Environment and Natural Resources Trust Fund (ENRTF) M.L. 2014 Work Plan

Date of Report: January 15, 2014
Date of Next Status Update Report: December 31, 2014
Date of Work Plan Approval:
Project Completion Date: June 30, 2017
Does this submission include an amendment request? _No_

PROJECT TITLE: Demonstrating innovative technologies to fully utilize wastewater resources

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Location: St. Paul, MN

Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$1,000,000**
	Amount Spent:	**$0**
	Balance:	**$1,000,000**

Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 08c

Appropriation Language:

(c) Demonstrating Innovative Technologies to Fully Utilize Wastewater Resources

$1,000,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to demonstrate innovative technologies to utilize and treat wastewater streams for conversion of treatment by-products to biofuels. This appropriation is subject to the provisions of M.S. 116P.10 Royalties, Copyrights, patents, and Sale of Products and Assets. This appropriation is available until June 30, 2017, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Demonstrating innovative technologies to fully utilize wastewater resources

II. PROJECT STATEMENT:

Minnesota municipal wastewater treatment plants (MWTP) generate large amounts of oily scum, concentrated liquid (also called "centrate"), and sludge each year. For example, each year, the 7 Metropolitan Council Environment Services (MCES) MWTPs treat more than 100,000 million gallons of wastewater and at the same time generate 1,000 tons of scum, 500 million gallons of centrate, and 85 million kg of dry sludge. These waste streams are either used as landfill (scum) and direct burning (sludge), or subjected to additional treatment (centrate). New technologies, developed by UMN researchers led by Dr. Ruan through several projects funded by federal and state grants, especially two ENRTF grants, can help capture the values from and lower the treatment costs for these waste streams (Figure 1). The **goal** of the project is to demonstrate the feasibility and effectiveness of implementing innovative technologies in municipal wastewater treatment plants. This project is expected to generate significant impacts including: (1) producing significant amounts of renewable energy for internal use or distributed to the market. About 5 million gallons of biofuels and similar quantity of other biochemicals could be produced from the waste streams in MCES' facilities alone; (2) generating considerable revenues. Estimated potential annual revenue of $20 million could be generated from the fuels and other chemicals derived from scum, centrate, and sludge in these facilities; (3) improving wastewater treatment efficiency and cost effectiveness. The waste streams are effectively treated while they are converted to renewable energy; utilization of scum results in hundreds of thousands of dollars savings in landfill cost; algae are more effective than current processes in removing low level phosphorus; and (4) reducing environment pollutants. Landfill and fossil fuel and coal use will be significantly reduced; algae will sequester a large amount of carbons; CO_2 emission from sludge burning will be reduced.

Currently, there are approximately 20,000 municipal wastewater treatment facilities operating in the US serving 226.4 million people. Many wastewater facilities are in the midst of a financial struggle, and face lower revenues combined with the potential of increasing costs. This scum-to-biodiesel conversion could not only bring them economic benefit but greatly reduce environmental impact. Take the wastewater treatment plant at St. Paul, MN (Metro Plant) as an example, the plant generates 3.5 wet ton scum per day; if all converted to biodiesel, it could bring $350,000/year revenue and save $100,000 landfill fee/year to the Metro Plant. This is an attractive financially sound and environmentally friendly approach to solving the scum problem.

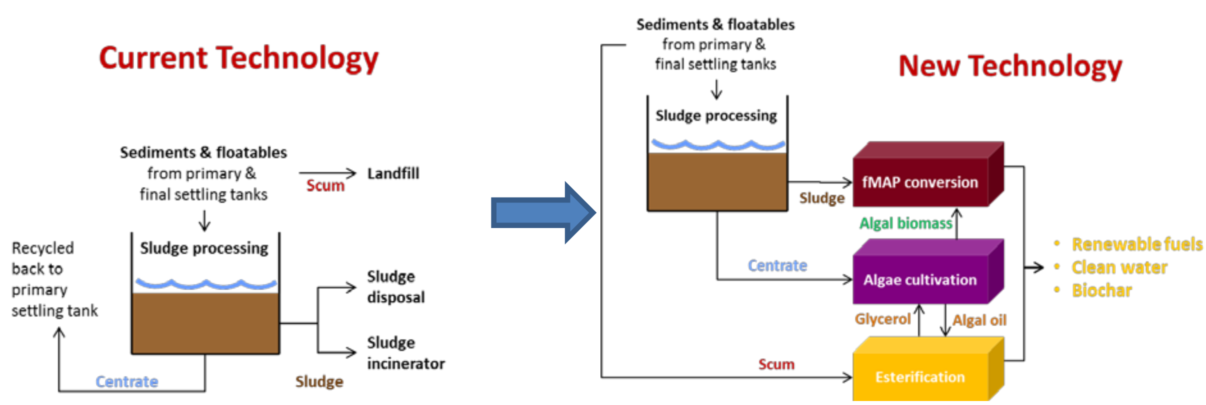

Figure 1. A comparison of waste stream pathways between the current and proposed new technologies.

