculture remote sensor technology is its capability to measure carbon dioxide (CO_2) concentrations through measurement of volatile organic compounds. Carbon dioxide measurements can be used as an early warning indicator of the onset of spoilage and as a means of detecting insect infestations. The Andersons Research Grant Program funded the PI's early work in the 2000s on the use of CO_2 as an indicator of spoilage. This technology has since been adopted by the global grain industry via off-the-shelf handheld sensors and three companies offering CO_2 sensing as part of automatic stored grain monitoring systems (AgriDry/GSI/AGCO, OPIsystems, CropProtetcor).

Additional research has recently been conducted on the use of CO_2 concentration values to predict number of insects active in a stored grain mass by calculating the amount of CO_2 produced per insect (Chotikasatian, 2017). This work continues at Iowa State University in collaboration with colleagues from Kasetsart University in Thailand. Its potential to provide an insect presence diagnostic tool would be improved with more accurate and spatially specific sensing technology such as the Amber wireless sensors. If these remote sensors were used to detect CO_2 values continually and throughout the stored grain mass, that would expand the application potential of this research to detecting localized insect infestations early. Being able to determine the probable location and size of an insect infestation in a grain mass well before a serious outbreak could inform the stored grain manager's decision regarding the most viable insect suppression intervention as well as determine its effectiveness afterwards in terms of reinfestation (or ideally not). Similarly, the location of the onset of spoilage due to mold activity within the grain could also be determined. This is currently not possible with existing CO_2 detection systems because they have to be installed in the headspace.



A grain stirring machine is a technology that originated in the 1960's to improve mixing of grain during in-bin drying in order to avoid overdrying of the bottom layers and ensure more uniformity of moisture content from the bottom to the top of the grain mass. Grain stirring can also be used to prevent formation of and break-up existing hot spots caused by insect infestation and/or mold spoilage. The technology consists of one or two vertical augers mounted on a rotating shaft that are moved in a circular fashion around the grain mass, and back and forth along the bin radius from center to perimeter creating upward movement of grain as illustrated in Figure 2 (see http://www.althoffsales.com/neco-stir-rite.php). The Iowa State University research farm has a grain bin fitted with a grain stirring system that will be used in this project to investigate the horizontal dispersion of the wireless sensors. This will be accomplished by intermittently operating the stirring augers and disturbing the grain mass in a controlled manner to dislocate the sensor pellets presumably horizontally upward. Given each sensor's built-in capacity to sense pressure differences due to elevation changes (i.e., vertical grain depth), disturbance by the stirring augers at a known radius would identify the horizontal location of a sensor. Using this technique, it would be possible to identify the number of sensors within specified radial bands and therefore determine the effectiveness of sensor distribution as a result of initial grain flow into the bin. This would allow for evaluation of the potential effectiveness of the wireless sensors to monitor grain conditions in a representative manner.

In order to better understand the stored grain ecosystem, numerous efforts have been undertaken to model it as a porous media using computational fluid dynamics. While these efforts have seen some success, the use of commercial fluid dynamics software limits the ability to expand the scope of investigation into novel areas and to make the resulting model available to other researchers and end users. However, a novel three dimensional finite element model coded in Fortran was developed by the PI (Maier) and one of his former Ph.D. students (Dr. Johnselvakumar Lawrence) as part of his dissertation research. The model was validated with experimental data and used to analyze biological changes in the form of dry matter loss of grain due to seed respiration, fungal infection and insect development as a function of aerating with ambient air under U.S. and Indian subcontinent climate conditions (Lawrence and Maier, 2011). This model was expanded from previous two dimensional models developed by another of the PI's Ph.D. students (i.e., Montross et al., 2002, Montross, 1999), and by Thorpe (1997). The Maier-Lawrence model has since been expanded as part of a current Ph.D. dissertation research through a fellowship project[2] funded by the Australian Plant Biosecurity Cooperative Research Center (PBCRC). The main advancements of the resulting Maier-Lawrence-Plumier (MLP) 3D ecosystem model are the prediction of: (1) chemical concentrations (PH_3, CO_2) throughout the stored grain porous media, (2) fumigant leakage from the bin structure, (3) fumigant (PH_3) adsorption to and desorption from the grain, and (4) insect growth throughout the stored grain porous media. Equations were derived from the literature estimating fumigant leakage, fumigant absorption rates, and insect growth rates that were modified to allow for hourly estimates dependent on ambient weather and stored grain conditions. The PH_3 leakage rates were then applied on the perimeter of the bin, while PH_3 sorption and insect growth rates were applied throughout the grain mass inside the bin.

