HERC/IGEM Project

Yr 3: 6-month Progress Report

Project Title:	Sustaining the Competitiveness of the Food Industry in Southern Idaho: Integrated Water, Energy and Waste Management
Principal Investigator:	Dr. Karen Humes
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1) Summary of project accomplishments for reporting period and Plans for Yr 3:

The accomplishments and plans for the four primary tasks identified in the original proposal are summarized here (Tasks A-D). A summary of accomplishments for the overall project management and coordinated stakeholder engagement activities are also summarized below, listed as Task E.

The team would like to stress that our partnerships with producers, processors, municipal treatment personnel and water management entities (private and public) are fundamental to all of our tasks and our project as a whole. Our Yr 3 activities have been influenced and enhanced by interactions with our Stakeholder Advisory Board (described in more detail under Task E below) and interactions with other stakeholders as well.

Task A) Recovery of energy, nutrients, water and bioproducts from waste streams: bench to place-based pilot projects

Team: Erik Coats (UI, environmental engineering/molecular biology; emphasis on resource recovery from waste streams); Armando McDonald (UI, biomass conversion and bioproducts); Kevin Feris (BSU, algae-based resource recovery and microbial ecology))

Team background and overall goals: This team collaborated for 10+ years and has the required multidisciplinary experience to integrate biological, chemical, physical and thermal approaches to the recovery of energy, bioproducts and nutrients from multiple waste streams. The team is leveraging investments made by the INL, CAES, HERC, and the IGEM incubation fund. Over the last 10 years our efforts have resulted in multiple extramurally funded awards, student training opportunities, scientific publications and a pending patent. We have worked across bench and pilot scales. Recent support from SBOE HERC allowed us to build a pilot scale system to convert dairy waste to value added products (biogas, bio-plastic, algal biomass); previous HERC funding supported construction of two pilot systems at UI by Dr. Coats–one located at the Moscow WWTP, designed for municipal wastewater and one mobile system (24 ft. trailer) designed for dairy manure resource recovery. We are engaged in testing, validating, and extending these systems to evaluate opportunities to recover high-value products (bioplastics, algae, biofuels) from industrial/municipal wastewater while achieving treatment. Research is focused on further understanding/optimizing our integrated system to maximize utility across input streams and demonstrate "real-world" applicability. Research objectives will further technology interrogations and advance wastewater as an economic resource. Ultimately, research will advance solutions that can be applied in Idaho agricultural and food processing sectors; producing economic value from waste will enhance Idaho-based industries by diversifying product portfolios.

Accomplishments this reporting period:

The following provides detail of progress in the first half of Year 3, building from Year 1-2 successes, towards the aims described in the original proposal.

i. Bench scale: Assess and evaluate nutrient recovery, energy reduction, bioplastics production, and algal production strategies to inform pilot scale operations.

a) Assessment of optimal process sequences (biological, chemical, physical, thermal) to recover energy, bioproducts (biofuels; bioplastics) and nutrients from mixed waste.

- (Coats) Phosphorus recovery from wastewater is most sustainably and reliably achieved through a process known as enhanced biological phosphorus removal, EBPR. Bench-scale EBPR operations are focused on ascertaining the effects of key process operational criteria on maximal P recovery. Building from past research efforts, current investigations are focused on two operational scenarios that integrate a new operational strategy. One operational scenario feeds all wastewater to the bioreactor at one time (beginning of the cycle), while the 2nd strategy feeds a more targeted, controlled wastewater (VFA-rich fermenter liquor) at the beginning of the cycle and then the raw wastewater stream at the end of the anaerobic period. The former operational strategy is identified as the A/O process, while the latter is known as the Westbank process. A central question relates to understanding the effect of adding VFAs outside of the anaerobic period. In Y2 research was expanded to incorporate a new operational strategy that controls the length of the anaerobic period, with concurrent measurement of the oxidation-reduction (redox) potential. Research suggests that "deep anaerobic" conditions (i.e., longer anerobic periods) can enhance and stabilize EBPR; we are utilizing real-time redox process monitoring to further evaluate this operational strategy and its impact on operational "success" vs. "failure." A Civil Engineering MS students has recently completed all these assessments, with data evaluations ongoing. Results will ultimately inform pilot (2021) and full-scale operations.
- (Coats) Integrated with ongoing bench-scale EBPR bioreactor operations, another focus is analysis of process "success" vs. "failure." Stable operations of any resource recovery system at full scale demands intrinsic knowledge on what constitutes stable operation, and how unstable, or "failed," operations might be recovered. Investigations are being conducted using macro- and molecular-level methods.
- (Coats) Complementing EBPR investigations, we are investigating nitritation in an activated sludge wastewater treatment system achieving carbon, ammonia-N, nitrite-N, nitrate-N, and phosphorus removal. Nitritation is a biological process whereby ammonia-N is oxidized only to nitrite. Process success will result in significant energy savings in wastewater treatment. Process success was realized at both bench and pilot scale in late Y1 and in Y2/Y3; results are being reviewed to inform 2021 pilot operations, and also to generate a peer-reviewed publication.
- Complementing the nitritation research are efforts to understand and better characterize denitritation, with the aim to further optimize the EBPR process for energy efficient nutrient recovery. Nitrate is a contaminant of concern in drinking water, and often must be removed from wastewater prior to discharge to the water environment. A primary concern with conventional EBPR processes that integrate nitrite/nitrate reduction is the potential production of nitrous oxide, which is a very potent greenhouse gas (300X CO_2). Bacteria exhibit variable metabolic pathways to reduce nitrate vs. nitrite; some bacteria cannot reduce nitrate to nitrite, which requires a more complex microbial culture to successfully eliminate nitrate from the wastewater. Ongoing efforts by one of Coats' PhD students is

centered on better understanding the metabolic capabilities of bacteria and how they reduce nitrate vs. nitrite.

