COVER SHEET FOR GRANT PROPOSALS

State Board of Education

SBOE PROPOSAL NUMBER: (to be assigned by SBOE)	AMOUNT REQUESTED: $34,198

TITLE OF PROPOSED PROJECT: Continued Process Evaluation of an Integrated Pilot Scale Algae Resource Recovery Unit and Bio-plastics and Bio-power System

SPECIFIC PROJECT FOCUS: Cultivation of algae for alternative energy sources provides a means by which nutrients from agricultural production systems can be captured and converted to valuable energy and other co-products, while simultaneously mitigating unwanted eutrophication of our lakes and rivers, and minimizing the potential for nutrient contamination of our aquifers. Idaho's climate and existing agricultural systems represent unique and high-value opportunities for the development of algae production systems. For example, Idaho's hot, arid summers and high volumes of agricultural irrigation water and nutrient laden waste streams can supply low-cost resources for algal cultivation. Investing in, and commercializing, algal biomass production for alternative energy, nutrient capture and trading, and other alternative co-products, will bring Idaho to the cutting edge of bio- and algae-based business development. Such investments will also help maintain our highly valued aquatic resources and tap into our predominantly untapped and underutilized wastewater resources.

An FY17 award from the SBOE Innovation fund supported a collaborative project between BSU and UI for the construction and initial testing of a pilot-scale Algae Resource Recovery Unit (ARRU) to be operated as an integrated component of a Bio-plastics, Bio-power, and Algal cultivation system. The ARRU is sited at the UI Dairy and is currently receiving wastewater from three different sources: a) the UI dairy wastewater lagoon, b) effluent from a manure-based bio-plastics reactor (developed by the Coat's lab), and c) a mixture of effluent from the bio-plastics reactor and an anaerobic digester (also developed by the Coat's lab). On-going operations are quantifying algal production yields, improvements in wastewater quality in response to algae-based water treatment (i.e. nutrient removal), and spatial and temporal variation in these processes as they relate to operational and environmental factors. This work has been highly successful. However, additional support is required to maintain operations for a full growing season. A longer operational period will provide the richness of data necessary to evaluate the utility and economic viability of deploying our technology at full scale. For example, we estimate that additional income derived from the ARRU is estimated to be up to $410 per cow/year for combined water quality trading and cattle feed. This is a significant value to the dairy operation where average returns are generally very narrow, averaging $41.25 per cow/year over a 20 year period [1]. However, evidence of process stability can greatly affect the utility of these estimates for scale up to commercial-size facilities. Continued operation of the integrated system for a full growing season will provide a unique opportunity to obtain long-term operational, productivity, and economic estimates for all three components of this integrated technology, thereby enhancing our ability to commercialize the technology a scale relevant to the dairy industry in Idaho.

PROJECT START DATE: July 1, 2017	PROJECT END DATE: June 30, 2018
NAME OF INSTITUTION: Boise State University and University of Idaho	DEPARTMENT: Biological Sciences (BSU) and Civil Engineering (UI)

ADDRESS: Boise State University: 1910 University Drive, Mail Stop 1515, Boise, ID 83725-1515
University of Idaho: Civil Engineering, 875 Perimeter Drive, MS 1022 Moscow, ID 83844-1022

E-MAIL ADDRESS: kevinferis@boisestate.edu, ecoats@uidaho.edu	PHONE NUMBER: (208) 426-5498 and (208) 885-7559

	NAME:	TITLE:	SIGNATURE:
PROJECT DIRECTOR/PRINCIPAL INVESTIGATOR	Kevin Feris	Professor	
CO-PRINCIPAL INVESTIGATOR	Erik Coats	Associate Professor	Erik R. Coats

NAME OF PARTNERING COMPANY:	COMPANY REPRESENTATIVE NAME:

	NAME:	SIGNATURE:
Authorized Organizational Representative	Karen Henry	

SUMMARY PROPOSAL BUDGET			
Name of Institution: Boise State University			
Name of Project Director: Kevin Feris			
A. PERSONNEL COST (Faculty, Staff, Visiting Professors, Post-Doctoral Associates, Graduate/Undergraduate Students, Other)			
Name/ Title	Salary/Rate of Pay	Fringe	Dollar Amount Requested
BSU Undergraduate Researcher (2 summer months)	$4,160.00	$416.00	$4,576.00
BSU Undergraduate Research (1.5 academic months)	$1,560.00	$62.00	$1,622.00

% OF TOTAL BUDGET:	18%	SUBTOTAL:	$6,198.00

B. EQUIPMENT: (List each item with a cost in excess of $1000.00.) Item/Description	Dollar Amount Requested
SUBTOTAL:	

G. TRAVEL:

Dates of Travel (from/to)	No. of Persons	Total Days	Transportation	Lodging	Per Diem	Dollar Amount Requested
	2					$1,000.00
SUBTOTAL:						$1,000.00

H. Participant Support Costs:	Dollar Amount Requested
1. Stipends	

4. Other	
SUBTOTAL:	
I. Other Direct Costs: Amount Requested	Dollar
1. Materials and Supplies	$2,000.00
2. Publication Costs/Page Charges	
3. Consultant Services (Include Travel Expenses)	
4. Computer Services	
5. Subcontracts	$25,000.00
6. Other (specify nature & breakdown if over $1000)	
SUBTOTAL:	
J. Total Costs: (Add subtotals, sections A through I) **TOTAL:**	$34,198.00
K. Amount Requested: **TOTAL:**	$34,198.00
Project Director's Signature:	Date: 5-25-17

INSTITUTIONAL AND OTHER SECTOR SUPPORT
(add additional pages as necessary)

