

Advancing Bio-Based Chemicals and Next-Generation Fuels from Montana's Agricultural Crops

Fourth Quarterly Report

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Advanced Fuels Center
Montana State University Northern

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Introduction

With the steady decline of manufacturing employment in Montana and as the search for alternative energy sources continues, industrial oilseed crops pose a unique opportunity in addressing these issues. This collaborative research effort between the Advanced Fuels Center, Montana State University Northern (AFC-MSUN) and Montana State University Billings (MSUB) City College aims at establishing and maintaining a biorefinery utilizing Montana-grown industrial oilseed crops. The establishment of this biorefinery will provide sustainable growth in Montana’s agriculture and manufacturing industry in two ways: [a] the research is expected to generate numerous Montana jobs and will allow the investment to be leveraged by attracting businesses and [b] the research can address the federal government’s thrust of utilizing alternative energy sources to achieve a cleaner environment. This report covers all activities performed from June 1 to August 31, 2016.

Personnel Recruitment and Employment

Advanced Fuels Center, Montana State University Northern

Four (4) undergraduate research assistants were hired to assist the leads with their respective tasks. The following are brief biographies for all AFC-MSUN researchers and staff supporting the project activities.

<p>Randy Maglinao, PhD <i>Lead Principal Investigator (AFC-MSUN)</i> Dr. Randy Maglinao earned his degree of Doctor of Philosophy in Biological and Agricultural Engineering at University of Idaho in 2011. His research interests are converting industrial oilseed crops and glycerol to value-added chemicals and next-generation fuels, scaling chemical processes to pilot-scale production, and heavy-duty engine emissions and performance of different fuels and additives.</p>	
<p>Eleazer P. Resurreccion, PhD <i>Principal Investigator (AFC-MSUN)</i> Dr. Eleazer Resurreccion obtained his Doctor of Philosophy degree in Civil Engineering (Environmental focus) from the University of Virginia in 2013. His interest is on the area of renewable energy and environmental sustainability, particularly in the nexus of energy-water systems. He utilizes an interdisciplinary systems approach that combines novel technology, environmental restoration, and economics to address challenges pertinent to these systems in an innovative manner. The application of these areas in industrial ecology allows him: (1) to perform both lab-scale investigations and multi-scale modeling of environmentally-conscious processes and (2) to implement environmental-economic modeling for policy analyses.</p>	

Alexandra Jones

Research Associate (Catalyst Development)

Alexandra Jones graduated from Washington and Lee University in May of 2015 with a Bachelor of Science in Chemistry. She began her work at AFC-MSUN in August of 2015 as a Montana State Energy Corps Service Member. She plays a key role in the catalyst development research and as much of the science, technology, engineering, and mathematics (STEM) outreach activities. Alexandra believes in equal education opportunities for all students and in the critical nature of teaching STEM skills.



Keith Richardson

Performance Engineer

Keith Richardson has over 40 years of experience in automotive, aircraft, motorcycle, agriculture, construction, and mining equipment repair maintenance and design. Keith designed and supervised the building and assembly of tractors for Big Bud Tractors starting in 1975. Keith has extensive experience in designing tractors, prototype power trains, hydraulic systems, and electrical systems. He also designed earth moving scrapers as well as several other equipment for railroads.



William Cochran

Senior Biology Student

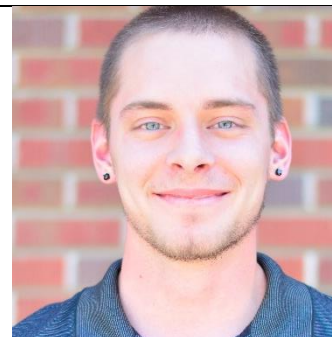
William Cochran was raised on the Fort Belknap Indian reservation, where he attended Hayes Lodge Pole High School. William is currently planning to commission into the Navy after graduation. William is currently assisting the Research Associate in the development of a sustainable heterogeneous catalyst that will be employed in AFC-MSUN's biorefinery process.



Chazley Hulett

Senior Biology Student

Chazley Hulett was born and raised in Havre, Montana. He graduated from Havre High school in 2011 and started attending MSUN in 2014 where he is currently studying Biology. After graduation Chazley plans to pursue higher education in healthcare professions. Chazley is critical in AFC-MSUN's lab-scale investigations, particularly with experiments related to production of bio-based chemicals and bio-based fuels.