- One of Coats' PhD students conducted intense evaluations of the dairy-based PHA pilot in Y1/Y2, with very successful results. Dr. Coats' student published a peer-reviewed journal manuscript that details the results from these investigations (Guho et al., 2020). The manuscript includes numerous team members, including McDonald's research team. Coats' PHA pilot also was operated spring/summer 2020 (Y2, Y3); a primary focus was to couple Coats' PHA pilot with his EBPR pilot to evaluate broader process integration for enhance waste resource recovery. Utilizing this data coupled with data generated from Coats' EBPR pilot, a peer-reviewed publication will be submitted in January 2021 that focuses on interrogating the "sustainability" of integrating the respective processes while also demonstrating proof of concept.
- Algal cultivars were used throughout year 3 for routine experimental deployment. On-going experiments continue to be focused on cultivation at both bench and pilot scales employing wastewaters and waste nutrient from multiple sources (e.g. currently PHA effluent provided by the Coats lab and struvite provided by the City of Boise, respectively) to maximize nutrient capture and algal biomass production as well as production of high-value PUFA enriched algal biomass. Bench scale experiments have identified which strains produce optimal levels of biomass under various cultivation conditions and have been translated to pilot-scale operations of our greenhouse-based algal cultivation systems. Current bench scale experiments are elucidating the effects of nutrient deprivation and temperature shock on biomass production and PUFA production rates, while simultaneously capturing struvite sourced nutrients (e.g. nitrogen (N) and phosphorus (P)). We are continuing to work with three algal strains known to produce high concentrations of omega-3 fatty acids under the proper cultivation conditions (i.e. *Chlamydomonas reinhardtii*, *Nannochloropsis oculata*, and *Paeodactylum tricornutum*). We are building on our initial experiments that suggested micronutrient supplementation was required to obtain significant levels of growth when using struvite as the primary nutrient source certain strains. We project that our bench scale experiments will hone our understanding of what cultivation media factors and growth conditions are required to maximize growth and high value biomass production by the Spring of 2021. Time and resources allowing we will then scale these experiments up to pilot scales in the BSU greenhouses (100L/replicate) to evaluate high-value algae production at larger scales.

  We also completed our greenhouse/pilot-scale cultivation experiments during Spring 2020 and Summer/Fall 2020 that utilized a mixed-culture approaches for the capture of nutrients from liquid wastewaters (i.e. PHA effluent from the Coats lab system). Produced algal biomass from these experiments has been dewatered and preserved for HTL processing by the McDonald lab. During the 2nd half of year 3 nutrients captured from the HTL processing of algal biomass will then be tested as inputs to a struvite production system (either via modeling or bench scale struvite production). Struvite produced in this way will then either be tested similar to the municipal struvite experiments described above or analyzed for mineral content to allow accurate estimate of the utility of the algae-capture nutrients purified by struvite production. Based on this suite of experiments we will determine the

most appropriate mechanism for algal cultivation and nutrient source in our integrated system.

Greenhouse cultivation results indicate we can generate high and consistent/repeatable levels of algal biomass on PHA reactor effluents and that the growth rates, biomass yields, and nutrient capture rates are repeatable and reliable as well. Indeed, the COVID-19 pandemic and associated laboratory closures provided an opportunity to test our systems through an unexpected complete shutdown and restart. With a gap of a few months between the shut down and restart. Our initial data analysis suggests that our algal community and nutrient capture/biomass production system is very resilient to a substantial perturbation such as this. Therefore providing additional evidence of the stability and reliability of this aspect of our system.

ii. Pilot scale assessments: Conduct pilot scale evaluations from mixed waste streams; implement/evaluate treatment resource recovery processes.

- Both Coats' pilot systems (PHA system located at the UI dairy; EBPR system located at the Moscow, Idaho treatment facility) were operational in Y1 and for spring/summer 2020 (end of Y2, beginning of Y3) . Coats' research team was fully trained on systems operation.
- Completed 2020 operations of Coats' pilot operations. Former efforts continued to focus on collecting data to facilitate ultimate transition to a full scale system; data was used to prepare a journal manuscript (Guho et al., 2020). PHA pilot data greatly informed potential future scale-up to commercial operations, and the team is evaluating potential new funding opportunities to make the transition to commercialization. Latter efforts focused on preliminary assessment of integrated EBPR-nitritation, with an emphasis on integrating ammonia-based aeration control (ABAC) to enhance nitritation over nitrification. Successful nitritation was achieved for the entire month of August 2019 (early Y2); data evaluation is ongoing, with the aim to inform 2020 pilot operations.
- The initial pilot scale greenhouse systems have been constructed at the Boise State research greenhouse and have been validated for suitability for cultivation of multiple algal strains. In 2019 we purchased, installed and tested a new 20L flow through centrifuge for rapid collection and concentration of the algal biomass produced in our pilot-scale greenhouse cultivation experiments. In 2020 we have used this centrifuge routinely for the collection of algal biomass associated with our greenhouse cultivation experiments. These experiments have produced significant quantities of algal biomass for testing in our HTL process development (McDonald lab). Data collection and analysis from the greenhouse/pilot scale experiments will be completed during the second half of year 3. These results will be used to inform decisions about which types of algal cultivation systems to couple with the AD/PHA aspects of our integrated system. We will continue to operate the pilot scale algal cultivation systems through 2021 in collaboration with the Coats and McDonald labs at UI and as described above for our struvite-based experiments.

iii. Produce prototype products (bioplastic mulch film, biochar, biofuel) for evaluation.

- One PhD student in McDonald's lab has been working on exploring "green" extraction and isolation procedures for producing pure PHA bioplastic generated from pilot plant operations in years 1 and 2. We have trialed the following solvents dimethyl carbonate

(DMC), cyclohexanone (CYC), and ethanol in comparison with the standard solvent chloroform. We have also modified an extraction system to accommodate (0.5 kg) batches of biomass for hot extraction. It was shown the DMC was a suitable solvent to extract PHA and can be purified in 1-step rather than a 2-step process using chloroform. The new DMC extraction protocols have not had a major influence on PHA properties.