The new model component that predicts chemical concentrations throughout the stored grain porous media has been validated using real world fumigation data. As a result of these engineering advancements we now have a 3D finite element ecosystem model that accurately predicts fumigation of stored grain porous media including gas concentration and movement, gas loss due to grain adsorption and from the storage structure, and development and mortality of insect populations as a function of temperature, moisture content and fumigant concentration. Given this model is not dependent on commercial fluid dynamics software, it can be more easily customized to the needs of stored grain managers in order to investigate a wide array of site-specific post-harvest loss prevention scenarios. Also, because the model does not require an expensive software license, the model has a greater potential as an extension and research tool that can be shared with others. Therefore, this model is an ideal tool to investigate the effectiveness of the Amber Agriculture wireless sensors in accurately predicting the temperature, moisture content and carbon dioxide conditions in a bin, and comparing these predictions to those determined from a traditional temperature cable system based on fixed sensor (cables) versus "random" sensor (Amber) distribution. This modeling approach will then be extended to bins of different sizes in order to create recommendations on the number of wireless sensors that would be best able to reliably monitor stored grain conditions in those bins. Moreover, costs for the wireless sensing technology per bushel could be quantified based on the recommended number of sensors needed per bin.

This project would provide for an opportunity to demonstrate the effectiveness and utility of the Amber Agriculture wireless sensor technology and lay the groundwork for upcoming research and industry involvement in this area by demonstrating the potential of this new technology in comparison to the existing temperature cable technology. This will be done by testing the wireless sensor technology in a grain bin at the Agricultural and Biosystems Engineering farm at Iowa State University that is equipped with temperature cables and stirring machines. Wireless and cable sensors will be used to monitor stored grain conditions during intermittent aeration and storage for at least nine months. The next step of the experiment will be to use a rotating grain stirring auger to disturb the grain in fixed radii, and monitoring the vertical displacement of

[2] http://www.pbcrc.com.au/research/project/63051

individual sensors in order to determine horizontal distribution as a result of grain flow during bin filling. This will allow for calculation of the percentage of sensors at set distances from the center of the silo. Then, the MLP 3D ecosystem finite element model will be applied to analyze the comparative effectiveness of the wireless versus fixed cable sensor distributions in predicting stored grain conditions for a range of different bin sizes. The results from this research will be disseminated to end users via the Iowa Grain Quality Initiative website (www.iowagrain.org), an Iowa State Extension bulletin, and articles in Grain Journal and World Grain in which the PI contributes a regular column on grain operations management.

OBJECTIVES

This proposed research fits into NC-213 multi-state project *Objective 2: To develop efficient operating and management systems that maintain quality, capture value, and preserve food safety in the farm-to-user supply chain*. The specific objectives of this project are to:

1. Compare the effectiveness of the Amber Agriculture wireless sensor technology against a conventional cable-based sensor system by monitoring temperature and relative humidity in the stored grain mass during aerated and non-aerated periods. [Year 1]
2. Determine the vertical and horizontal distribution of the wireless sensors as a result of gravity-filling a storage bin, and quantify the uniformity of sensor distribution and usefulness of data for stored grain quality monitoring in comparison to a cable-based sensor system. [Year 1]
3. Apply the existing MLP 3D ecosystem model to determine the number of wireless sensors needed to achieve sufficient accuracy for stored grain quality monitoring based on the predicted temperature, moisture content and carbon dioxide values in the grain mass using cable-based sensor systems versus the Amber Agriculture wireless sensors as a function of different bin sizes and predicted sensor distribution. [Year 2]

METHODS

Objective 1: Compare the effectiveness of the Amber Agriculture wireless sensor technology against a conventional cable-based sensor system by monitoring temperature and relative humidity in the stored grain mass during aerated and non-aerated periods. [Year 1]