Maria Christina Resurreccion

Education Graduate Student (Master of Science in Education: Instruction and Learning)

Christina is a vital component in AFC-MSUN's daily administration operations and outreach activities. Prior to coming to MSUN, she holds a Masters degree in Science Teaching from Laguna State Polytechnic University and a Bachelor of Science degree in Zoology from the University of the Philippines Los Baños. She also holds a degree in Special Education from Singapore. While an undergraduate student, Christina performed wildlife research and her work was featured at National Geographic Society Magazine. She worked as a finance and administration manager at Olive Green, Singapore for five years.



Lane Urick

Senior Civil Engineering Technology Student

Lane Urick attended high school in Great Falls, Montana. He is currently entering his senior year at MSUN as a Civil Engineering Technology major. He plays football for the Northern Lights and hopes to pursue a graduate degree in Environmental Engineering. Lane is involved in the life cycle assessment (LCA) and techno-economic modeling of bio-based fuels and chemicals. His knowledge in modeling and laboratory will undoubtedly prepare him for a future in research and academe.



Montana State University Billings City College

Seven (7) undergraduate students completed a total of 998 hours of research on the project at MSUB City College over the summer of 2016. Two (2) students worked for credit as part of course PPT 292-Independent Studies in Bio-Based Chemicals and Fuels. The remaining five (5) students worked part-time for pay within the scope of the grant. Paid students worked a total of 736.5 hours. The grant supported the student researchers with \$7,365 in pay excluding benefits. The MSUB Principal Investigator completed 207 hours of research on the grant over the summer of 2016. Total pay earned for the work was \$8,613 excluding benefits. Through August 2016, a total of \$18,322 was utilized for student and faculty salaries and benefits. This amount represents 41% of the \$44,688 budgeted for MSUB.

Brief bios for all MSUB researchers supporting the project follow.

Andrew D. Sullivan

Principal Investigator (MSUB City College)

Andy is the Process Plant Technology Instructor at MSUB City College. He holds a Bachelor of Science degree in Chemical Engineering from MIT, and has 20 years of operations and technical experience in refining at ExxonMobil. His research interests focus on process operations excellence, operator training, and renewable fuels process design and optimization.



Cody Dayley

2nd Year Process Plant Technology Student

Cody is the 2016 Student Employee of the Year for his service as the Process Plant Laboratory Technician, a position he has held since fall 2015 under the Federal Work Study program. He has an entrepreneurial spirit and brings a high level of enthusiasm and skill to everything he does. He has interest in starting a biofuels business and in developing advanced training tools for processing industries.



Adam Goodburn

2nd Year Process Plant Technology Student

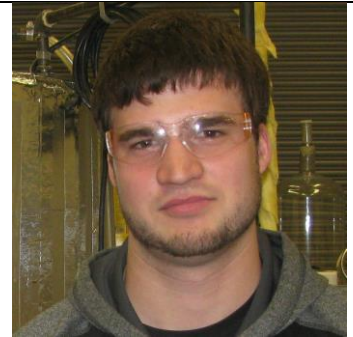
Adam plans on pursuing an Engineering Degree after completing his AAS in Process Plant Technology. He works as a machinist and brings a high level of knowledge and practical skills to his work at MSUB City College. He has interest in advanced process control and was selected to present his work on a self-balancing robotic platform at the 2016 Research and Creativity Conference at MSUB City College.



Garth Webster

2nd Year Process Plant Technology Student

Garth plans to work in the refining sector when he graduates with an AAS in Process Plant Technology. He brings a background in agriculture that benefits his research at MSUB City College.



Paul Bledsoe

1st Year Process Plant Technology Student

Paul is serving as a Process Plant Laboratory Technician under the Federal Work Study program. He has worked in hard rock mining and brings considerable computer experience to his work at MSUB City College. He has interest in renewable fuels, and is designing and retrofitting a vehicle to operate on 100% vegetable oil.



Greg Howick*1st Year Process Plant Technology Student*

Greg has served in the Navy and in the Air National Guard as an Avionics Technician. He plans to use his skills in the Refining sector when he graduates with an AAS in Process Plant Technology.