- One M.S. student has been working on cross-linking pilot plant extracted and commercial PHA to improve its melt flow properties (rheology) for producing film products. The work shows that cross-linking has improved its melt strength (viscosity) and toughness of the modified PHA. The next stage will be to extrude the modified PHA in blown film experiments.
- Greenhouse scale experiments in the Feris lab have been completed to produce suitable quantities of algal biomass. Trials are under way to extract protein (value added product) from the algae prior to HTL experiments by the McDonald lab. We will compare protein extracted/non-extracted algae for HTL. Primary outputs of HTL processing of algal biomass will include biofuel (i.e. biooil), biochar, and aqueous phase nutrients. The aqueous phase will be recycled to the algal cultivation system to enhance algal biomass production.

iv. Partnerships with producers, processors and municipal treatment personnel are fundamental to all of these tasks. Team will build on existing relationships with Twin Falls wastewater treatment facility, Food Northwest, Chobani, Amalgamated Sugar, J.R. Simplot, Idaho Dairymen's Association, and Glanbia, and expand to new partners throughout this project

a. A third SAB meeting was convened virtually on December 15, 2020. This meeting focused on providing research updates to our SAB committee members and inquiring with them on where they felt we should focus our efforts over the remainder of year 3. Importantly, a significant component of this conversation was focused on strategies and pathways to commercialization of the technologies we have studied and developed during this project. More work is needed in this area and will likely continue beyond the scope of this project. However, the relationships and advice developed and received by our SAB will be essential to our successful translation from the laboratory to "real-world" deployment.
b. A second SAB meeting was held virtually on December 17th, 2019. This meeting focused on providing research updates to our SAB committee members and inquiring with them on where they felt we should focus our efforts over the remainder of year 2. SAB members were supportive of the direction of the research but provided feedback that the team should continue to focus on potential routes towards commercialization of the technologies under investigation. SAB members renewed their commitments to help the team pursue potential routes for commercialization as opportunities arise. Additionally, the SAB provided additional detail on how to best help move portions of our work towards commercialization. These included suggestions to focus interpretation and analyses of experimental outcomes in the context of typical or example real world systems. Specifically, to look into how our technology would translate to implementation at a 1500 head dairy (the typical dairy size in ID). The SAB also suggested we look into how implementation of our technology would help Idaho Dairies reach a net zero status. One means by which the team could achieve these goals would be to engage students and faculty from the Business schools in our respective universities.

c. Additionally, our SAB engagement resulted in leadership from the Idaho Dairymen's Association inviting two members of our team (Feris, Coats) to the joint Idaho/Utah Dairymen's association meeting in Salt Lake City, UT in July 2019. This meeting provided an opportunity to further develop relationships with regional dairy producers and to introduce them to the potential outcomes of our project. Additionally, the Idaho Dairymen's Association networked Coats/Feris with Newtrient LLC (Steve Rowe, CEO). Newtrient is advancing an integrated set of technologies focused on achieving 'net zero' emissions from dairies. Discussions will continue with Newtrient to i) potentially ascertain how the PHA technology might be integrated, and ii) potentially collaborate on future commercialization funding.

d. Research plan adjustments in response to our Stakeholder Advisory Board (SAB): SAB feedback from the mid-year meeting in December 2020 continued to support our focus on the utilization of struvite as a nutrient source for algal cultivation for production of high value biomass. Further, current algal cultivation experiments are being planned within the context of potential future application at a typically sized ID dairy and in the context of net economic return. The Task A team also intends to build upon the SAB recommendations by contacting our university and regional support networks for business development. One of the Task A team's goals is commercialization of our integrated technology and during the 2nd half of year 3 we will work towards making appropriate contacts to forward this goal.

e. Another recommendation from our December 2019 SAB meeting was to evaluate i) the greenhouse gas footprint of Coats' PHA process, and ii) evaluate the potential of Coats' PHA process to remove phosphorus. These evaluations are ongoing.

f. One of our goals for year 3 of this project was to continue to build on our budding Stakeholder relationship with the hopes that they will blossom into partnerships for seeking pre-commercialization funding beyond the scope of this project. We continue to work towards this goal and during year 3, and beyond, we will focus our data collection efforts on system development and scale up as well as communication of research findings with our stakeholder group.

g. Research plan adjustments in response to the COVID-19 pandemic: Research facilities at the University of Idaho and Boise State University were shut down for a significant component of the second half of year 2 of this project. During the facility shut down research activities were focused on data analysis, literature reviews, and planning for experiments once facilities were reopened. Although some delays in data collection were experienced due to the COVID-19 pandemic, as of early June 2020, research facilities at both institutions are re-opening and since that time we have made significant progress towards our year 2 and year 3 research goals. Travel to and attendance at conferences/meetings that were planned were halted during this period and delivery of presentations impeded.

Goals/Plans for Year 3 (Task A):

i: Bench scale

- In year 3 nutrients captured from the HTL processing of algal biomass will then be tested in a secondary stage algae production system for high value commodity production

either directly as aqueous nutrients or via production of struvite. Based on these experiments and those of the primary stage algal cultivation we will determine the most opportune mechanism for algal cultivation in our integrated system as a primary nutrient capture stage and a secondary high value biomass production stage or as a single primary or secondary stage system. Our evaluation will be based on the algae's growth rates, yields, biomass characteristics, and economic potential when grown in the different wastewater nutrient sources.

- Advance new knowledge on operational criteria to discern between process "failure" and "success" for enhanced biological phosphorus removal. Generate a publication.
- Advance new knowledge on achieving shortcut nitrogen removal in biological wastewater treatment. Emphasis will be both on reactors performing enhanced biological phosphorus removal and on reactors just performing ammonia-nitrogen removal. Generate a publication.
- Finalize a metabolic model for producing biodegradable plastics from fermenter dairy manure. Generate a publication.

ii: Pilot scale:

- Operate and analyze performance of Dr. Coats' bioplastics pilot system at the UI dairy.
  - Refine and evaluate operational criteria based on successes from Y2 operations.
  - Produce quantities of bioplastic material from Coats' pilot scale system for McDonald's ongoing polymer characterization work.
  - Undertake blown film trials using pilot scale produced bioplastics
- Operate and analyze performance of Dr. Coats' municipal enhanced biological phosphorus removal system located at the city of Moscow wastewater treatment system. Focus on translating/assessing operational criteria from Coats' bench scale reactors to his pilot scale systems. Specific focus will be:
  - Achieve and assess shortcut nitrogen removal
  - Evaluate the impacts of the return activated sludge flow rate on process stability and performance
  - Evaluate the impacts of integrating effluent from Dr. Coats' bioplastics pilot on overall wastewater treatment and resource recovery
- We will continue to operate the pilot scale algal cultivation systems through 2020-2021 in collaboration with the Coats and McDonald labs at UI.