A. INSTITUTIONAL / OTHER SECTOR DOLLARS	
Source / Description	Amount

B. FACULTY / STAFF POSITIONS
Description
C. CAPITAL EQUIPMENT

Description
D. FACILITIES & INSTRUMENTATION (Description)

FY 2018 SBOE IDAHO INCUBATION FUND PROGRAM

Title: Continued Process Evaluation of an Integrated Pilot Scale Algae Resource Recovery Unit and Bio-plastics and Bio-power System

1. **Name of Idaho public institution:** Boise State University and University of Idaho
2. **Name of faculty member directing project:** Kevin Feris and Erik Coats
3. **a) Original proposed submission:** 2016 **b)** Prior award in FY17. This proposal leverages significant success on our prior award, and continues to enrich the long-running collaboration between Drs. Feris and Coats. Specifically, we request support to extend and continue operation, testing, and integration of the Algae Resource Recovery Unit (ARRU) with the Bio-plastics and Bio-power system at UI that incorporates a full annual growing season.
4. **Executive Summary:**

Large-scale algae cultivation provides a means by which nutrients (nitrogen, phosphorus) from agricultural waste streams can be recovered and converted to alternative energy and other valuable co-products, while simultaneously mitigating unwanted and damaging eutrophication of freshwater resources. Idaho's climate coupled with its existing agricultural systems represent unique and high-value opportunities for the development of algae production systems; the hot, arid summers and high volumes of agricultural irrigation water and nutrient laden waste streams can supply low-cost resources for algal cultivation. Investing in algal biomass production for alternative energy, nutrient capture/trading, and other alternative co-products will bring Idaho to the cutting edge of bio- and algae-based business development. Such investments also maintain our highly valued aquatic resources and tap into our predominantly untapped and underutilized wastewater resources. Finally, such investments help diversify the base agricultural industry through synthesis of high-value products while concurrently mitigating environmental impacts.

An FY17 SBOE Innovation fund award is supporting a collaborative project between BSU and UI for the construction and initial testing of a pilot-scale Algae Resource Recovery Unit (ARRU) to be operated as an integrated component of a Bio-plastics, Bio-power, and Algal cultivation system (Figure 1). The ARRU is sited at the UI Dairy and is currently receiving wastewater from three different sources: a) the UI dairy wastewater lagoon, b) effluent from a manure-based bio-plastics reactor (developed by the Coats' lab), and c) a mixture of effluent from the bio-plastics reactor and an anaerobic digester (also developed by the Coats' lab). System operations integrate Dr. Coats' bio-plastics pilot system (SBOE funded) and continuous flow centrifuge (SBOE funded). On-going operations are quantifying algal production yields, algae-based wastewater treatment (i.e. nutrient removal), and spatial and temporal variation in these processes as they relate to operational and environmental factors. To-date this work has been highly successful. For example, current operational conditions are resulting in 86-97% capture of soluble phosphorus (P) and 82-84% capture of soluble nitrogen present in the dairy-based wastewaters feeding the ARRU. This magnitude of nutrient removal from dairy wastewater is critical for the Idaho dairy industry; a recent ruling in Washington State against dairy operations on nitrogen contamination of water supplies potentially imperils Idaho dairy operations. Additional support is required to evaluate operations for a full growing season and provide the richness of data necessary to more fully evaluate the utility and economic viability of deploying our technology (coupled with Dr. Coats' systems) at full scale. Just considering algal production, we estimate that income derived from the ARRU is up to $410 per cow/year for

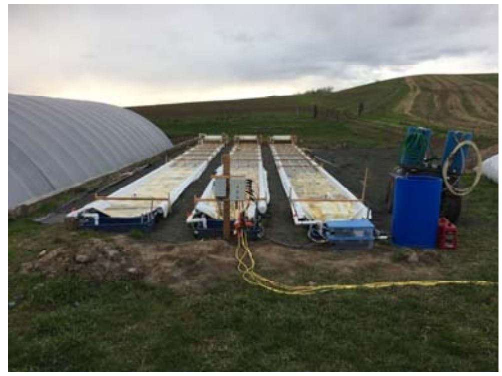

Figure 1. BSU and UI's pilot scale algal resource recovery unit at the UI dairy, Moscow, ID.

combined water quality trading and cattle feed. This is a significant value to the dairy operation where average returns are generally very narrow, averaging $41.25 per cow/year over a 20 year period [1]. Continued operation of the integrated system for a full growing season will provide a unique opportunity to obtain long-term operational, productivity, and economic estimates for all three components of this integrated technology, thereby enhancing our ability to commercialize the technology at a scale relevant to the dairy industry in Idaho.

5. "Gap" project objective and total amount requested

Project objective: Wastewater-to-algae research began eight years ago at Boise State University (BSU) and is ongoing today. This research has yielded multiple externally funded projects, graduate students, publications, and a pending patent. Our research and development has ranged from laboratory to greenhouse scale, and we maintain a primary focus on dairy wastewater remediation. We have built on this knowledge by constructing a pilot scale ARRU, integrated into a broader dairy-resource recovery system which also includes a Bio-plastics and Bio-energy reactor (i.e., anaerobic digester). The integrated system treats dairy solid and liquid wastes, thereby maximizing resource recovery and production of high value co-products while concurrently realizing excellent wastewater treatment. This large scale demonstration of our integrated suite of technologies is facilitating "real-world" value estimates for algal biomass production and water quality trading (WQT) scenarios. Extending this work for a full growing season will allow us to accurately project dairy based income potential, coupled with wastewater treatment potential, for multiple value propositions that may be realized with an integrated full scale system and for each of the unit operations.