Corn will be procured by the ABE farm at Iowa State University and placed in a farm-size bin equipped with an aeration fan, perforated floor, gravity distributor, one stirring auger, and five temperature and moisture cables with sensors spaced 4 ft apart. Each bin holds approximately 15,000 bushels. Samples will be collected during bin loading and analyzed for initial corn quality parameters (FGIS grade based on test weight, BCFM, heat damage; moisture content; mold count; aflatoxin and fumonisin content) by the Iowa Grain Quality Lab. Corn will be added to the bin in approximately 4-foot layers and leveled manually in order to allow the remote sensors to be placed next to the reading locations on the five temperature and moisture cables (center and half bin radius east, west, south, north). The bin will then be subjected to periods of aeration and non-aeration according to a conventional three-phase fall cool-down strategy recommended for central Iowa. Contrary to the recommendation of keeping cold grain cold into the spring, the bin will be aerated beginning in March using a three-phase warm-up strategy. The grain will be stored from the fall 2018 harvest through the winter months and into spring 2019 (at least 9 months) with the wireless and cable sensors collecting data continuously. The grain mass will be sampled monthly and at the beginning, middle and end of each aeration period with a deep probe near the sensor locations but ideally without disturbing them. Samples will be analyzed for the same as the initial corn quality parameters plus temperature at the time of probing.

Data from both monitoring systems and the grain samples will be analyzed and statistically compared for grain temperature and moisture content to determine level of agreement between the two systems and actual sample values. The Amber Agriculture wireless sensor technology will be considered effective in monitoring temperature and relative humidity in stored corn *if* grain temperature and moisture content values reported are within the same level of accuracy as those reported by the conventional cable-based sensor system when compared to the measured values of the probe samples during the aeration and non-aeration periods, respectively.

Objective 2: Determine the vertical and horizontal distribution of the wireless sensors as a result of gravity-filling a storage bin, and quantify the uniformity of sensor distribution and usefulness of data for stored grain quality monitoring in comparison to a cable-based sensor system. [Year 1]

Experiment 1: Upon completion of Objective 1, the corn will be emptied from the bin and the wireless sensors recovered by screening the corn during unloading based on the recommended practice by Amber Agriculture. The number of sensors recovered will be compared to the number placed. The original locations where missing sensors were placed in the grain mass will be noted. The temperature and moisture cables will be rolled up into the headspace to avoid them getting tangled up in the stirring augers. The corn will then be placed back into the bin using the same procedure as described under Objective 1 with the wireless sensors placed at the same vertical and horizontal locations in each grain layer. The stirring auger will be modified so it moves around the bin diameter at a constant radius. The radius will be adjusted to match the horizontal location of the wireless sensors. After an initial 360-degree sweep of the grain stirrer, readings from the data relay hub will be used to estimate the number of wireless sensors that changed vertical (and presumably not much in horizontal) location and by what amount (distance from original placement). Depending on the distance sensors move vertically, 360-degree sweeps will be repeated and vertical distance changes recorded until all sensors are moved upward in the grain mass and presumably appear at the grain surface. Observed distance moved upward per sweep will be used to estimate the number of 360-degree sweeps that would theoretically be needed to move all wireless sensors to the grain surface. Once that number of sweeps is exceeded by 10% and not all sensors have appeared at the grain surface, this experiment will be considered complete. The results will ideally confirm that wireless sensors can be moved as a result of stirring and thus detected in the grain mass which will be critical in conducting the second experiment under this objective.

Experiment 2: Upon successful completion of Experiment 1, the corn will be emptied from the bin and the wireless sensors recovered by screening the corn during unloading based on the recommended practice by Amber Agriculture. The number of sensors recovered will be compared to the number placed. The original locations where missing sensors were placed in the grain mass will be noted. Each wireless sensor will be marked and added sequentially to the corn stream as it is placed back into the bin through gravity filling as specified by Amber Agriculture. This will result in presumably random vertical and horizontal placement of the wireless sensors in the grain mass with lower numbered sensors in the bottom layers and higher numbered sensors in the upper layers. Once filled, the grain surface will be leveled manually. The data relay hub will determine the vertical placement of each sensor once the sensor network communication has established itself. This will allow verification whether the lower to higher numbered sensors distributed from the bottom to the top grain layers. This will also yield the depths at which each sensor came to rest. However, it will not give the horizontal locations of the sensors.

The radius of the stirring auger will be adjusted after each 360-degree sweep around the bin diameter starting at the wall and moving progressively inward to the center. The radius will be decreased by one foot after each sweep (or a different amount based on the results of Experiment 1). After each 360-degree sweep of the grain stirrer, readings from the data relay hub will be used to identify each wireless sensor that changed vertical location (and presumably not much in horizontal) location and by what amount (distance from original placement). The horizontal location of each sensor that moved will be known by the radius at which the stirring auger moved during the respective sweep. Once all 360-degree sweeps are completed and ideally all wireless sensors have been moved vertically, the horizontal location of each wireless sensor has been identified. This then allows for the determination of the vertical and horizontal distribution of the wireless sensors as a result of gravity-filling the storage bin, and quantifying the uniformity of sensor distribution and usefulness of data for stored grain quality monitoring in comparison to a cable-based sensor system. Ideally, this experiment will be repeated three times to determine the randomness of sensor distribution during gravity filling and whether horizontal location where a sensor comes to rest could be influenced in some manner.