iii: Producing prototype products:

- Ongoing experiments in the Feris lab will begin to produce suitable quantities of algal biomass in year 2 and 3 for use in HTL experiments by the McDonald lab. Primary outputs of HTL processing of algal biomass will include biofuel (i.e. biooil), biochar, and aqueous phase nutrients. The aqueous phase will be recycled to the algal cultivation system to enhance algal biomass production.
- Produce bioplastic blown films for assessment

iv: Training:

- Conducting training for the city of Moscow, Idaho wastewater treatment staff, focused on the basics of biological wastewater treatment and integrating knowledge on the operation of their enhanced biological phosphorus removal system.

Task B) Decision-support tools for industry and community leaders to quantify and visualize trade-offs among water, energy, land use and municipal growth

Team: Jae Ryu, UI, systems dynamics modeling, water resources; Karen Humes (UI, water/energy nexus, geospatial analysis

Overall Goals:

The goal of this task is to integrate energy components into an updated version of a pre-existing system dynamics model for water supply, use and flows in the region of the Eastern Snake Plain Aquifer. The model which will serve as a decision-support tool for stakeholders (including the food producers, food processors, irrigation districts, water and energy providers and municipal communities/citizens). The tool will quantify and provide users with visuals on the linkages between water, energy, land use and municipal growth, to be used for planning and decision-making by producers, water users, businesses, utilities, state agencies and communities.

Accomplishments this period:

- Evaluated the existing model to determine how to implement water management options (e.g., managed aquifer recharge) given the existing data types available
- Interacted with IDWR on their newest ESPAM (Eastern Snake Plain Aquifer Model) model version and updated data to be released early next year 2021
- Evaluated the feedback from IDWR and Surface Water User's Association at the stakeholder meetings in May 2019, Dec 2019, and Oct 2020 and how the model could be more useful for stakeholders
- Incorporated new features that are available in Stella Architect into the system dynamics model and user interface.
- Performed an-in-depth review of the theoretical and technical background of each variable applied to the water balance, including the way it was produced by or for the IDWR ESPAM, how the data was accessed in 2008, and how it may change under new versions of ESPAM.
- Developed adaptable and individualized R coding to organize recent versions of the ESPAM data to work with the existing System Dynamics framework. All of this data may change along with changes to ESPAM, including units, size/number of entities, how calculations are performed, and format of the data. Thus, it was necessary for our R coding to be flexible in order to evolve with frequent changes.
- In order to formalize the process for reviewing and adapting the data in the future, R "markdown" files were used to begin development of a "bookdown", which can be used as an instructional guide and reference for future users working with the ESPAM data and system dynamics model.
- Explored available data on energy use in irrigation, including interactions with IDWR and collaboration with experts on energy use in irrigation at Idaho Power.

- Further evaluation of spatial patterns in energy use for irrigation in the ESPA and controlling factors in order to identify key variables to relate water and energy use in irrigation (i.e., crop type, irrigation system characteristics, water source, etc.). Data analysis nearly complete, with publication to be submitted in Jan 2021.

Plans for remainder of Yr 3 (Task B):

- We are expecting the newest version of ESPAM to be approved and the latest data set to be released for use early next year 2021. Thus we will need to update all R coding and processes to match the data set made available at that time.
- We will verify all units and calculations in the system dynamics model to ensure that they continue to match any formatting changes with the ESPAM data.
- The newest version of the R bookdown file will be completed and published in such a way that it is widely accessible, including researchers and water stakeholders.
- We will consider previous and new ways to use the new data in the system dynamics model for stakeholder engagement and scenario planning.
- We will improve graphical user interface by making the decision support tool available in the public domain over the internet so that all water interest groups can evaluate various scenarios by incorporating their interest and needs, ultimately enhancing water management decisions in ESPA.
- We will update available water and energy data for Stella Architect once the latest version of ESPAM model becomes available to the public
- We will continue exploring management options to incorporate into the model, such as water conservation, managed recharge, etc.
- We will be developing system evaluation criteria associated with new data inputs and potential uses for the expanded and update model, such as system reliability, vulnerability, resilience, etc.
- We will complete our analysis of available data on energy use in irrigation
- We will complete the development of a module for the system dynamics model that quantifies energy use in irrigation for two meteorological scenarios (average and above average demand in a growing season) and number of acres with other key variable combinations (eg., crop type, irrigation source/type)
- We will begin incorporating supply side scenarios to quantify the linkages between water, energy and land use and address the uncertainty of the water/energy nexus in the Eastern Snake Plain Aquifer.
- Submit draft of journal article describing the linkages between water and energy use in Idaho
- We will continue to seek input from our Stakeholder Advisory Board and other water and energy providers, managers and community leaders on how to make the tool/model most useful to them.
- We will explore water supply uncertainties driven by climate variability in the ESPA, particularly the impacts of more frequent drought conditions.

Task C) Technical innovations/sensing systems to reduce water/energy/nutrient use in targeted production systems:

Primary team members: Donna Delparte, (ISU, drone and satellite-based sensing systems) and partners among growers and crop consultants.