Total amount requested: A total of $34,198 is requested to leverage the previous SBOE Innovation fund investment and to allow us to extend and continue integrated system operations for a full growing season. A majority of funds will be used for labor ($28,398) and analysis costs ($4,800) with the remainder being used travel to support sample collection ($1,000).

6. Description of how resource commitments reflect the priorities of the home institution

Continued development of the algae biofuels and bio-products program at BSU is supported by the Department of Biological Sciences and the State of Idaho; for example we have received funding through the Idaho National Laboratory and the Center for Advanced Energy Studies. Additionally, the Environmental Protection Agency (EPA) and the US Department of Agriculture (USDA) focus on agriculture-to-algae research and both agencies have provided multiple funded grants to support our researchers and graduate students over the years.

This proposal also builds on and continues a long-running collaboration with the University of Idaho's Civil and Environmental Engineering department (Erik Coats) with a focus on development of value added products from dairy wastewater systems, such as bio-plastics, biogas, and algae based products [2, 3]. We have leveraged these investments to construct, test, and operate algal cultivation systems at the laboratory, greenhouse, and now the pilot scale. Here we request support to extend and continue operations and daily monitoring of the ARRU process parameters to assess algal productivity rates, nutrient capture rates, and biomass yields on daily, weekly, and seasonal time scales. This temporal resolution and duration of operation will allow us to assess process stability and variability, thereby enhancing our ability to estimate economic viability of the ARRU. What follows in sections 7 through 12 is very similar text to our original proposal addressing the other aspects of the RFP.

7. Evidence that the project will have a potential impact to the economy of Idaho

The ~530,000 dairy cows in Idaho generate ~3 million tons of dry manure each year (2010) [4], with each ton containing approximately 4.5 kg of nitrogen (N) and 0.82 kg of phosphorus (P) [5].

These waste streams are traditionally dealt with via land application, a practice that can threaten waterways due to runoff and infiltration, facilitating the release of N and P to surrounding waters and causing aquifer contamination and/or surface water eutrophication and hypoxia [6, 7]. Resource recovery of the P and N emitted from Idaho dairies can be upcycled to create significant value added products, including WQT credits for statewide watersheds. In addition, a biomass based commodity will be cultivated and harvested with the option for pivoting the value proposition between bio-crude, cattle feed, or other products based on market pricing and demand. A model 200 head dairy farm is used for income projections, generating an estimated ~1,100 tons of manure per year and ~11 tons of P. A reasonable algal P uptake rate of 60% of available manure based P can be assumed, with the following value propositions:

1) **Water quality trading:** The market value of P based water quality trading is estimated at $20 per kg [8]. Income potential stands at ~ **$132,000 per year** for the 200 head farm or $660 per cow/year.

2) **Bio-crude commodity**[*]: Dry algae biomass production is estimated at 660 tons/year, with bio-crude production from hydrothermal liquefaction at 35,000 L/year. Income potential from bio-crude is projected at ~ **$11,000 per year** or $55 per cow/year.

   *Assuming biomass at 4% lipids. Bio-crude priced at West Texas Intermediate @ $0.31/Liter

3) **Cattle feed commodity**[*]: 660 tons of dry algae biomass per year can be substituted for high protein cattle feed with an income potential of ~ **$125,000 per year** or $625 per cow/year.

   *High protein cattle feed priced at Dry Distiller's Grain commodity pricing @ $190/ton

Pizarro et al. calculated the capital cost for a 27 acre dairy based algal attached growth system to be $1.68 million with an operating cost of $454 per cow/year for wet algae production [9]. Based on the value propositions mentioned above and 20-year amortization of capital on estimates from Pizarro et al., the profit/loss from an ARRU can be estimated to be: **-$160 per**

cow/year for combined WQT and bio-crude products and **$410 per cow/year** for combined WQT and cattle feed products. Currently, a net loss is projected for the combined WQT and bio-crude products, although fluctuating oil prices may push this option to profit in the future. These biomass production estimates are consistent with published attached growth biomass yield estimates of 25 $g \cdot m^{-2} \cdot day^{-2}$, see section 9 below.

8. The market opportunity

a) Describe need the project would address

Idaho's dairy industry production stands at 3rd in the nation and is a significant contributor to Idaho's economy. The industry as a whole is under increasing pressure to mitigate run off and ground water infiltration of N and P from wastewaters. The goal of the federal Clean Water Act (1972) is to "restore and maintain the integrity of the nation's waters" and requires adoption of water quality standards necessary to protect aquatic life, human health, and the environment. The Idaho Department of Environmental Quality states that 36% of Idaho's streams do not meet water quality standards and are subject to total maximum daily load limits (TMDLs) for multiple parameters, including N and P. The lower Boise phosphorus TMDL was approved by EPA in 2015 and requires a combined 77% reduction from non-point sources, stormwater, wastewater, and improvement in ground water quality [10]. To meet these goals, municipal wastewater treatment plants (WWTPs) are required to reduce P discharge by 97% in the summer (May-Sept) and 89% in the winter. Unfortunately, the TMDL provides no reserve for future population growth, so increased discharge can only occur through a combination of expensive additional treatment infrastructure plus WQT. In addition, an agricultural P discharge reduction of 61% is necessary for the TMDL goal to be met. The Lake Lowell Watershed (LLW) within the Lower Boise River Subbasin is another area that surpasses the TMDL, requiring a 56% reduction of P inflow to meet the 70 µg/L limits [11]. The LLW is dominated by farms, irrigated crops, and pasture land, including seventeen dairies that are nonpoint sources contributing to the TMDL.

b) Describe applications and markets for the technology. Include market size and demand projections

See response for section 7 above and 8 (c) below.

c) Describe the product, its potential market audience, the competition, and barriers to market entry