Objective 3: Apply the existing MLP 3D ecosystem model to determine the number of wireless sensors needed to achieve sufficient accuracy for stored grain quality monitoring based on the predicted temperature, moisture content and carbon dioxide values in the grain mass using cable-based sensor systems versus the Amber Agriculture wireless sensors as a function of different bin sizes and predicted sensor distribution. [Year 2]

Using the distribution pattern determined under Objective 2, the existing MLP 3D ecosystem model will be used to predict temperature, moisture content, and carbon dioxide values for the long-term grain storage experiment conducted under Objective 1. The model predictions will be analyzed in three ways in order to calculate overall averages and standard deviations: (1) using values calculated at all nodes in the grain mass, (2) using values only at the nodes that match the sensor reading locations from the temperature and moisture cables, and (3) using values only at the nodes that match the wireless sensor reading locations. The overall average and standard deviation for the predicted temperature and moisture cable sensors and the wireless sensors will be compared to those of the predicted values at all nodes in the grain mass. If the same level of accuracy by the wireless sensors is not achieved as predicted for the cable-based sensors, independent on how accurately the cable-based sensors predict overall average and standard deviation, the number of wireless sensors will be increased in the simulation by 10% and results rerun repeatedly until the desired level of accuracy is achieved. The possibility exists that adding more sensors will not improve accuracy due to poor distribution of the sensors (e.g., coming to rest in the grain mass at a preferential location such as near the core or the wall). If that were to be the case, then the wireless sensors would not be considered sufficiently distributed to replace cable-based systems. In such a case, sensor design in terms of density and shape may need to be considered to increase representative distribution. In case there were too many sensors initially, the number of wireless sensors will be decreased. The number of wireless sensors per bushel of stored grain will be recorded and the simulation process repeated for a range of commercial and farm bin sizes ranging from 10,000 to 1,000,000 bushels. For each bin size, the number of wireless sensors needed to achieve sufficient accuracy for stored grain quality monitoring will be determined based on the predicted temperature, moisture content and carbon dioxide values in the grain mass compared to cable-based sensor systems.

Simulations will be run using a minimum of 5 years of historic weather data. Additionally, weather data for key Midwestern locations (i.e., Columbus, Ohio; Indianapolis, Indiana; Peoria, Illinois; Des Moines, Iowa; Lincoln, Nebraska; Minneapolis, Minnesota; Columbia, Missouri) will be utilized to determine to what extent geographic location might influence the number of wireless sensors needed for a specific bin size. This investigation will result in a substantial number of computer simulations that will occupy most of Year 2 of this project with the balance of effort dedicated to preparing the peer journal manuscripts and Extension publications to disseminate the research findings of this project.

ANTICIPATED RESULTS, PRODUCTS, AND IMPACTS

The primary anticipated result of this research project is demonstration and confirmation that the wireless sensors developed by Amber Agriculture can be used to monitor stored grain conditions in real time with comparable accuracy to existing temperature and moisture cable technology. Ideally, this project will also demonstrate that wireless sensors can be added to the gravity flow of grain during filling a bin and distribute vertically and horizontally in a pattern that allows stored grain managers to rely on temperature, moisture content and CO_2 readings to make management decisions that will preserve stored grain quality and minimize shrink loss. Complementary to adding sensors to the grain, this project will demonstrate that 100% of the wireless sensors can be recovered from the grain during unloading of the bin using a reliable and cost-effective method. This project also has the potential to provide temperature and moisture monitoring sensors for grain bins equipped with stirring machines which cannot co-exist with cable-based monitoring systems leaving operators currently without any options for monitoring stored grain quality.

Based on the simulation results from the MLP 3D ecosystem model, this project will yield the number of wireless sensors needed for different sizes of bins in key geographic locations to manage stored grain quality effectively and reliably. The expectation is that wireless sensors will detect quality changes in the stored grain mass earlier than cable-based systems giving managers more flexibility in deploying intervention strategies. Knowing the number of sensors needed will allow for calculating the costs of the wireless sensor technology and compare those against existing temperature and moisture cable systems.

