Idaho Incubation Fund Program

Final Project Report

Proposal No. **IF18-001**
Name: **Kevin Feris and Erik Coats**
Name of Institution: **Boise State University**
Project Title: **Operation, Optimization, and Evaluation of a Pilot Scale Algae Resource Recovery Unit (ARRU)**
Reporting Period: **July 1, 2017 to June 30, 2018**

Information to be reported in your progress report is as follows (attach additional information as needed):

1. Summary of project accomplishments for the period just completed and plans for the coming reporting period:

Task 1 – Continue operations and data acquisition from of the ARRU for a full growing season (i.e., through September/October 2018): The ARRU was operated continuously into September 2017. Operations ended 9-4-17 as night time temperatures were becoming cool, the lagoon water required for one of our treatments was no longer available (the UI dairy had conducted their annual lagoon draining to irrigate local fields), and smoke from wildfires in the region made it unsafe to work outdoors (air quality index of 280, 20 points below "hazardous"). After this time we continued to focus our efforts on sample analysis and data interpretation. As noted in our December 2017 report, we 1st completed our algal biomass productivity measures (Figure 1) and our nutrient uptake measurements (Figure 2) (here we present results of phosphorus uptake, however nitrogen uptake rates illustrate similar patterns).

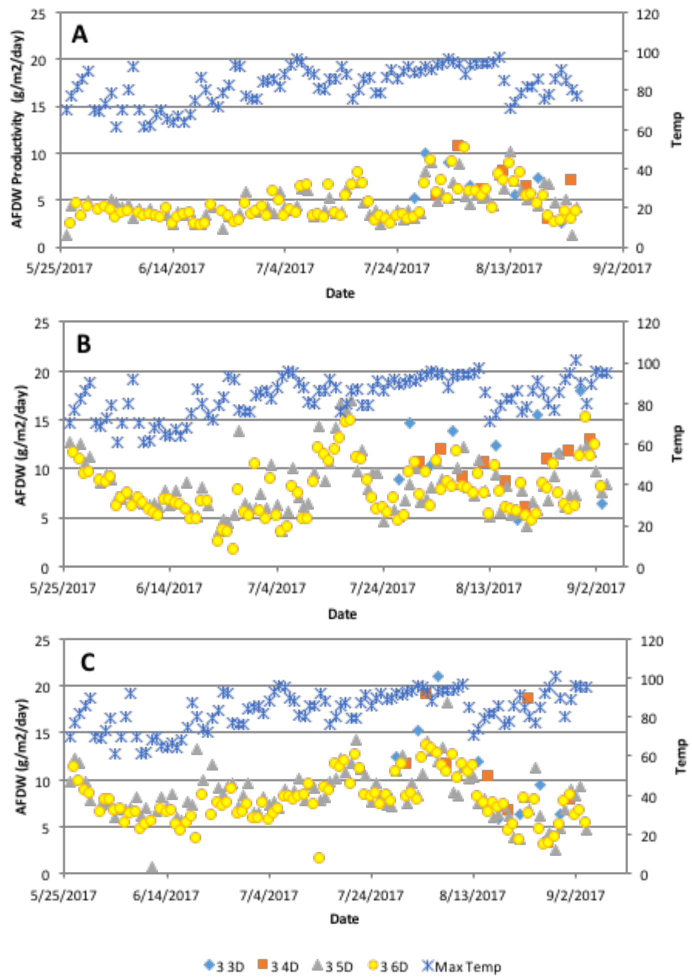

Figure 1. Algal biomass produced in the ARRU across all three treatments (A: Lagoon water; B: AD/PHA effluent mixture (10:90); C: 100% PHA effluent) measured as ash free dry weight (AFDW) and maximum daily temperature.

Since December 2017 we have focused our analytical work on measuring the biomass quality of the cultivated algal biomass. To do this we directly measured the protein content, carbohydrate content, and ash content of the algal biomass. Project resources did not allow for direct measures of lipid content of the algal biomass therefore we have estimated average lipid content by a difference method after accounting for the other major macromolecular biomass components. We are exploring opportunities to gather direct measures of lipid content of the algal biomass for key time points representative of the trends of productivity across effluent types and retention times. Although, the specific lipid content measures were beyond the scope of support of this project we are working to build these data into our future analyses and estimates of biomass quality. Results from the biomass quality analyses are presented as productivity estimates for the carbohydrate and protein biomass quality metrics (Figures 3 and 4).