Accomplishments this period:

Progress in the following task area has been made through the subcontract award to Idaho State University and included:

- **Goal 1 – Decision Support Systems**
    - Decision support online prototype tool for sustainable agriculture decision making: http://avalanche.geology.isu.edu/i2i/progro_hist2.html
    - This decision support tool was developed by working with stakeholders and our Advisory Board member (Brandon Vining, ProGro) to provide remote sensing data/tools to aid decision making that is relevant to business decision making and operations
    - A key component of the decision support system is to use a historical record of vegetation health over growing seasons going back to 2016 to develop a field prescription map for variable rate nutrient application
    - Stakeholders are excited about the potential of the tool to improve ROI, reduce fertilizer inputs and improve precision farming techniques for sustainable agriculture
    - Stakeholders can now browse satellite imagery taken over growing seasons 2016-2020 showing field variation within individual fields online and review prescription recommendations for the coming year
    - Python code to automate nutrient prescription generation is now ready to be integrated in to the online tool

- **Goal 2 - Pilot projects to use drone-based, other field-based and satellite sensors to reduce water/nutrient/energy use in production of targeted crops**
    - Work supported by this project using remote sensing analysis to forecast yield for potato growers based on a growing season of high-resolution satellite imagery has been published. Abou Ali, H., Delparte, D. and Griffel, L. M. (2020). From pixel to yield: forecasting potato productivity in Lebanon and Idaho. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-3/W11, 1–7, https://doi.org/10.5194/isprs-archives-XLII-3-W11-1-2020, 2020
    - Thermal camera surveys of irrigated cropland using UAS in the 2019 and 2020 growing seasons was collected to assess efficiency and support water reduction efforts. Analysis in progress.
    - Hyperspectral camera data collection during the 2019 and 2020 growing seasons of potato crops to detect Potato Virus Y (PVY) has been processed and made analysis ready.
    - PhD student developed Python code to identify essential spectral signatures from UAS flights to detect individual unhealthy plants in a grower's field. This approach leverages

machine learning of hyperspectral imagery – thus offering the opportunity to reduce inputs for control and mitigation of disease.
- Co-I Delparte launched a new Idaho based spin-off company (I2IGeo) to provide growers with technological innovations and decision support to assist their operations, leveraging the research outcomes from this grant.

Plans for next reporting period:

For the next reporting period, the team will focus on the continued development and testing of UAS platform and sensor combinations for data collection and validation in the early part of the 2021 growing season. The emphasis will be on in-situ PVY detection, nutrient management decision support systems, and evaluating the applicability of thermal imagery for efficiencies in irrigation. Dr. Delparte will also continue to work actively toward commercialization of the most promising technologies from this research through her new Idaho company (I2IGeo).

- New thermal and hyperspectral data will be acquired in the early portion of the 2021 growing season to validate findings from 2019 and 2020 for early detection of PVY
- Additional training/testing with growers on the effectiveness of the satellite-based decision support tool for nutrient application prescriptions
- Early season in-situ detection of PVY

Task D) Engaging the present and future workforce in the adoption of new technologies

Team members for training (primary): Karen Humes, Erik Coats, Kevin Feris, and partners at CSI, UI Idaho Falls and professional organizations such as Food Northwest, *Primary team member for drone outreach activities:* Jae Ryu (Idaho Drone League (I-Drone), Founder).

Overall goals:

The overall goals in this task are two-fold: 1) to provide direct support to our stakeholders in the near-term by identifying workforce development needs that universities could plan and implement, together with partners at community colleges and professional organizations (resourced primarily in Yrs 2 and 3) and 2) contribute to longer-term workforce needs by holding outreach events designed to engage the future workforce in STEM activities that will serve the food industry in Idaho in the future, such as drone operations and the analysis of data from sensors onboard drones.

Accomplishments this period:

- Goal 1: Current/near-term workforce development needs
  - Due to Covid-19 and the cancellation of the meetings for the rural water treatment association, some of the outreach planned for the end of Yr 2 and early Yr 3. The team is working with the SAB and other stakeholders to plan for activities in the reaminder of Yr 3 and beyond.
  - In order to better prepare university graduates for careers in integrated management of food production/processing, water and waste streams, as well as maintaining the tri-

institution collaboration in this IGEM grant, the universities plan to develop and maintain an ongoing seminar series in Food-Energy-Water-Waste for faculty, undergrads and undergraduates. The seminar will be joint among the three universities and include coordination with the CAES (Center for Advanced Energy Studies) organization.

- Goal 2: Longer-term workforce needs
    - Hosted a virtual education program known as "Idaho Drone League(iDrone)" in the Treasure Valley in Fall 2020 to promote STEM pipelines and skills important to the Idaho food industry in the future. Despite the virtual format, the event was very well attended.

Plans for remainder of Yr 3:

- Training sessions to be held in conjunction with the Rural Water Treatment Association meeting and similar venues. If travel and in-person meetings continue to be problematic, we will hold virtual training sessions.
- Two more Idaho Drone League events will be scheduled in Year 3. These event will include a table highlighting how drones can be used in food production (from Task C of this research).
- Continue to engage with our Stakeholder Advisory Board and professional organizations such as Food Northwest to identify and implement professional development needs in food, water, energy and waste and how the universities can catalyze and facilitate these.
- Continue to engage with other stakeholders such as the IDEQ on needs and opportunities in professional development on pollution control and management.

Task E) Project Management/Stakeholder Engagement

Background: An important element of our project management was to put together and meet regularly with an advisory board comprised of stakeholders in the food production and processing industries, water user groups and state agencies. In Year 1 we formed this advisory and had a very successful 1st meeting in person in Boise in early May 2019. As noted in the technical progress reports (earlier sections of this report), the board feedback influenced our research plans in Year 2, as planned. The board agreed to meet in it's entirety once/yr in person (Apr/May), once/yr via videoconference (Nov/Dec) and have specialized meetings between specific sub-groups of team and advisory board members in between.