The wireless sensors from Amber Agriculture are advanced technology that is nearing commercialization. This ability to measure grain temperature and moisture content at infinitely more locations than cable-based system allow for, and early detect the onset of spoilage and insect infestation through CO_2 measurement, makes this a revolutionary product that has the potential to positively impact the grain handling and storage industry *globally*. A single wireless sensor if inexpensive enough could be placed in the hermetic 100 kg bag or 500 kg silo of a smallholder farmer in West Africa and could be monitored by him and his potential buyer via smart phone. Stored grain management advice could be relayed back based on measured real time conditions in the storage bag or silo resulting in the prevention of post-harvest loss that often is as high as 50%. Thus, the results from this research and the potential of these wireless grain quality sensors will constitute a significant step towards bringing a new grain storage monitoring technology to market which has the potential to completely displace existing cable-based systems that have been used for more than 50 years.

LEVERAGING RESOURCES

This project leverages existing resources at Iowa State University (ISU) and Amber Agriculture, a start-up company funded in part by University of Illinois' venture capital fund. ISU's Agricultural and Biosystems Engineering (ABE) department has its own research farm that includes the grain bins that will be used for this research and access to the corn that will be used for this study. ISU ABE is also home to the Iowa Grain Quality Lab that will analyze the samples for quality free of charge. ISU ABE is completing development of the MLP 3D ecosystem simulation model that will be available for Objective 3 of this project. The PI has an existing non-financial working relationship with Amber Agriculture whose partners have committed to provide the wireless sensors and data collection network to this project free of charge (see enclosed letter of support).

In addition, this research would be a significant milestone in the development of a promising new technology, the Amber Agriculture remote sensing system. If successful it has the potential to attract funding for additional future research projects on this and related technologies.

TIMETABLE

October 2017: Prepared grain bin at ISU ABE farm site and assembled all equipment for Objective 1 research. Conducted outside of the scope of this proposal.

March – April 2018: Initiate Objective 1 by utilizing harvested dried grain placed in the bin in October 2017 and place temperature and moisture cables and Amber Agriculture wireless sensors in the grain mass.

May – September 2018: Conduct preliminary trials to test the wireless sensor system and its performance compared to the temperature and moisture cable system.

October 2018 – April 2019: Refill bin with freshly harvested dried grain placed in the bin and conduct the 7-month storage trial using intermittent aeration in the fall and spring, collecting regular grain samples through probing, and recording data from both monitoring systems.

May 2019: Empty bin of stored corn and recover remote sensors. Initiate Objective 2, Experiment 1 utilizing grain stirrer to determine vertical displacement of intentionally placed wireless sensors.

June 2019: Empty bin of stored corn and recover remote sensors. Initiate Objective 2, Experiment 2 utilizing grain stirrer to determine horizontal location of randomly placed wireless sensors.

July 2019 – February 2020: Initiate Objective 3 and use the MLP 3D ecosystem model to analyze a range of scenarios to determine the number of wireless sensors needed in different size storage bins. Initiate publication and dissemination of research findings.

LITERATURE CITED

FAO, 2014. Stemming post-harvest waste crucial to African food security. United Nations Food and Agriculture Organization (FAO), Rome, Italy.

FAO, WFP, IFAD, 2012. The state of Food Insecurity in the World: Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition. United Nations Food and Agriculture Organization (FAO), Rome, Italy.

Lawrence, J. and Maier, D. E. (2011). Development and validation of a model to predict air temperatures and humidities in the headspace of partially filled stored grain silos. Transactions of the ASABE, 54(5), 1809-1817.

Montross, M. D., Maier, D. E. and Haghighi, K. (2002). Development of a finite-element stored grain ecosystem model. Transactions of the ASAE, 45(5), 1455-1464.

Montross, M. D. (1999). Finite element modeling of stored grain ecosystems and alternative pest control techniques (Ph.D.). Available from ProQuest Dissertations and Theses Global. (276290016).

Thorpe, G. R. (1997). Modelling ecosystems in ventilated conical bottomed farm grain silos. Ecological Modeling, 94(2).

World Bank, NRI, FAO, 2011. Missing food: The case of postharvest grain losses in Sub-Saharan Africa (No. 60371-AFR).

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Education

Ph.D., Agricultural Engineering, Michigan State University, East Lansing, MI. March 1992.
M.S., Agricultural Engineering, Michigan State University, East Lansing, MI. Dec. 1988.
B.S., Agricultural Engineering, Michigan State University, East Lansing, MI. June 1987.
A.S., Engineering, Grand Rapids Junior College, Grand Rapids, MI. May 1985.