**Jason Kills Pretty Enemy***1st Year Process Plant Technology Student*

Jason is an enrolled Crow tribal member. He is a member of the Whistling Water Clan and a child of the Greasy Mouth. He graduated from Plenty Coup High School and has spent a few semesters at Haskell Indian Nations University located in Lawrence, KS and Little Big Horn College located in Crow Agency, Montana. Jason has experience in wild land fire-fighting as a crew and engine boss. He plans on working as a Process Plant Technician in the Billings, Montana area.

**Equipment Purchased****Advanced Fuels Center, Montana State University Northern**

No equipment was purchased for June-August 2016 period.

Montana State University Billings City College

Total expenditures for equipment and supplies through August 2016 are \$26,716 of \$44,000 budgeted for MSUB City College. This represents 61% of the funds allotted. The project is on track to effectively utilize allocated funds to effectively meet our objectives.

The following equipment has been received at MSUB City College:

- Buskirk Engineering PM605 pellet mill
- 12' pellet cooling conveyor
- 10" wide vibratory screener
- 60" paddle mixing auger
- 10 cubic foot surge tank
- Motor control equipment

Remaining equipment and supplies to order include:

- 4 multi-fuel pellet stoves
- Bacharach ECA 450 Environmental Analyzer
- Smoke Tester Kit

Progress Towards Meeting Milestones

Task 1: Life Cycle Analysis (LCA) and Techno-Economic Assessment of Green Diesel and Bio-jet Fuel (Lead: E.P. Resurreccion, eleazer.resurreccion@msun.edu). Evaluate the environmental life cycle impacts and techno-economic feasibility of green diesel and bio-jet fuel (next-generation fuels) and high-value added chemicals (bio-based chemicals).

Key Milestones:

- a) Development of a thorough unit process analysis and life cycle inventory of the entire camelina-to-next-generation fuels/bio-based chemicals process chain. (Timeline: July 1, 2015 to July 2016)
- b) Comparative assessment of "cradle-to-gate" life cycle impacts of camelina-to-next-generation fuels/bio-based chemicals. (Timeline: July 1, 2016 to January 1, 2017)
- c) Evaluation of techno-economic feasibility of camelina-to-next generation fuels/bio-based chemicals via life cycle costing (LCC). (Timeline: January 1 to July 1, 2017)

Key Activities for June-August 2016 period:

The life cycle analysis framework has been partially developed. The results will be presented by Dr. Resurreccion at the American Center for Life Cycle Assessment (ACLCA) on September 2016 in Charleston, SC. Lane Urick, one of the senior student researchers, was also selected to participate in the 2016 Chemical Life Cycle Collaborative (CLiCC) Workshop administered by the Institute of Energy Efficiency, UC Santa Barbara on June 25th, 2016. Additionally, a proposal has been submitted to the National Science Foundation: Innovations at the Nexus of Food, Energy, and Water Systems (NSF-INFWEWS) on March 2016. This proposal is a collaboration between MSUN and Old Dominion University (ODU), Norfolk, VA. AFC-MSUN has fostered a relationship with ODU because the institution has developed a novel and efficient oil extraction method from oilseed.



Figure 1. Lane Urick trains newcomer Mason Martin in LCA.

Task 2: Production of Camelina-Derived Alkylated Aromatics as a Blend Component to Aviation Gasoline (Lead: R.L. Maglinao, randy.maglinao@msun.edu). Propose and validate the mechanism of producing high-octane number chemicals (e.g., alkylated aromatics) from camelina.

Key Milestones:

- a) Validation of the mechanism of producing high-octane number chemicals from camelina. (Timeline: July 1 to December 1, 2015)
- b) Identification of optimum ratio of camelina-derived alkylated aromatics and unleaded avgas with desired anti-knock value identified. (Timeline: December 1, 2015 to October 1, 2016)
- c) Certification of the newly-formulated unleaded avgas. (October 1, 2016 to June 30, 2017)

Key Activities for June-August 2016 period:

Experiments producing octane boosting chemicals were completed and data analysis is on-going. The team is investigating a formula to predict octane number rating contribution of different molecules present in the bio-based avgas. Dr. Maglinao attended the ASTM D02 Petroleum Products, Liquid Fuels, and Lubricants Committee meeting in Bellevue, WA last June 27-30. In this meeting, members reviewed ballot closing reports and ASTM methods for petroleum products. The methods discussed included certifying

renewable diesel, bio-jet fuel, and unleaded avgas. A collaborative proposal headed by University of Montana and Montana State University Bozeman was submitted to National Science Foundation.