Accomplishments this period:

- We held a 3rd meeting of our full Stakeholder Advisory Board (SAB) on Dec 15, 2020. Due to travel restrictions because of the ongoing pandemic, the meeting was held by video conference. The following SAB members attended and those listed with a (*) were invited and had hoped to attend but were not able to do so:
    - Jeff Bohlscheid, Senior Principal Scientist, J.R. Simplot Company*
    - Shawn Moffitt, Regional Business Manager, Jacobs Engineering (contractor for City of Twin Falls and Chobani water treatment plants)
    - Megan Satterwhite, Operations Manager, Idaho Dairyman's Association

- Ben Nydegger, Biosolids Program Manager, City of Boise
- Sean Vincent, Hydrology Section Manager, Idaho Dept of Water Resources*
- Ben Jarvis, Pollution Prevention Projects Coordinator, Idaho Department of Environmental Quality
- Brian Olmstead*, President, Surface Water Appropriators and General Manager, Twin Falls Canal Company
- Brandon Vining, ProGro Consulting

Plans for the remainder of YR 3:

- Hold a SAB meeting in June 2021
- Develop a task force that will continue to meet beyond the June 2021 end date of the grant to discuss mechanisms for transfer of applied research from the grant into the private sector. The task force will consist of personnel from the research team, tech transfer and economic development officers from the Office of Research and Economic Development from UI, BSU and ISU, plus stakeholder advisory board members as available.
- Continue to build on existing relationships with Twin Falls wastewater treatment facility, Food Northwest, Chobani, Amalgamated Sugar, J.R. Simplot, Idaho Dairymen's Association, and Glanbia, and expand to new partners throughout this project
- Continue to hold monthly team meetings to monitor progress and facilitate coordination of all project tasks and stakeholder engagement activities. In coming months these meetings will focus on student presentations of research.

2. Summary of budget expenditures for Yr 3 (July 1, 2020 – Dec 31, 2020)

A detailed expenditure report is provided in Appendix A. The table below summarizes the spending in the major budget categories, relative to the budgeted amounts for Year 3. The expenditure report was run on December 22, 2020 and thus, due to lags in the last three weeks of 2020 payroll being posted, those 2020 expenditures have not yet cleared the system. Although the total "burn rate" for the entire grant is below 50%, this is primarily due to the lag in receiving invoices from our subcontractors, primarily at this point this year, from Idaho State University. The numbers below indicate that for UI expenditures other than subcontractors, the "burn rate" is 46.2% at this point in Year 3. Please note that the line below for Operating Expenses (OE) includes the amounts originally budgeted for both OE and Participant Costs. This is because the expenses placed under participant costs in the original 2018 budget were judged by the UI accounting personnel to be more appropriately placed under the category of Operating Expenses.

	Budget	**Expenses Cleared**	**Remaining**
Salaries & Hourly (IH)	$240,295	$119,916	$120,379
Fringe Benefits	$27,194	$12,743	$14,451
Travel	$29,334	$2,103	$27,231
OE (includes Part Cost)	$71,352	$38,361	$32,991
<$5K Capital	$11,000	$85	$10,915
Trustee/Benefits	$69,411	$33,966	$35,445
Sub Contracts	$247,414	$36,170	$211,244
Total	$696,000	$243,344	$452,656
UI expenditures other			
than subcontracts	$448,586	$207,174	$241,412
Burn rate - UI only			46.2%

3. Demonstration of economic development/impact

- Patents, copyrights, Plant Variety Protection Certificates received or pending

Co-I Dr. Donna Delparte has formed a private company in Idaho called ***I2IGeo*** and is working to develop a commercialization pathway for her research on this grant related to the use of satellite and drone technology to assist growers in the application of nutrients, herbicides, pesticides and water.

- Private sector engagement

Because every aspect of our work involves considerable private sector engagement, we have noted those engagements in each of our five tasks described in Section 1, particularly under *Task E: Project Management/Stakeholder Engagement.*

- Jobs created

Several of the research assistant and all of student research assistantship positions described in the next section were newly created in Year 1 of this grant.

4. Numbers of faculty and student participation

In the Yr 3, the numbers of faculty, students and other researchers participating are as follows:

Faculty: 6 (4 UI, 1 BSU, 1 ISU)
Graduate Students: 11 (7 UI, 2 ISU; 2 BSU (both of whom are from groups underrepresented in STEM fields)
Undergrad Students: 7 (5 at UI, 2 at BSU)
Research Scientists: 1 (1 ISU, both partially supported by this grant)

More details on staffing, by Task:

Task A: Recovery of energy, nutrients, water and bioproducts from waste streams

Coats staffing: 2 PhD students in Environmental Engineering (one PT, one FT); 3 MS student in Environmental Engineering; 4 undergraduate students in Environmental Engineering. 4 women, 5 men.

McDonald staffing: 1 PhD student in Environmental Science. 1 woman.

Feris staffing: Current staffing includes 2 male graduate students (both from underrepresented groups in STEM). Both graduate students were previously employed as research technicians on this project, however, by Jan 2020 both transitioned to the MS graduate program in the Biological Sciences with a Spring 2020 start date. Both students will participate in experimental development, data collection, and data analysis. We have recruited 2 undergraduate students (1 or 2) for the second half of year 2 and year 3 to assist with laboratory and greenhouse scale experiments.

Task B: Quantifying Water/Energy Linkages

- 2 PhD students (1 in Geography, 1 in Water Resources)

Task C:

- 1 PhD students in Geosciences
- 2 summer Masters students in Geoscience
- 1 research/programming technician

5. Description of future plans for project continuation or expansion

- PI Karen Humes is a Co-Lead on the newly formed CAES Focus Area group in the Energy-Water Nexus arena. Being a CAES Focus Area lead provides some access to CAES resources, including program development funds, to build a team of CAES researchers in pursuit of establishing CAES as a global leader in research, education, and innovation related to the energy-water nexus. Team members of this project are looking forward to leveraging our current work to pursue future opportunities. The coupling of food, water and energy is exceptionally strong in southern Idaho, from both a national and international standpoint, making a compelling case for other funding sources. Our integrated approach to water, energy and waste is also unique among teams studying the food-energy-water nexus. She and Co-I Erik Coats organized and attended a workshop at CAES in Idaho Falls on Nov 25, 2019 and are now involved in developing proposals.

- Team members are also actively writing grants to other agencies for related work, such as the NSF, USDA and NASA. This includes a current effort led by PI Karen Humes and involving Co-I Erik Coats and 6 other UI faculty) for a graduate student training grant to NSF (the NSF Research Training Grant progam, or NRT) related to water quality and public health, with emphasis on Idaho (proposal was submitted to NSF in Feb 2020 and is currently pending). This effort includes also stakeholder partners such as IDWR, IDEQ, and the City of Boise Dept of Public Works. The NSF-NRT program is highly competitive and it would be very unusual for the proposal to be

funded on the first attempt; however, if not funded, the team is dedicated to strengthening the proposal (particularly the partnerships with stakeholders) and resubmit in Feb 2021.