Employment and Professional History

2017- Graduate Faculty, Agricultural & Biosystems Engineering, Kwame Nkrumah University of Science & Technology, Ghana
2017- Visiting Professor, Agricultural & Biosystems Engineering, Makerere University, Uganda
2015- Professor, Agricultural & Biosystems Engineering and Food Science & Nutrition, Iowa State University (ISU)
2015- Associate Director, Global Food Security Consortium (ISU)
2013-2015 Founding Director, Feed the Future Innovation Lab for the Reduction of Post-Harvest Loss, Kansas State University
2008-2015 Professor & Head, Grain Science & Industry, Kansas State University
2009-2015 Director, International Grains Program, Kansas State University
2008- Adjunct Professor, Agricultural & Biological Engineering, Purdue University
2005-2008 Associate Head & Graduate Program Chair, Agricultural & Biological Engineering, Purdue U
2002-2008 Professor & Extension Agricultural Engineer, Purdue University
2004 DAAD Guest Professor. University of Hohenheim, College of Agricultural Sciences and Institute of Agricultural Engineering in the Tropics and Subtropics, Stuttgart, Germany
2003 Guest Professor. University of Torino, College of Agriculture and Dept of Agricultural Economics & Mechanization, Torino, Italy
1997-2002 Associate Professor & Extension Agricultural Engineer, Purdue U
1992-1997 Assistant Professor & Extension Agricultural Engineer, Purdue U

Honors and Awards (past 7 years)

Grain Industry Leader Award, Grain Elevator & Processing Society (GEAPS), 2011
Distinguished Alumni Award, Biosystems and Agricultural Engineering Department, Michigan State University, 2011.
Baking Management's 2011 Influential 20, 2011.
Association for Continuing Higher Education (ACHE) 2012 Distinguished Program: Non-Credit Award for GEAPS/K-State Grain Operations Distance Education Program
Presidential Award for Outstanding Department Head nominee of the College of Agriculture, Kansas State University, 2013.
ASABE Superior Paper Award, American Society of Agricultural and Biological Engineers, 2014.

Synergistic Activities (past 4 years)

1. Associate Director, Global Food Security Consortium which includes coordinating annual student research poster competition
2. Member, Organizing Committee, ASABE Global Food Security Conference, Stellenbosch, South Africa, October 2016
3. Co-chair, Scientific Program Committee, Post-Harvest Loss Prevention Congress, Rome, Italy, October 2015
4. Founding Director & Lead PI, Feed the Future Innovation Lab for the Reduction of Post-Harvest Loss
5. Associate Director, Global Food Security Consortium, Iowa State University
6. Advisor to 37 graduate students and sponsor of 14 postdoctoral scholars since 1992.

Licenses - Registered Professional Engineer, State of Indiana, PE10100369

Grants - Over $20 million in research, technology transfer, and extension education grants.

Research Focus

Research program focuses on post-harvest engineering applied to grain and feed operations and processing. Projects involve post-harvest loss reduction and prevention, food security, grain operations management, feed technology, post-harvest engineering (crop handling, drying, storage, processing and loss prevention), value-added processing of agricultural crops and food/feed products, ecosystem modeling, stored products protection (IPM, fumigation), alternative crop storage systems (grain chilling, hermetic storage), dehydration of biological products, bulk material (grain, feed) handling and segregation (IP), quality assurance of agricultural crops and biological products, and facilities planning and design (including safety, entrapment rescue, dust explosion prevention, system simulation).

Extension and International Outreach

Active technology transfer and continuing education program in crop post-harvest handling, drying, storage, processing and loss prevention, global food and nutrition security, and continuing education and credentialing of industry professionals in the global grain and feed industry. He provides leadership to and teaches a number of distance courses in the newly established Iowa Grain Quality Initiative Master Credential in Grain and Feed Processing, and the GEAPS Continuing Education and Credentials Program Host of international visitors and delegations from Argentina, Australia, Brazil, Canada, China, Germany, India, Italy, Mexico, New Zealand, Nigeria, Pakistan, Russia, Sweden, Thailand.