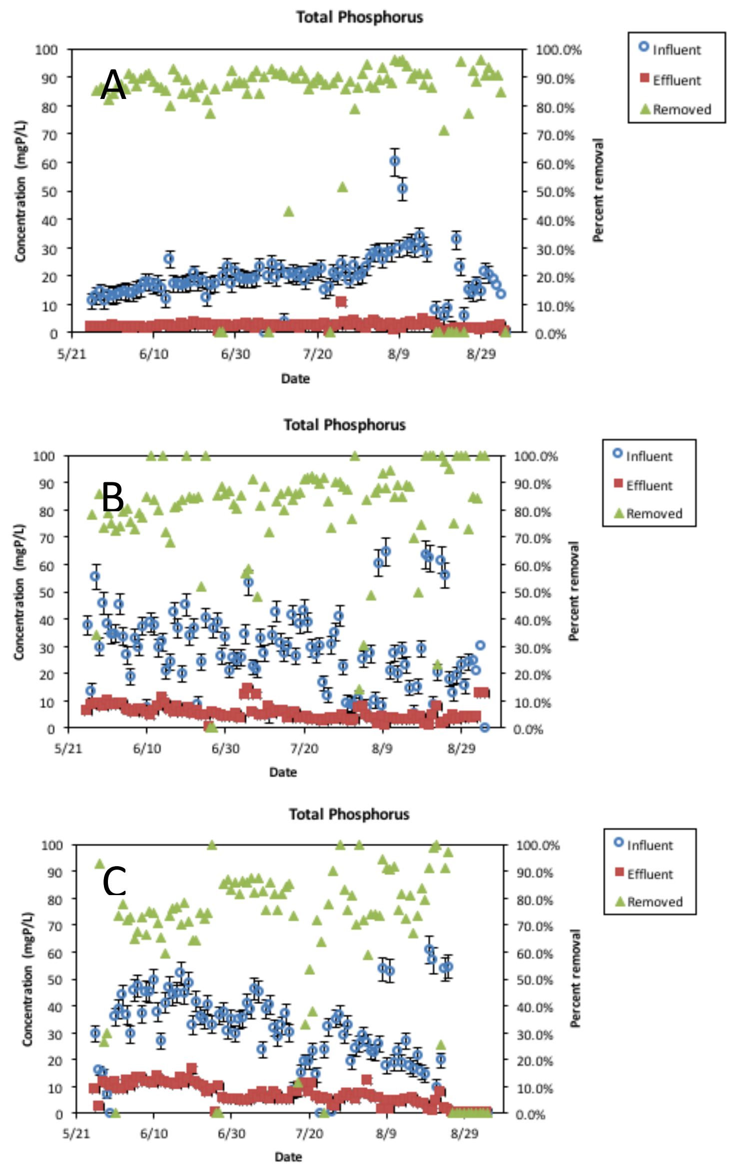

Figure 2. Nutrient uptake (i.e. Total Phosphorus removal) by the ARRU across all three treatments (A: Lagoon water; B: AD/PHA effluent mixture (10:90); C: 100% PHA effluent) fur the full duration of operation.

We utilized our biomass productivity observations and nutrient capture measurements (P as soluble reactive phosphorous) to calculate initial estimates of the Gross economic value of the ARRU system (Table 1, see page 7). The biomass production and cattle feed value estimates were generated considering the different system retention times we tested for each effluent type. The nutrient capture and Water Quality Trading credits (WQT) were estimated using mean soluble reactive phosphorous retention rates for each wastewater type (as due to our system and sampling design we were not able to calculate P-retention by retention time). Clearly, the value of the ARRU is largely driven by the nutrient trading calculations (estimated annualized value ranges from $518,242 to $1,051,00), however there is also value in the algal biomass if marketed as an organic feed supplement (although palatability and digestibility tests would be necessary to confirm these value estimates). As noted by these calculations, the source of the wastewater affects both algae productivity rates and nutrient trading value as a function of the wastewater quality from an algal cultivation perspective, retention time employed, and wastewater nutrient content, respectively.

An additional outcome of this work that is important to the Dairy industry in Idaho is that both the ARRU biomass productivity and nutrient capture was remarkably stable over the duration of the operation. Although each aspect of the system varied through time, after an initial period of establishment, biomass productivity and nutrient removal rates were remarkably stable. These observations suggest that a commercial scale ARRU may be feasible both operationally and economically.