- PI Karen Humes submitted a proposal to UI Presidential Initiative on Water and Sustainability for seed funding to begin discussions with stakeholders for the possible formation of an Industry-University Cooperative Research Center on topics studied in this IGEM grant. The NSF supports the development of these with a process that involves a planning grant and then a full proposal the following year. The NSF goal for this program is as follows: "*The IUCRC program generates breakthrough research by enabling close and sustained engagement between industry innovators, world-class academic teams and government agencies."* We would see this as a way to institutionalize and sustain the research and industry relations developed in this grant. If successful in a full proposal, the NSF provides up to 10 yrs of base funding to establish and maintain such a center. We will also discuss this program at our SAB meeting in early July 2020.

- Co-I Erik Coats (and team leader for Task A of this grant) is a Co-I on the recently awarded 5-yr $10M grant funded by USDA, led by the College of Agriculture and Life Science, that has among its goals the recovery of byproducts from dairy waste. Dr. Coats will ensure that progress made in the IGEM grant will be brought to bear on the USDA grant and vice-versa.

- Delparte (Lead Task C) received funding to further the PVY testing for the upcoming growing season from the Idaho Specialty Crop Block Grant (Idaho State Department of Agriculture/US Department of Agriculture). Awarded. Field Trials for an Automated Early Season Potato Virus Y (PVY) Detection System. PI- Delparte. Oct 2020 to Oct 2022. $97,803.16

6. Expenditure reports

The expenditure reports presented in Appendix A details the expenditures at the University of Idaho, including the amounts for three paid invoices from Boise State University that totaled $36,170. Please note that that this report was run on Dec 22, 2020 and not all expenses from December 2020 have cleared the system, including the payroll period that ended on Dec 25, 2020 and the first half of the current pay period. The University of Idaho has not yet received any invoices from Idaho State University this year, but will follow-up with invoicing in January.

7. Commercialization Revenue

None to report yet, but the company I2IGeo (Co-I Delparte as Founder) has been formed.

Publications:

Guho, N. M.; Pokhrel, D.; Abbasi, M.; McDonald, A. G.; Alfaro, M.; Brinkman, C. K.; Coats, E. R. (2020) Pilot-scale production of poly-3-hydroxybutyrate-co-3-hydroxyvalerate from fermented dairy manure: Process performance, polymer characterization, and scale-up implications. *Bioresource Technology Reports*, 12, 100588.

Appendix A

Detailed Expenditure Reports

1) University of Idaho Expenditures -December 22, 2020

2) Invoices received from Subcontractors – December 22, 2020

FWRITEM

University of Idaho
Itemized Expenditures by Grant Code
From 01-JUL-2020 To 22-DEC-2020

Grant: SG4609 - ISBOE IGEM FY21 Sustain Food Ind-KH 22-Dec-2020 07:08 AM

Salaries		
E4106 Staff		
Brinkman, Cynthia		6059.23
334.02 hours		
E4108 Summer Salary		
Humes, Karen		11793.60
160.00 hours		
Ryu, Jae		15483.60
264.00 hours		
E4109 IA/GA Salary		
Abbasi, Maryam		8652.96
432.00 hours		
Brower, Nicole		8100.00
432.00 hours		
Deyo, Brent		10800.00
432.00 hours		
Mellin, Jason		9903.52
272.00 hours		
Pokhrel, Dikshya		6469.20
360.00 hours		
Smoot, Lindsey		8100.00
432.00 hours		
Thompson, Emily		6633.00
300.00 hours		
E4175 Overtime - Covered by FLSA		
Brinkman, Cynthia		45.59
5.02 hours		
		$ 92040.70
Temporary/Irregular Help		
E4135 Temporary Student		
Black, Edward		4199.25
388.75 hours		
Crites, Willow		4540.27
414.50 hours		
Cutler, Kylie		221.38
20.50 hours		
Guho, Nicholas		6549.15
235.75 hours		
Neupane, Saurav		5497.26
512.00 hours		
Thompson, Emily		3220.00
140.00 hours		
Walters, Riveraine		3648.00
154.00 hours		
		$ 27875.31
Fringe Benefits		
E4280 Faculty CFR Benefit Expense		8374.10
E4281 Staff CFR Benefit Expense		2551.81
E4282 Student CFR Fringe Expense		1817.28
		$ 12743.19
Travel		

E5360 Personal Vehicle - In-State	
E5367 Rental Vehicles - In-State	
E5396 Lodging & Per Diem ? In State	
	$ 2103.30
Operating Expenses	
E5025 Printing & Binding	
E5070 Conference/Registration Fees	
E5152 All Other Services	
E5199 Other Professional Service	
E5330 Software/Applications - College/Dep	
E5720 Educational Supplies	
E5724 Research Supplies	
E5741 Med Lab & Tech Supplies	
	$ 38361.20
Subawards	
ES001 Subaward 1 Expenses	
	$ 36170.00
Small Equipment (<$5K)	
E7951 <5K Office Furniture	
	$ 84.79
Tuition Remission and Training	
E7140 Tuition and Fees - Grad Assistants	
	$ 33965.50
Total Expenses	$ 243343.99

BOISE STATE UNIVERSITY
OFFICE OF SPONSORED PROGRAMS

Invoice

103475

Invoice Date	Invoice Amount	Due Date
10/26/2020	$24,016.80	Payment due upon receipt

Bill To
University of Idaho
875 Perimeter Dr
Moscow, ID 83844

Sponsor Award Number	Project Title	Department Number	BSU Award Number	Project Number	Invoice Period
SGA609-877862	Sustaining the Competitiveness of the Food Industry in Southern Idaho YR 3	70600	3221007	2000001742	7/1/2020 to 9/30/2020