Selected Relevant Publications (past 4 years; total of 72 peer journal articles)

1. Martinez-Kawas, A. and Maier, D.E. 2014. Improvements in quantification of biomass feedstock availability to a biorefinery using a GIS-based method. Transactions of the ASABE, 57(2):533-542.
2. Boac, J.M., Ambrose, R.P.K., Casada, M.E., Maghirang, R.G., and Maier, D.E. 2014. Applications of discrete element method in modeling of grain postharvest operations. Food Engineering Reviews. 10.1007/s12393-014-9090-y
3. Roberts, M.J., Field, W.E., Maier, D.E. and Stroshine, R.L. 2015. Determination of entrapment victim extrication forces with and without use of a grain rescue tube. Journal of Agricultural Safety and Health. 21(2):71-83.
4. Coradi, P.C., Maier, D.E., Channaiah, L.H. and Campabadal, C. 2015. Effects of processing on the distribution of aflatoxin and fumonisin levels in corn fractions and feeds. Journal of Food Process Engineering. 38(6) (11p)

CURRENT & PENDING SUPPORT

Name: **Dirk E. Maier**

NAME (List/PD #1 first)	SUPPORTING AGENCY AND AGENCY ACTIVE AWARD/PENDING PROPOSAL NUMBER	TOTAL $ AMOUNT	EFFECTIVE AND EXPIRATION DATES	% OF TIME COMMITTED	TITLE OF PROJECT
	Active:				
Mosher G.A. Maier, D.E. Ambrose, K.	DOL-OSHA	$126,000 ($65,500 to ISU)	09/30/2016 – 09/30/2017	4%	Continuation of Training to Prevent Grain Dust Explosions
Maier, D.E.	USAID-BHEARD via Michigan State University	$191,745	08/01/2016 – 07/31/2021	20%	BHEARD PhD Training Program – Rwanda
Maier, D.E.	USDA-FAS	$36,084	02/13/2017 – 12/31/2017	6%	Borlaug Fellowship Program, Fellow #6 (Rwanda) Identification and Characterization Methods of Aspergillus Flavus Strain & Aflatoxin Control
Maier, D.E. Ambrose, K. McNeill, S. Campabadal, C. Opit, G. Armstrong, P.	USDA-FAS-SCRP	$40,000	09/01/2016 – 08/31/2018	8%	Ghana Solar Biomass Hybrid Dryer
Stark, C. Campabadal, C. Maier, D.E. McNeill, S. Opit, G.	USDA-FAS via WISHH	$1.9 million ($220,896 to ISU)	09/01/2015 – 08/31/2019	20%	Ghana Poultry Layer and Feed Value Chain Food for Progress Project
Maier, D.E. Bowers, E. Nishimwe, K.	USAID via Livestock Systems Innovation Lab/University of Florida	$99,904	01/01/2017 – 12/31/2017	8%	Assessment and Mitigation of Aflatoxin and Fumonisin Contamination in Animal Feeds in Rwanda
	Pending:				
Chopra, S. Maier, D.E. Brumm, T.	USDA-NIFA-HEC	$750,000	08/01/2017 – 07/31/2020	8%	Global e-learning platform for graduate education in post-harvest loss prevention and food waste reduction
Oppert, B. Arthur, F. Brabec, D. Casada, M. Jones, C. Maier, D.E. Opit, G. Perkin, L. Phillips, T. Zhu, K.	USDA-AFRI via USDA-ARS-CGAHR	$494,377 ($90,807 to ISU)	01/01/2018 – 12/31/2019	8%	An Integrated Approach to Preserving Phosphine for the Control of Stored Grain Insect Pests

ANDERSONS RESEARCH FUND – RESEARCH PROPOSAL BUDGET

Category	Year 1 Amt. requested from Andersons	Year 2 Amt. requested from Andersons	Total
Salaries and Wages*			
Post-Ph.D. research associate(s)			
Graduate assistant			
Stipend	**$ 22,769**	**$ 22,769**	
Tuition and fees			
Hourly wage			
Other (specify in Budget Narrative)			
Total	**22,769**	**22,769**	**$ 45,538**
Fringe Benefits			
Post-Ph.D. research associate(s)			
Graduate assistant	**2,231**	**2,231**	
Hourly wage			
Other			
Total	**2,231**	**2,231**	**4,462**
Materials and Supplies			**0**
Equipment (List individual pieces of equipment that are essential to the project in the Budget Narrative.)			**0**
Travel			**0**
Publication charges			**0**
Indirect costs**			
Total (Max. $25,000/yr. from Andersons Research Grant Program)	**$ 25,000**	**$ 25,000**	**$ 50,000**

*Andersons funds cannot be used for faculty salaries, departmental space, or facilities.