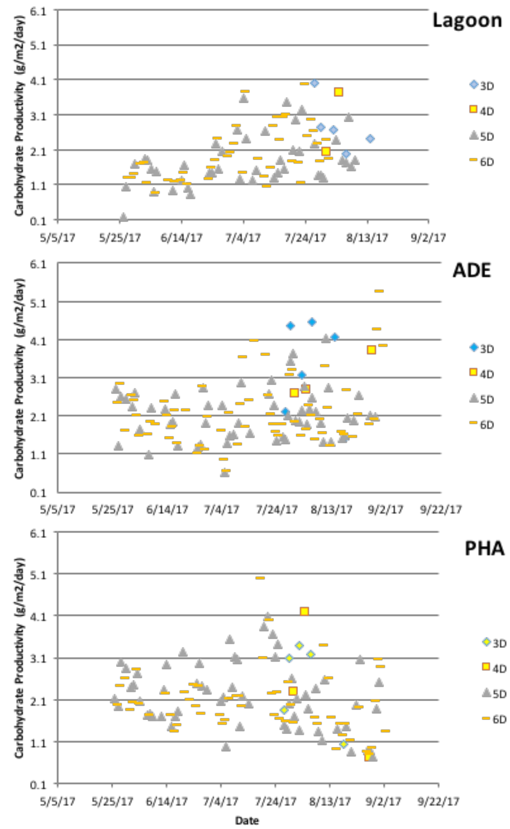

Figure 3. Algal biomass carbohydrate content expressed as a rate of carbohydrate productivity (g/m^2/day) for each ARRU treatment (A: Lagoon water; B: AD/PHA effluent mixture (10:90); C: 100% PHA effluent). 3D, 4D, 5D, 6D = retention times expressed as 3, 4, 5, and 6 days of mean retention time, respectively.

Final Project Findings: Since the submission of our annual report we have completed the majority of the biomass quality measures. Further, the full scope of originally proposed activities have been completed including measures of productivity and biomass quality (i.e. protein, carbohydrate, and ash content), and initial estimates of the value proposition for the produced algal biomass and nutrient capture exhibited by the ARRU. However, as noted in our annual project report, more work remains to be done to compare these measures to environmental and operational factors monitored during the operational period, including higher resolution measures of the relationships between these parameters and biomass quality, their consequent effects on projected productivity rates, and nutrient capture. Going forward, we will use these latter analyses as a means by which to better understand the limits on algal productivity, nutrient capture, and biomass quality in these types of systems. These analyses will also be used to make more complete projections of the economic potential of the technology when operated as a stand-alone system or in concert with a PHA/AD treatment system (i.e. including scalable estimates of capitol and operational costs for all components of the integrated system). Such projections will then be used to better refine estimates of the economic potential of our integrated system and subsequently be used to present the value of the technology to potential commercial partners. We will present these findings to our Industrial Advisory Group that is being launched as part of a new USDA award our team was recently granted (described below).

2. Summary of budget expenditures for the period just completed (include project burn rate):

$34,198 of the awarded $34,198 was been expended as of 6-30-18. This represents 100% of the project budget. 76% of the project budget was expended between 7-1-17 and 9-30-17, the remaining 24% was expended between 10-1-17 and 6-30-18. The second half of the project experienced a slower burn rate due to the fact that the majority of the experimental work associated with this project occurred in the first few months of the project. The remaining budget supported data collection and data analysis and thus required a slower rate of expenditure.

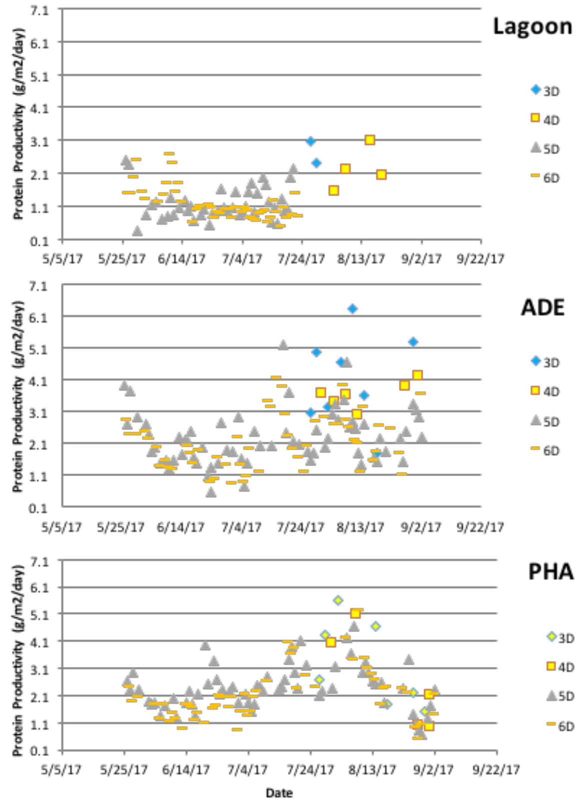

Figure 4. Algal biomass protein content expressed as a productivity rate (g/m^2/day) for each ARRU treatment (A: Lagoon water; B: AD/PHA effluent mixture (10:90); C: 100% PHA effluent). 3D, 4D, 5D, 6D = retention times expressed as 3, 4, 5, and 6 days of mean retention time, respectively.