Water Quality trading: The emerging WQT industry has tallied $52 million in transactions between 2000 and 2008 in the U.S. [12]. Currently, 16 states have active WQT programs with 24 programs operating under specific national pollutant discharge elimination system (NPDES) permits or state water quality guidance. Such programs include the Maryland and Virginia Chesapeake Bay and Oregon's Willamette, Rogue, and Lower Columbia Rivers [13]. Under Idaho's water quality standards (IDAPA 58.01.02.055.06), water quality development and improvements to TMDLs may be accomplished through WQT. The WQT framework developed for the Lower Boise River (2000) allows for point and nonpoint source reduction in P with target trading partners identified as NPDES permit holders [14]. Nonpoint source agriculture P mitigation is accomplished through best management practices (BMPs), addressing the farm P surplus with soil and water conservation practices [15]. We maintain that an ARRU system will be consistent with current BMPs for agricultural P mitigation, particularly in the case where algae biomass is used for cattle feed.

Cattle feed: The guideline for feeding crude protein for early lactating dairy cows is 17-19% of dry mass and is an important component of the total mixed rations traditionally used for dairy feed [16]. Crude protein content of algae varies by species with *C. vulgaris* generally ranging between 51-58% dry matter [17], comparing favorably to traditional ruminant feed stocks, i.e. corn contains 10% crude protein while soybeans contain 37% [17]. Additionally, algae biomass is a source of n-3 fatty acids and lactating cows have been shown to increase milk n-3 fatty acid yield, particularly docosahexaenoic acid (DHA), with the inclusion of an algal biomass diet [18]. The use of algae as cattle feed can be useful in closing the P mass balance around dairy farms, allowing for onsite recycling of P that follows with the USDA guidelines for BMPs [15].

Bio-fuel: Algae based bio-crude is a direct replacement for crude oil and may be processed into transportation fuels as well as a multitude of hydrocarbon based commodities. The EPA's Renewable Fuel Standard (RFS) requires that 3.6 billion gallons of advanced renewable biofuels be blended into transportation fuel in 2016, with algae and cellulosic biofuel making up the majority of this requirement. Compliance of the RFS is monitored through the renewable identification number (RIN) system, whereby refiners, blenders, and importers are required to meet a renewable volume obligation (RVO). Businesses falling under the RVO may satisfy requirements by blending biofuel or by purchasing RINs from other entities that exceed their RVO. Economic incentive is realized in RIN credits that are bought and sold on the market; the current equivalent RIN allocation for algae biofuel is 1.7 per gallon compared to 1.0 per gallon for ethanol with an approximate trading value is $0.50 per RIN. One local biofuel blending company, Campo & Poole (Ontario, OR) has expressed interest in purchasing algae biofuels from western Idaho and eastern Oregon. Campo & Poole distributes B10 to B100 blends and is currently selling in excess of 20 million gallons of biodiesel (B10 to B100) per year with sources from as far away as Canada.

9. The technology and path to commercialization: The ARRU operational conditions are based on properties of the three wastewater streams we are treating and environmental variables such as minimum/maximum daily temperatures and photo period. The ARRU is constructed of three main parts: the headworks, the floway, and the effluent reservoirs. The unit is modeled based on Walter Adey's Algal Turf Scrubber (ATS^{TM}) whereby biomimicry of the highly productive ocean coral reefs provides high biomass yields [19-21]. Versions of the ATS^{TM} have been implemented in several states to help mitigate eutrophication in lakes and streams.

Other projects with this technology include an algal growth bed (AGB) constructed at the University of Arkansas Center for Agricultural and Rural Sustainability (CARS). The AGB was constructed downstream from the city of Fayetteville Wastewater Treatment Plant discharge point. The 1 x 300 foot floway averaged a biomass yield of 26 $g \cdot m^{-2} \cdot day^{-1}$ (March through November) and reduced P discharge into the Illinois River. This successful project led to collaboration with Fayetteville's Noland WWTP and CH2M Hill for construction of a phase II AGB to remove P from the plant's effluent. An ATS^{TM} design was also installed near the Port of Baltimore to remove nutrients and sediments while adding dissolved oxygen to the harbor. The group from the University of Maryland including Dr. Patrick Kangas and Dr. Peter May are pushing to gain EPA's BMP certification for the process.

Examples of commercial scale algal turf scrubber operations include 1) a Tilapia fish farm in Falls City, Texas where a turf scrubber system was used to clean fish wastewater, and 2) a WWTF in northern Central Valley California where the system provided tertiary water treatment, producing 35 $g \cdot m^{-2} \cdot day^{-1}$ of dry biomass [22].

10. Commercialization partners: As this is a multi-faceted and emerging industry, we have engaged many players to ensure proper execution and to account for the needs of all parties involved. We have networked with academic, industry, agriculture, and government stakeholders within the state, including: The University of Idaho's Department of Civil and

Environmental Engineering and Dr. Erik Coats, The Center for Advanced Energy Studies, The Idaho Dairymen Association, the City of Boise, Idaho Department of Environmental Quality, Idaho Soil and Water Conservation Commission (SWC), Idaho's USDA office, and Campo & Poole Distributing (Ontario, OR).

11. Specific project plan and detailed use of funds: Our diverse group of professionals offers extensive algae cultivation and wastewater knowledge with the primarily focus of utilizing wastewater based mediums for value added products. We will use the requested funds to extend and continue operation of our pilot-scale facility for a full growing season. This is a critical next step in fulfilling the data needs and in establishing stability of the ARRU as a basis for Idaho's WQT market as well as algae biomass end products. The funds from this proposal will be utilized according to the following tasks.