**The Andersons Research Grant Program policy specifies that no indirect costs can be charged to this project.

BUDGET NARRATIVE

IOWA STATE UNIVERSITY

Sponsor: The Ohio State University
Prime Sponsor: The Andersons Inc.
ISU GoldSheet #: 140302 – Maier

SALARY AND WAGES

- ***Senior Personnel:***

Principal Investigator – Dr. Dirk Maier: no salary support is requested. Role on the project: To oversee and direct the Graduate Research Assistant who will be hired to conduct this research project.

- ***Other Personnel:***

1 - Graduate Research Assistant (GRA), PhD, Non-engineering – 10.84 months of stipend support requested in Year 1 and 10.53 months is requested in Year 2 for half-time effort of the GRA. Role on the project: To conduct the proposed research under the direction and supervision of Dr. Maier.

Labor costs for the Graduate Research Assistant include projected costs based on current monthly stipend rates, plus a 3% increase for Year 2.

FRINGE BENEFITS

Fringe benefits are specifically identified to each employee at Iowa State University and charged individually as direct costs. These costs are budgeted as a percentage of an individual's salary based on his/her labor category. Current rates for applicable labor categories are as follows:
Graduate Research Assistants – 9.8%

INDIRECT COSTS ($0)

The indirect cost applied to this proposal is $0, per the restriction in the sponsor's guidelines (page 9).

BUDGET SUMMARY

Total Direct Costs	$50,000
Indirect Costs	$ - 0 -
TOTAL PROJECT COST	**$50,000**

September 7th 2017

Dr. Dirk Maier
Department of Agricultural and Biosystems Engineering
3325 Elings Hall
Ames, Iowa 50011-3270

RE: Letter of Collaboration for NC-213 Grant

Dr. Maier,

We are excited for the opportunity to work with you on the proposed Andersons NC-213 grant entitled "Wireless Sensors for Quality Monitoring and Management of Stored Grain Inventories".

Amber Agriculture has agreed to supply our EVT wireless sensors and weather / data collection hub for this project. Aside from providing the technology, we will support your lab as requested in the exploration of comparing Amber's wireless sensor pellets against cable technology as ground truth, distribution flow of wireless sensor pellets in stored grain, and data modeling of metrics captured.

As to provide background, our team includes expertise in electrical / embedded systems engineering and instrumentation design as well as computer science and software stack development. Amber has been exploring new sensor technology development and analytics opportunities in postharvest agriculture since the Fall of 2015.

We look forward to continuing our development and testing with you through the NC-213 project.

Respectfully,

Lucas Frye
CEO of Amber Agriculture, Inc.

2129 N. Campbell 101 Chicago, IL 60647
lucas@amber.ag
309-472-5659

PROPOSAL SUBMISSION

Sponsor: The Ohio State University
Prime Sponsor: The Andersons, Inc.

Title of Proposal:	Wireless Sensors for Quality Monitoring and Management of Stored Grain
Principal Investigator:	Dr. Dirk Maier
Project Period:	March 1, 2018 – February 29, 2020
Requested Amount:	$50,000
ISU Reference Number:	GS 140302

Approved for Iowa State University by:

Lynn A. Bagley

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Lynn A. Bagley, CRA
Pre-Award Administrator

Iowa State University
Office of Sponsored Programs Administration
1138 Pearson Hall, 505 Morrill Road
Ames, IA 50011-2103
Phone: (515)294-5225
Email: egrants@iastate.edu

Pre-submission checklist

To ensure that your grant proposal meets all criteria to be reviewed, the following items must be checked-off and reviewed prior to submitting your grant proposal. Missing any of the items below will make your grant proposal ineligible for this opportunity.

_x__ At least one of the principal investigators must be a member of Multistate Research Project NC-213 and is their name listed in Appendix E.

__x_ At least one investigator must have a current report included in the current Annual Report of Progress. Please visit the NC-213 website to review the latest report.

_x__ Any investigator with outstanding annual or final reports from previously funded Andersons Grant programs must meet all reporting obligations or the grant proposal will be ineligible for the competition.

Your grant proposal must contain, in this order, the following:

_x_ Cover page.

_x__ Problem Identification and Related Research.

_x__ Objectives.

_x__ Methods.

_x__ Anticipated results, products, and impacts.

__x_ Leveraging Resources.

_x__ Timetable.

__x_ Literature Cited.

__x_ CV – (U.S.D.A. guidelines for CVs may be followed).

_x__ Current and Pending.

__x_ Budget.

_x__ Budget Narrative.