Category	Budget	Current Expenditures	Cumulative Expenditures	Remaining Budget
Salary	$ 75,850.00	$ 11,259.65	$ 11,259.65	$ 64,590.35
Fringe	$ 13,227.00	$ 2,024.76	$ 2,024.76	$ 11,202.24
Other Expense	$ 13,000.00	$ 1,094.39	$ 1,094.39	$ 11,905.61
Travel	$ 2,333.00	$ 0.00	$ 0.00	$ 2,333.00
Student Costs	$ 18,935.00	$ 9,638.00	$ 9,638.00	$ 9,297.00

Original Budget	Total Current Expenditures	Total Expenditures	Remaining Budget
$ 123,345.00	$ 24,016.80	$ 24,016.80	$ 99,328.20

Total Expenditures:	$ 24,016.80
Less: Revenue Received:	$ 0.00
Less: Outstanding Invoices:	$ 0.00
Amount Now Due:	$ 24,016.80

Where required for federal or federal flow-through agreements, by signing this report, I certify to the best of my knowledge and belief that the report is true, complete, and accurate, and the expenditures, disbursements and cash receipts are for the purposes and objectives set forth in the terms and conditions of the Federal award. I am aware that any false, fictitious, or fraudulent information, or the omission of any material fact, may subject me to criminal, civil or administrative penalties for fraud, false statements, false claims or otherwise. (U.S. Code Title 18, Section 1001 and Title 31, Sections 3729-3730 and 3801-3812).

Please direct questions regarding this invoice to Isabell Bruce at postaward@boisestate.edu.

Payment Options

By Mail:

Boise State University
1910 University Drive
Accounts Receivable
Boise, ID 83725-1247

ACH/Wire Payments:

Account Name:	Boise State University
Account Number:	20000011141546
Bank:	JPMorgan Chase
ACH Routing Number:	028000024
Wire Routing Number:	021000021

Please reference invoice number on electronic payments

BOISE STATE UNIVERSITY
OFFICE OF SPONSORED PROGRAMS

Invoice

103714

Invoice Date	Invoice Amount	Due Date
11/24/2020	$7,119.96	Payment due upon receipt

Bill To

University of Idaho
875 Perimeter Dr
Moscow, ID
83844
US

Attn: Kay Dee Holmes

Sponsor Award Number	Project Title	Department Number	BSU Award Number	Project Number	Invoice Period
SGA609-877862	Sustaining the Competitiveness of the Food Industry in Southern Idaho YR 3	70600	3221007	2000001742	10/1/2020 to 10/31/2020

Category	Budget	Current Expenditures	Cumulative Expenditures	Remaining Budget
Salary	$ 75,850.00	$ 6,451.70	$ 17,711.35	$ 58,138.65
Fringe	$ 13,227.00	$ 593.38	$ 2,618.14	$ 10,608.86
Other Expense	$ 13,000.00	$ 74.88	$ 1,169.27	$ 11,830.73
Travel	$ 2,333.00	$ 0.00	$ 0.00	$ 2,333.00
Student Costs	$ 18,935.00	$ 0.00	$ 9,638.00	$ 9,297.00

Original Budget	Total Current Expenditures	Total Expenditures	Remaining Budget
$ 123,345.00	$ 7,119.96	$ 31,136.76	$ 92,208.24

Total Expenditures:	$ 31,136.76
Less: Revenue Received:	$ 24,016.80
Less: Outstanding Invoices:	$ 0.00
Amount Now Due:	$ 7,119.96

Where required for federal or federal flow-through agreements, by signing this report, I certify to the best of my knowledge and belief that the report is true, complete, and accurate, and the expenditures, disbursements and cash receipts are for the purposes and objectives set forth in the terms and conditions of the Federal award. I am aware that any false, fictitious, or fraudulent information, or the omission of any material fact, may subject me to criminal, civil or administrative penalties for fraud, false statements, false claims or otherwise. (U.S. Code Title 18, Section 1001 and Title 31, Sections 3729-3730 and 3801-3812).

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Accounts Receivable
Boise, ID 83725-1247

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Account Name:	Boise State University
Account Number:	20000011141546
Bank:	JPMorgan Chase
ACH Routing Number:	028000024
Wire Routing Number:	021000021

BOISE STATE UNIVERSITY
OFFICE OF SPONSORED PROGRAMS

Invoice

103908

Invoice Date	Invoice Amount	Due Date
12/15/2020	$5,033.24	Payment due upon receipt

Bill To
University of Idaho
875 Perimeter Dr
Moscow, ID 83844

Sponsor Award Number	Project Title	Department Number	BSU Award Number	Project Number	Invoice Period
SG4609-877862	Sustaining the Competitiveness of the Food Industry in Southern Idaho YR 3	70600	3221007	2000001742	11/1/2020 to 11/30/2020

Category	Budget	Current Expenditures	Cumulative Expenditures	Remaining Budget
Salary	$ 75,850.00	$ 4,067.80	$ 21,779.15	$ 54,070.85
Fringe	$ 13,227.00	$ 581.78	$ 3,199.92	$ 10,027.08
Other Expense	$ 13,000.00	$ 383.66	$ 1,552.93	$ 11,447.07
Travel	$ 2,333.00	$ 0.00	$ 0.00	$ 2,333.00
Student Costs	$ 18,935.00	$ 0.00	$ 9,638.00	$ 9,297.00

Original Budget	Total Current Expenditures	Total Expenditures	Remaining Budget
$ 123,345.00	$ 5,033.24	$ 36,170.00	$ 87,175.00

Total Expenditures:	$ 36,170.00
Less: Revenue Received:	$ 24,016.80
Less: Outstanding Invoices:	$ 7,119.96
Amount Now Due:	$ 5,033.24

Where required for federal or federal flow-through agreements, by signing this report, I certify to the best of my knowledge and belief that the report is true, complete, and accurate, and the expenditures, disbursements and cash receipts are for the purposes and objectives set forth in the terms and conditions of the Federal award. I am aware that any false, fictitious, or fraudulent information, or the omission of any material fact, may subject me to criminal, civil or administrative penalties for fraud, false statements, false claims or otherwise. (U.S. Code Title 18, Section 1001 and Title 31, Sections 3729-3730 and 3801-3812).

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