Task 3: Development of Heterogeneous Grubbs Catalyst for Biomass Conversion (Lead: A.K. Jones, alexandra.jones@msun.edu). Develop a novel and robust heterogeneous Grubbs catalyst that achieves efficient conversion of natural oils to next-generation fuels and bio-based chemicals.



Figure 2. William Cochran assists in catalyst synthesis.

Key Milestones:

- a) Synthesis of a silica-supported polymeric Grubbs catalyst for olefin metathesis of natural oils. (Timeline: July 1, 2015 to June 30, 2016)
- b) Synthesis of a novel silica-supported Grubbs catalyst for olefin metathesis of natural oils. (Timeline: July 1 to December 31, 2016)
- c) Comparative analysis of the two heterogeneous Grubbs catalysts. (January 1 to June 30, 2017)

Key Activities for June-August 2016 period:

After a parting of ways with the previous lead chemist, a nationwide search was held to replace the AFC-MSUN chemist and a qualified candidate was hired. Since then, a promising new synthesis route has been proposed for milestone *b* and will be reviewed by collaborators at Elevance Renewables and a chemistry faculty at MSUN. Confirmation of the synthesis is underway.

Task 4: Design of an Optimum Process Configuration and Economic Analysis for Medium- and Large-Scale Pelletizing Plants for Camelina Meal (Lead: A. Sullivan, andrew.sullivan3@msubillings.edu). Develop and prepare a design study documenting an optimum process configuration and economic analysis for medium- and large-scale pelletizing plants for camelina meal (next-generation fuels).

Key Milestones:

- a) Development of an optimized process for fuel pellet production from camelina meal and manufacture a range of pellet compositions to verify producibility. (Timeline: Summer 2016)
- b) Testing of products in a range of commercially-available multi-fuel pellet stoves and identification of potential markets to determine product price including a fish food for export. (Timeline: Winter 2016)
- c) Preparation of study design for 40,000 to 500,000 ton per year pelletizing plant with economic analysis. (Timeline: Summer 2017)

Key Activities for June-August 2016 period:

The Process Plant Technology (PPT) lab at MSUB City College has been rebranded as the Process Plant Technology and Fuels Research Laboratory to better reflect the full scope of work. The laboratory has since continued to upgrade the camelina oil extraction process and has begun prototyping a more efficient drying process for the oil and biodiesel product. The dried biodiesel product is being utilized by MSUB City College facilities in their diesel equipment. The lab is also working to perfect the methanol recovery in their biodiesel production. Successes in this research have led to the construction of a methanol flash drum that will be used to pre-flash methanol from biofuel and byproduct streams such as camelina

oil, biodiesel, and glycerin. Pre-flash products will be further refined in the Armfield UOP3CC distillation unit for reuse.



Figure 3. Banner celebrating student research at MSUB City College and the PPT lab rebrand.

A pilot-scale pelletizing plant, including hammer mill, cyclonic separator, conveyor, agitated feed hopper, conditioner, pellet mill, and particle size screener, with a capacity of approximately 3,600 lbs/day or 657 tons/year was commissioned. Research will continue on the automation of the facility to minimize manual intervention.

Additionally, a patent application for the process has been reviewed by the MSUB City College Provost and Director of Grants and Sponsored Programs resulting in an agreement to fund the initial exploration of the feasibility of the patent. Initial review work is underway with local legal counsel specializing in intellectual property. Lastly collection of high quality grass clippings continued this season. Adequate lawn clippings have been collected, dried, and stored for future use as a component in fuel pellets made with camelina meal. We currently have about 600 lbs of dry grass clippings for further research.



Figure 6. Student developed and built salt dryer for biofuels including pump and contacting vessel.



Figure 5. Garth Webster monitoring camelina seed conditioning operations using a cement mixer and hot air gun.

Expenditures

MSU Northern	Expenditures to Date
Personnel Services	\$381,365. ⁷⁰
Operations	\$84,061. ⁵³
Equipment	\$14,935. ⁸⁵
MSU Billings	
Personnel Services	\$18,322. ⁰⁰
Operations	\$1,988. ⁰⁰
Equipment	\$24,982. ⁰⁰
TOTAL	\$525,655.⁰⁸
Percent Spent	65.71%