Task 1 – Continue operations and data acquisition from of the ARRU for a full growing season (i.e. through September/October 2018): The ARRU is currently operational with the effort equivalent to 1 full time person for system operation, maintenance, harvesting, and data collection. We are currently collecting data to characterize biomass productivity, biomass quality, cattle feed productivity, bio-crude potential, N removal, P removal, and WQT potential. Information from the full growing season run is expected to be used for design of a full scale ARRU, including capital and operating costs estimates and value propositions.

12. Institutional and other sector support: The ARRU will be instrumental in establishing value propositions that include biomass based products (biofuel, cattle feed, and slow release fertilizer) and the secondary value proposition of WQT that is yet untapped in Idaho, enhancing the opportunity for commercialization of an algae agriculture infrastructure in the state.

Appendices

Facilities & Equipment

Boise State University

Facilities

Boise State University is the fastest growing university in Idaho with the most rapidly increasing research portfolio among the three research institutions in the state. Undergraduate enrollment has been > 18,000 over the last three years and approximately 2000 graduate students. Dedicated laboratory space with essential equipment and instrumentation is available along with office and greenhouse space. In addition, the Department of Biological Sciences also has multi-user facilities that this project will have access to that include laminar flow cabinets, centrifuges, autoclaves, microscopes, plate readers, etc. A valuable asset to the proposed work scope is the state-of-the art greenhouse. The greenhouse is divided into a head house and four bays. Temperature, watering, and light can be controlled separately in each of the bays by a fully automated system. One of the bays is 400 sq. ft. and the other three 200 sq. ft. each. This facility also has suitable bench space for set up, maintenance and operation of pilot-scale algal cultivation systems. Boise State University has guaranteed us sufficient space in the greenhouse facility to construct and run our experiments. All costs associated with maintaining climate controls, water supplies, and water removal will be covered by the Boise State Universities Biological Sciences Greenhouse Facility.

Equipment

- Dr. Feris has been supplied with approximately 750 sq. ft. of dedicated research lab space for these and other experiments, in addition to the departmentally available sterilization, storage, and other facilities.
- Agilent 6890N GC (network communication) Dual split/splitless inlet with Electronic Pressure Control FID Detector and Thermal Conductivity Detector (TCD) with Electronic Pressure Control. Dual 7683 injection towers and autosampler 100-sample tray. GC system includes an Agilent 7694 headspace sampler for measurement of volatile organics associated with intact solid and liquid environmental samples.
- Applied Biosystems 310 Capillary Electrophoresis DNA Analyzer
- Applied BIosystems 7300 Real-time PCR machine
- Techne Genius Thermocycler with 96-well block
- ESCO Airstream PCR Cabinet model PCR-3AX
- Molecular biology supplies (e.g. electrophoresis rigs, pipettors, freezers, refrigerators, microcentrifuges, etc.)
- -20oC and -80oC freezers for storage of clones and environmental isolates
- Microbiological culturing supplies
- Incubators, water baths, etc.
- Autoclave
- Shaking and static incubators (both dark and those with controlled light sources)
- UV-Vis Hach 2800 spectrophotometer
- Zeiss Confocal microscope

- BioTex Synergy MX fluorescent plate reader
- Nanodrop ND-1000 spectrophotometer for quantifying DNA for plasmid sequencing, transformation studies, etc..
- Bio-Rad Gel doc XR for agarose gel imaging

Multi-User University equipment

- Lachat's QuikChem® 8500 Series 2 Flow Injection Analysis System
- ThermoElectron X-Series II quadrupole ICPMS
- FlashEA 1112 NC Analyzer

University of Idaho

FACILITIES

The University of Idaho (UI) was founded in 1889 as the state's comprehensive land-grant institution with primary responsibility statewide for doctoral degrees, research programs, and professional public service. UI maintains significant infrastructure to support research. The UI library has subscriptions to an extensive list of peer-reviewed journals (hardcopy and electronic) as well as books and databases necessary to support the proposed project. The library also maintains a subscription to SciFinder Scholar, ISI Web of Knowledge, and many other database search engines to support research. The UI has multi-user facilities for mass spectrometry, electron microscopy, NMR spectroscopy, chemical analysis, confocal microscopy and image analysis, molecular biology and proteomics which are available to researchers.

The Civil Engineering environmental engineering laboratory (Dr. Coats') is housed in the Buchanan Engineering Laboratory on the University of Idaho campus in Moscow, ID. The laboratory, which is temperature controlled, has facilities to undertake in-depth environmental research, including physical, chemical, biological, microbiological, and molecular biological investigations, in a 4,000 ft^2 laboratory space (which includes benches, utilities, fume hoods, laminar flow cabinet, reagent-grade water, etc.). Available equipment, in both Dr. Coats' lab and otherwise accessible on campus by Dr. Coats' research group, is listed below.

Graduate students have office space in the Department of Civil Engineering equipped with personal computers, each of which has independent access to a 100 megabits-per-second internet connection.