3. Numbers of faculty and student participation resulting from the funding, including internships:

2 tenured faculty:
 Dr. Kevin Feris (Boise State University) and Dr. Erik R. Coats (University of Idaho)
1 PhD student
 Nicholas Guho (University of Idaho)
5 Undergraduate research assistants
 Gary Dunn (Boise State University)
 Katie Maries (University of Idaho)
 Alex Crozes (University of Idaho)
 Cody Barrick (University of Idaho)
 Andrew Blanchard (University of Idaho)
 Kyle Allen (University of Idaho)
1 Research Scientist
 Cindi Brinkman (University of Idaho)

4. List patents, copyrights, plant variety protection certificates received or pending:

No invention disclosures, patents, copyrights, etc. have been filed as of yet for this project. However, our on-going analyses may yield opportunities for such filings, we are not currently ready to pursue such activities.

5. List technology licenses signed and start-up businesses created:

No technology licenses or start-up businesses have been filed or created as of yet for this project. However, we are actively discussing how to pursue commercialization of the technology optimized in this project. The experimental findings and system operation experience from this project were leveraged to help our investigative team acquire additional new support from the United States Department of Agriculture and an new FY19 SBOE HERC IGEM award. Components of these sources of support will allow us to continue to refine and advance different aspects of our integrated system while we also explore avenues for commercialization of the technology advanced here.

Status of private/industry partnerships (include enough information to judge level of engagement):

As noted in our annual report, as part of this project we are developing an Industrial Advisory Group (IAG) as a means by which to present our findings, gather feedback on the viability of the ideas in real world applications, and seek input on our plans for future commercialization. Our overall goal is to leverage the expertise of these industry professionals to help realize technology commercialization. We have assembled an IAG associated with our new USDA award. This IAG consists of members of the Idaho Dairymen's Association and the Washington Dairy Products Commission. We will leverage this group for discussions of the work performed associated with this project as well.

6. Any other pertinent information that will indicate to the council that the project is meeting satisfactory progress.

History and on-going success of the collaboration between Drs. Feris and Coats: Dr. Feris and Dr. Coats have been collaborating for approximately 10 years on wastewater to biopower-bioplastics-algae systems. We have received funding through the US Department of Agriculture (USDA), Idaho National Laboratory (INL) and the Center for Advanced Energy Studies (CAES), and the Environmental Protection Agency (EPA) in support of this work.

The ARRU pilot-scale system we constructed as part of our prior SBOE award and continued operation and optimization of as part of this project was recently used as the basis for successfully pursuing additional extramural research funding. More specifically findings from this project were used, in part, as justification for two additional research proposals that were recently awarded. One from the USDA (PI: Erik Coats, Co-PIs: Kevin Feris and Armando McDonald) and a second from SBOE HERC (IGEM Initiative grant ID-002, PI Karen Humes, Co-PIs: Erik Coats, Armando McDonald, Jae Ryu, (University of Idaho), Co-PI: Kevin Feris (Boise State University), and Co-PI: Donna Delparte (Idaho State University). These fundings sources will allow us to continue the work and system optimization well beyond the scope of the project supported by the SBOE. Further, we will utilize the IAG developed around our new USDA award to leverage the findings of this project and to explore possible avenues for findings from this project to be applied at a larger scale.