EQUIPMENT

<u>Civil Engineering Environmental Laboratory</u>

- Over 4,000 ft^2 of laboratory space for water and environmental studies
- Shimadzu RF 5301 PC Spectrofluorophotometer with 3D visualizing software
- Shimadzu uv/visible spectrophotometer
- Thermo visible spectrophotomers
- Lachat FIA for P and N analysis (including autosampler)
- Unisense meter with nitrate and nitrite probes

- Hach digestion blocks
- Muffle furnace & autoclave
- Reagent grade water system
- HP model 6890 GC-FID
- Agilent model 6890 GC-NPD
- Gow Mac GC/TCD
- Waters HPLC with RI, UV, and DA detectors
- Laboratory-scale bioreactors with 16 Watson-Marlow peristaltic pumps and 30+ microprocessor-controlled magnetic stir plates
- Programmable Logic Controller (PLC) to automate laboratory operations, with 32 input/output relays
- Applied Biosystems Step One Plus real time PCR system
- Bio-Rad 96 well PCR with Dcode DGGE system and UV imager with camera
- Thermo-electron RC6+ and RC5B floor mounted centrifuges
- Micro centrifuges
- Laminar flow hood
- High volume muffle furnace
- Incubator and incubator/shaker table
- Balances (10^{-3} and 10^{-4} gram accuracy/precision)

<u>Multi-User University equipment</u>

- Mass-spectrometry facility
  - LC-MS-MS (Micromass Quattro-II mass spectrometer,0- 4000 Da; electrospray andAPCI ionization modes)
  - Hewlett Packard 5973 GC/MS system (EI and CI ionization modes)
  - Waters QTof-Premier MS-MS system with APCI/MALDI MS/MS platform for proteomics analysis.
- Multiple HPLCs (Hewlett Packard 1090 instruments with UV-visible scanning diode array and radioactivity detectors);
- Several UV-visible spectrometers;
- FluorMax 3 fluorimeter (Jobin-Yvon SPEX);
- Bruker 300, 400 and 500 MHz NMR spectrometers
- OI Analytical Flow Solution 3000 Flow Injection Analyzer
- Machines for microtiter plate reading (fluorescence of transmitted light);
- Pulsed-field gel electrophoresis (BioRad)
- High-throughput PCR (4 x 384 well blocks; MBS Thermocyclers, ThermoHybaid)
- Real-time PCR
- Highly controlled microtiter plate temperature incubation and shaking (HiGrow)
- Olympus and Zeiss Confocal Laser Scanning microscopes
- Zeiss variable pressure field emission scanning electron microscope and a conventional SEM with EDS capabilities
- Two transmission electron microscopes with EDS capabilities
- Siemens' powder x-ray diffraction spectrometer

<u>Renewable Materials Laboratory (Dr. Coats has unlimited access)</u>

- Waters Breeze HPLC/ Viscotek GPC system which has quad detection (UV-VIS, laser light scattering (LALLS, RALLS), differential viscometer and refractive index)
- Dionex 1000/pulsed ampiometric detection ion exchange carbohydrate analysis system
- GC-MS^n (PolarisQ iontrap with EI and CI ionization modes) with pyrolysis capabilities
- GC-MS (Focus-ISQ quadrapole with EI)
- LC-MS^n (Thermofinnigan LCQ deca iontrap with ESI and APCI ionization source) with TSP HPLC system
- FTIR spectrometer (Thermonicolet Avatar 370) with ATR and DRIFT probes
- FT-Raman spectrometer (Thermonicolet 960,1064 nm excitation)
- Portable Raman spectrometer (Enwave Optronics portable) (785 nm excitation)
- UV-VIS spectrometers (Beckman 640 and StellarNet with various fiber optic probes)
- NIR spectrometer (900-1700nm; Control Development) with various fiber optic probes
- Olympus BX51 microscope (fluorescence, polarized light, DIC) with digital image capture
- Protein 1D and 2D-electrophoresis system (mini-Biorad) and protein extraction/purification
- SPSS, Unscramber and Design-expert statistical analysis software
- Instron 5500R-1137 and 5500R-1122 universal testing machines (bending, tensile and compression testing modes) with variable temperature testing oven/chamber
- Differential scanning calorimeter (DSC) TA instruments model Q200 with cooling
- Dynamic mechanical analyzer (DMA) TA instruments model Q800 with cryogenic cooling
- Thermal mechancial analyzer (TMA) Perkin Elmer model TMA-7
- Thermogravimetric analyzer (TGA) Perkin Elmer model TGA-7
- Differential Thermal analyzer (DTA) Perkin Elmer DTA-7
- Two flow through bed bench top reactors (for biofuels catalysis work) with tube furnace, metering pumps and gas mass flow controllers.
- Parr Instruments high pressure/temp reactors (model 4740, 75mL; model 4652, 500mL) plus controllers and (model 4561, 300mL) with heating/cooling control and stirrer
- 2L bioreactor STR with feed/effluent control, pH control, with aeration and DO monitoring
- Lab auger pyrolysis unit (1 kg/h) and ABRI Pilot scale auger pyrolysis unit (1/2 ton/day) with biomass dryer and grinder
- Dynamic Rheometer Bohlin CVO100 with extended temperature oven
- Laboratory hot presses 50 ton (Wabash 18"x18") and 30 ton (12"x12") both with cooling
- Leistritz co-rotating twin screw extruder (18 mm dia, LD40) with gravimetric feeding, sheet forming die/3-roll calendaring unit, pelletizing unit, ribbon die, and strand die
- Injection molding machine (15 Ton, Yuh-Dak model YH30) for test specimen preparation
- Q-Sun model Xe1S xenon-arc accelerated weathering chamber
- Contact angle goniometer (Pocket goniometer model 2)
- Benchtop lab molding machine (Dynisco LMM) for preparation of test specimens
- CEAST model 7203 Melt Flow indexer
- QMS x-ray profile densitometer
- Stress wave non-destructive test equipment (FibreGen ST300 and HT200; Metriguard)
- General wet chemistry lab, ovens, centrifuges, extractors, reactors, balances, fume hoods, furnaces, freeze drier, mills, vacuum system, environmental chambers, autoclave
- Electrophoresis 1D and 2D units (Biorad

Biographical Sketch

Kevin P. Feris, Ph.D. (Co-PI) E-mail: kevinferis@boisestate.edu
1910 University Dr. Phone: (208) 426-5498
Boise, ID 83725 Fax: (208) 426-3262

Education and Training

University of Alaska Anchorage, Biology, B.S. 1995

University of Montana, Microbial Ecology, Ph.D. 2003

University of California, Davis, Microbial Ecology, Post-Doctoral Researcher 2003-2005

Professional Experience

Professor, Biology Department, Boise State University, Boise, ID 2015- present

Associate Professor, Biology Department, Boise State University, Boise, ID 2010- 2015

Assistant Professor, Biology Department, Boise State University, Boise, ID 2005 – 2010

Postdoctoral Research Associate, Microbial Ecology, Kate Scow's lab University of California at Davis, Department of Land, Air, and Water Resources 2003-2005

Research Assistant, Molecular Microbial Ecology Lab, University of Montana 2000 - 2003

Microbiology laboratory instructor: University of Montana 1998 - 2000

Laboratory Technician: Neurobiology Lab, University of Alaska Anchorage, Biological Sciences Department 1997-1998

Laboratory Technician: Biogeochemistry Lab, University of Alaska Anchorage, Biological Sciences Department 1996

Five products (i.e. publications) most closely related to the proposed project:

Coats, E.R., Searcy, E., Feris, K., Shrestha, D., McDonald, A.G., Briones, A. *et al.* (2013). An integrated two-stage anaerobic digestion and biofuel production process to reduce life cycle GHG emissions from US dairies. *Biofuels, Bioproducts and Biorefining*, 7, 459-473.

Passero, M., Cragin, B., Coats, E.R., McDonald, A.G. & Feris, K. (2015). Dairy Wastewaters for Algae Cultivation, Polyhydroxyalkanote Reactor Effluent Versus Anaerobic Digester Effluent. *BioEnergy Research*, 8, 1647-1660.

Passero, M.L., Cragin, B., Hall, A.R., Staley, N., Coats, E.R., McDonald, A.G. *et al.* (2014). Ultraviolet radiation pre-treatment modifies dairy wastewater, improving its utility as a medium for algal cultivation. *Algal Research*, 6, Part A, 98-110.

Smith, S.A., Hughes, E., Coats, E.R., Brinkman, C.K., McDonald, A.G., Harper, J.R. *et al.* (2016). Toward sustainable dairy waste utilization: enhanced VFA and biogas synthesis via upcycling algal biomass cultured on waste effluent. *Journal of Chemical Technology & Biotechnology*, 91, 113-121.

Thomas, P., Coats, E., Newby, D., Passero, M. & Feris, K.P. (in preparation). Algal polyculture diversity increases culture stability and annualized yield by inhibiting grazing pressure and not by over yielding. Planned submission to Algal Research Spring 2016.

<u>Five other significant products (i.e. a related patent and publications):</u>

Patent US 2015/02755166 71. Ultraviolet Radiation Pre-treatment of Wastewater Improving its Utility as an Algal Cultivation Medium. Inventors: Kevin P. Feris and Maxine Prior (now M. Passero).

Sorensen, P.O., Germino, M.J. & Feris, K.P. (2013). Microbial community responses to 17 years of altered precipitation are seasonally dependent and coupled to co-varying effects of water content on vegetation and soil C. *Soil Biology and Biochemistry*, 64, 155-163.

McTee, M.R., Gibbons, S.M., Feris, K., Gordon, N.S., Gannon, J.E. & Ramsey, P.W. (2013). Heavy metal tolerance genes alter cellular thermodynamics in Pseudomonas putida and river Pseudomonas spp. and influence amebal predation. *FEMS microbiology letters*, 347, 97-106.

Stanaway, D., Haggerty, R., Benner, S., Flores, A. & Feris, K. (2012). Persistent metal contamination limits lotic ecosystem heterotrophic metabolism after more than 100 years of exposure: A novel application of the resazurin resorufin smart tracer. *Environmental science & technology*, 46, 9862-9871.

Gibbons, S.M., Morales, S.E., Gannon, J.E., Feris, K., McGuirl, M.A., Ramsey, P.W. *et al.* (2011). Use of microcalorimetry to determine the costs and benefits to Pseudomonas putida strain KT2440 of harboring cadmium efflux genes. *Applied and Environmental Microbiology*, 77, 108-113.

<u>Synergistic Activities</u>

Project director for moderate scale multi-investigator FEWS related project: USDA NIFA Climate. PI: Feris, K. P.; Co-PIs: Coats, E. (UI), McDonald, A. (UI); Post-Guillen, D (INL), Hamilton, M. (CAES). Title: "Enhancing greenhouse gas mitigation and economic viability of manure management systems via production of value added carbon sequestration". $681,143.

Co-PI on for moderate scale multi-investigator FEWS related project: Idaho National lab. PIs: Deborah Newby (INL), Feris, K. P. (BSU), Erik Coats (UI) "Integrated Approach to Algal Biofuel, Bio-power, and Agricultural Waste Management". $250,153. 2012-2015

Co-PI on for moderate scale multi-investigator FEWS related project: Center for Advanced Energy Studies: "Design and Operational Improvements, and LCA in Anaerobic Digestion of Fermented Dairy Manure Using a 2-Stage process." PI: Erin Searcy (INL), Co-PIs: A Briones (UI), E Coats (UI), K Feris (BSU), D Keiser (UI), T Magnuson (ISU), A McDonald (UI), D Shrestha (UI). Total funding level: $592,000; Feris share of funding: $74,001. 2010-2012.

Hydroclimatology team member for Idaho NSF Epscor RII project 2008-2013 and Senior Personel with the newly developed Reynolds Creek Critical Zone Observatory (2014- present).