Table 1: Gross Estimates of the ARRU Value Proposition

Effluent type	Lagoon	Lagoon	Lagoon	Lagoon	PHA/AD 90/10% mixture	PHA/AD 90/10% mixture	PHA/AD 90/10% mixture	PHA/AD 90/10% mixture	100% PHA effluent	100% PHA effluent	100% PHA effluent	100% PHA effluent
Retention time (days)	3	4	5	6	3	4	5	6	3	4	5	6
Max productivity rate (AFDW g/m2/day)	10.02	10.60	10.08	10.56	17.98	12.92	16.99	15.08	21.06	18.96	18.12	13.61
Mininum productivity rate (AFDW g/m2/day)	2.59	2.95	1.22	2.29	4.83	5.96	3.53	1.55	5.89	3.13	0.78	1.46
Average productiivty rate (AFDW g/m2/day)	6.63	6.60	4.54	4.45	11.65	10.20	8.25	7.61	10.76	11.05	8.48	7.74
total area of ARRU/treatment (m2)	25	25	25	25	25	25	25	25	25	25	25	25
Projected area of a 20 AC "commercial scale" system	80,937	80,937	80,937	80,937	80,937	80,937	80,937	80,937	80,937	80,937	80,937	80,937
Volume of wastewater L/m2	189	189	189	189	189	189	189	189	189	189	189	189
Volume of water treated per day for 20 AC commercial scale system (L)	15,297,093	15,297,093	15,297,093	15,297,093	15,297,093	15,297,093	15,297,093	15,297,093	15,297,093	15,297,093	15,297,093	15,297,093
Phosphorous concentration mg/L	11.4	11.4	11.4	11.4	21.21	21.21	21.21	21.21	10.12	10.12	10.12	10.12
% Phosphorours removal	0.97	0.97	0.97	0.97	0.90	0.90	0.90	0.90	0.93	0.93	0.93	0.93
Days of operation (Assume continuous operation April-September)	180	180	180	180	180	180	180	180	180	180	180	180
Harvests per year	60	45	36	30	60	45	36	30	60	45	36	30
Amount of biomass recovered/harvest (proportion of ARRU area harvested)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Average dry biomass production (tons/year)	17.70	13.23	7.27	5.95	31.10	20.43	13.22	10.16	28.75	22.14	13.58	10.34
Max dry biomass production (tons/year)	26.75	21.24	16.16	14.10	48.01	25.88	27.23	20.14	56.26	37.97	29.03	18.18
Mininum dry biomass production (tons/year)	6.93	7.88	3.25	6.13	12.89	15.91	9.43	4.13	15.72	8.36	2.07	3.90
Gross Estimated Annualized Value Produced from ARRU												
Value based on algae biomass as cattle feed:												
Average cattle feed ($/year) @ $390/ton*	$6,902	$5,160	$2,837	$2,320	$12,131	$7,968	$5,154	$3,961	$11,211	$8,635	$5,297	$4,033
Maximum cattle feed ($/year) @ $390/ton*	$10,433	$8,285	$6,303	$5,499	$18,725	$10,094	$10,619	$7,853	$21,942	$14,810	$11,323	$7,090
Minimum cattle feed ($/year) @ $390/ton*	$2,701	$3,074	$1,267	$2,390	$5,027	$6,206	$3,677	$1,612	$6,131	$3,261	$807	$1,520
Average cattle feed ($/year) @ $500/ton**	$8,849	$6,615	$3,637	$2,974	$15,552	$10,216	$6,608	$5,078	$14,374	$11,070	$6,791	$5,171
Maximum cattle feed ($/year) @ $500/ton**	$13,376	$10,621	$8,081	$7,050	$24,006	$12,941	$13,614	$10,068	$28,131	$18,987	$14,517	$9,090
Minimum cattle feed ($/year) @ $500/ton**	$3,463	$3,941	$1,624	$3,064	$6,445	$7,956	$4,714	$2,067	$7,860	$4,180	$1,035	$1,949
Value of ARRU based on nutrient trading (N and P):												
Water quality trading ($/day) @ $20/kg Phosphorus*** (assuming P removal rates noted abov	$3,383	$3,383	$3,383	$3,383	$5,840	$5,840	$5,840	$5,840	$2,879	$2,879	$2,879	$2,879
Water quality trading ($/year) @ $20/kg Phosphorus*** (assuming P removal rates noted abo	$608,959	$608,959	$608,959	$608,959	$1,051,222	$1,051,222	$1,051,222	$1,051,222	$518,292	$518,292	$518,292	$518,292
Grross ARRU Operational Outputs for a 20 Acre system (Avg biomass productivity + WQT)	**$617,808**	**$615,574**	**$612,596**	**$611,933**	**$1,066,775**	**$1,061,438**	**$1,057,830**	**$1,056,301**	**$532,666**	**$529,362**	**$525,084**	**$523,463**

Commodity price citations:

* Non-GMO Dairy feed price reference (http://www.woodshayandgrain.com/woods_grain.html#cattle)

** https://www.ams.usda.gov/mnreports/lswfeedseed.pdf

https://www.deq.idaho.gov/media/60179211/water-quality-trading-guidance-1016.pdf