Proposal lead for development of a transdisciplinary PhD program in Ecology, Evolution, and Behavior at Boise State University

ERIK R. COATS, P.E., Ph.D.

Department of Civil Engineering, University of Idaho

875 Perimeter Drive, MS1022, Moscow, Idaho 83844-1022

208.885.7559

ecoats@uidaho.edu; http://www.webpages.uidaho.edu/ecoats/

Professional Preparation

University of Idaho - B.S., Civil Engineering	1990
University of Idaho - M.S., Civil Engineering	1994
Washington State University - Ph.D., Civil Engineering	2005

Appointments

Teaching, Extension and Research Appointments:

Director of Engineering Management, University of Idaho, 4/2016-present

Associate Professor (Civil Engineering), University of Idaho, 7/2012-present

Affiliate Faculty (Chemical Engineering), Univ of Idaho, 6/14-present

Assistant Professor (Civil Engineering), University of Idaho, 8/2006-6/2012

Lecturer, University of Idaho (Civil Engineering), 8/2005-5/2006

Postdoctoral Scholar (Civil Engineering), Univ of California-Davis, 9/2005-8/2006

Adjunct Professor (Civil Engineering), University of Idaho, 8/2002-5/2005

Graduate Research Asst (Civil/Environmental Engr), Washington St. Univ, 8/2002-5/2005

Non-Academic Appointments:

Murray, Smith & Associates, Inc., Portland, OR, Sr. Project Manager, August 1998-July 2002.
Balfour Consulting, Inc., West Linn, OR, Principal, July 1995-August 1998
Cascade Pacific Engineering, Inc., Milwaukie, OR, Project Engineer, February 1994-July 1995
KPFF Consulting Engineers, Portland, OR, Project Engineer, July 1992-February 1994

Five Products (most closely relevant to the research)

1. Coats, E.R., B. Watson, and C.K. Brinkman, Polyhydroxyalkanoate Synthesis by Mixed Microbial Consortia cultured on Fermented Dairy Manure: Effect of Oxygen Mass Transfer on Process Rates/Yields and Microbial Ecology. Water Res., 2016. 106: p. 26-40.
2. Hanson, A.J., Guho, N.M., Paszczynski, A.J. and Coats, E.R. (2016) Community proteomics provides functional insight into polyhydroxyalkanoate production by a mixed microbial culture cultivated on fermented dairy manure. Appl. Biochem. Biotechnol., 1-20.
3. Hanson, A.J., Paszczynski, A.J. and Coats, E.R. (2016) Proteomic profiling of an undefined microbial consortium cultured in fermented dairy manure: Methods development. Electrophoresis 37(5-6), 790-794.

4. Winkler, Matt J., Coats, Erik R., Brinkman, C.K. 2011. Advancing Post-Anoxic Denitrification for Biological Nutrient Removal. Water Res. 45(18), 6119-6130.

5. Coats, Erik R., Mockos, Alexander, Loge, Frank J. 2011. Post-anoxic Denitrification driven by PHA and Glycogen within Enhanced Biological Phosphorus Removal. Bioresource Technology. 102 (2), 1019-1027.

Five Additional Products

6. Coats, E.R., Brinkman, C.K. and Lee, S. (2016-accepted) Characterizing and Contrasting the Microbial Ecology of Laboratory and Full-scale EBPR Systems Cultured on Synthetic and Real Wastewaters. Water Res.

7. Dai, J., E.R. Coats, A.G. McDonald. (2015) Multivariate near infrared spectroscopy for predicting polyhydroxybutyrate biosynthesis by mixed microbial consortia cultured on crude glycerol. Biomass Bioenerg., 2015. 81: p. 490-495.

8. Coats, E. R.; Dobroth, Z. T.; Brinkman, C. K. (2015) EBPR using crude glycerol: Assessing process resiliency and exploring metabolic anomalies[1]. Water Environ. Res., 87, 68-79.

9. Wei, L.; Guho, N. M.; Coats, E. R.; McDonald, A. G. (2014) Characterization of poly(3-hydroxybutyrate-co-3-hydroxyvalerate) biosynthesized by mixed microbial consortia fed fermented dairy manure. J. Appl. Polym. Sci., 131.

10. Al-Najjar, M.M., Coats, Erik R., Loge, Frank J. (2011) The Role of the Microbial Stringent Response in Excess Intracellular Accumulation of Phosphorous in Mixed Consortia Fed Synthetic Wastewater. Water Research. 45 (16), 5038-5046.

Synergistic Activities

Synergistic activities that have arisen from research projects include: (1) development of research collaborations with Drs. Andrzej Paszczynski (UI), Ken Cain (UI), and Stephen Lee (UI) that include application and multivariate statistical analysis of proteomic and transcriptomic techniques to better understand microbial functions in wastewater environments, (2) development of research collaborations with Dr. Armando McDonald (U Idaho) focused on alternative methods to synthesize and characterize bio-commodities using waste organic matter, (3) development of research collaborations with Dr. Ron Crawford (U Idaho) focused on application of microarrays and PCR to detect human pathogens in agriculturally-impacted waters, (4) collaboration with Dr. Aurelio Briones (UI) to integrating environmental engineering with molecular biology to advance a novel two-stage process for methane production via anaerobic digestion of manure, and (5) collaboration with the Idaho National Lab and the Center for Advanced Energy Studies to advance sustainable technologies for converting dairy manure into energy and other co-products.

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[3] Smith, S. A., Hughes, E., Coats, E. R., Brinkman, C. K.*, et al.*, Toward sustainable dairy waste utilization: enhanced VFA and biogas synthesis via upcycling algal biomass cultured on waste effluent. *Journal of Chemical Technology and Biotechnology* 2015.
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