III. PROJECT STATUS UPDATES:

Project Status as of December 31, 2014:

Project Status as of June 30, 2015:

Project Status as of December 31, 2015:

Project Status as of June 30, 2016:

Project Status as of December 31, 2016:

Project Status as of June 30, 2017:

Overall Project Outcomes and Results:

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Develop and demonstrate scum to biodiesel process and system
Description: Scum is the floatable materials skimmed from the surface of primary and secondary settling tanks of the wastewater treatment plant. It contains grease, vegetable and mineral oil, animal fats, waxes, soaps, food wastes, plastic materials and other impurities. High energy content was found in scum that could be recycled and reused. In our lab study, it was found at least 60% of the dry matter of the scum can be converted to high quality biodiesel. In our lab study, it was found at least 60% of the dry matter of the scum can be converted to high quality biodiesel (Figure 2). The conventional technology to recover energy from scum is to co-process scum with sludge in anaerobic digestion (AD) where the biogas produced is used to generate electricity for plant use (Outwater 1994). However, this technology causes many problems in operation. For example, the scum floats on the top of the digester and forms a thick layer that impedes digester performance. As a result, many wastewater treatment plants choose to directly dispose scum in landfills. The scum disposal increases the cost of treatment facilities. For instance, the Metropolitan Wastewater Treatment Plant at St. Paul. MN (Metro plant) spends $100,000 a year just for landfilling the scum. Therefore, there is an urgent need to develop other technology to recover energy stored in scum effectively. In addition, the biodiesel produced from scum oil will be more desirable than biogas produced from traditional AD process. It is also expected that the economic benefits for scum-to-biodiesel production will be superior over the traditional AD process. With this in mind, we propose to develop and demonstrate a scum-to-biodiesel technology with following objectives: (1) to develop a cost effective conversion process capable of converting scum oil to biodiesel that meets ASTM standard, and (2) compare the optimized biodiesel production process with traditional anaerobic digestion system for LCA and economic analysis.

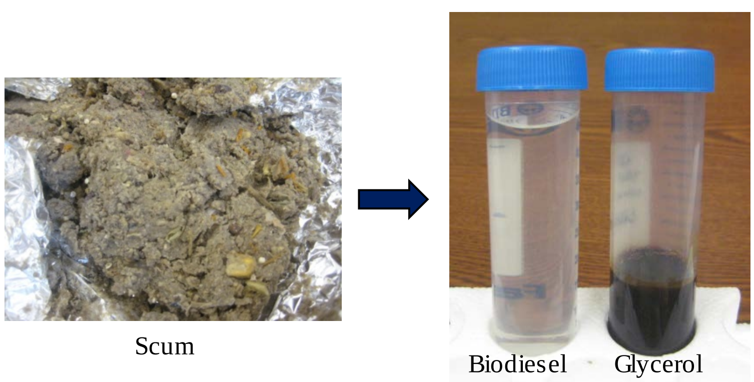

Figure 2. In our lab, oil was extracted from scum (left) and converted to biodiesel and glycerol.

The concept of converting scum to biodiesel is easy to prove; however, there are several process steps which must be taken to deal with the physical and chemical properties of the scum unique to a wastewater source. For example, we need to develop and optimize (1) a cost effective dewatering process that can be incorporated with the existing wastewater treatment operations, (2) an oil extraction and recovery process which is efficient and allows recycling of extraction solvent, and (3) a robust conversion process capable of dealing with lipid profiles which are quite different from that of traditional biodiesel oil feedstock.

Since the trans/esterification process has been developed in our lab, we will focus on the supercritical methanol method and compare these two processes with AD process in terms of technical, economic, and environment performance. The specific objectives of the scum to biodiesel component are (1) to optimize trans/esterification process, (2) to develop and optimize supercritical methanol method, (3) to compare these two processes with the conventional AD process, and (4) develop a scum to biodiesel demonstration system based on the optimum process. The process flow chart is illustrated in Figure 3.

Specific task will be:

1. Optimize trans/esterification process. This task is intended to optimize the processes in conversion pathways and determine conversion efficiency, chemical use, and operation parameters.
    a. Minimize acid usage during the acidification process; investigate the possibility of using recycled acid from acid-esterification process to reduce the material cost.
    b. Investigate effect of catalyst and methanol to oil ratio for oil conversion efficiency
    c. Determine optimized parameter incorporated with task 3. Design parameters of unit processes will be determined for process design and modeling. The quality of final products and byproducts will be also examined.
2. Develop and optimize supercritical methanol method
    a. Lab scale system development
    b. Investigate catalysts, temperature and pressure effects on oil conversion efficiency
    c. Determine optimized the process incorporated with task 3.
3. Compare these two processes with the conventional AD process
    a. Process modeling for three different pathway for material balance and energy balance using ASPEN Plus, discuss the relationship and trade-offs among the energy yields and energy/material inputs
    b. Optimize the process with the goal of maximum oil conversion rate and minimum energy consumption.
    c. Economic analysis. Based on the model established, an economic analysis will be conducted to show the initial investment and estimated operational costs, and to prove the economic validity of scum-to-biodiesel technology. ASPEN Plus has a function for economic analysis, which will be used as a tool in our analysis. Costs of equipment and chemicals will be based on literature review and supplier's information.
4. Development of scum to biodiesel demonstration system. Based on the information provide in task 3, a scum to biodiesel demonstration system will be developed according to the optimized parameters. An estimated capacity of 150 ton biodiesel/year facility or smaller system will be developed depends on the budget. A complete scum to biodiesel production system will be designed and then bided for contract-fabrication. More accurate data will be obtained through the demonstration system that can be used for further comparison.
5. Environmental impacts analysis (Optional). Our analysis will follow the LCA standards created by International Organization for Standardization (ISO): ISO 14040 and ISO 14044. The LCA analysis will include all direct impacts and upstream impacts of chemicals and energy inputs. The process simulation models combined with existing modeling software will be applied in developing life cycle inventory. Software for modeling efforts, including Excel, GREET, GaBi, and Ecoinvent database, are currently owned by the research group. The LCA will include of environmental impact of fossil fuel use (MJ) and GHG emissions (kg CO_2 eq.) and final results of scum-to-biodiesel technology are supposed to compare with conventional biodiesel production.

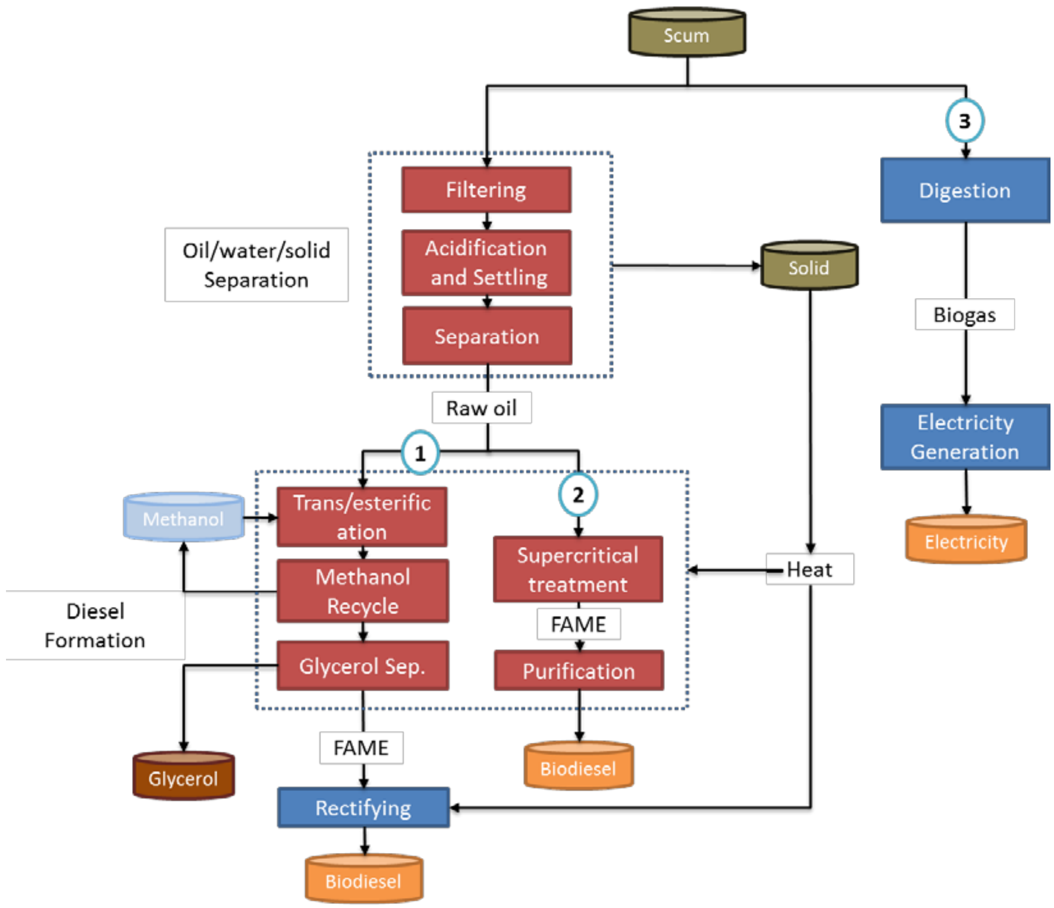

Figure 3. Scum conversion pathways for analysis: 1) trans/esterification for biodiesel production; 2) supercritical methanol method for biodiesel production; 3) AD with electricity generation.

Summary Budget Information for Activity 1:

ENRTF Budget:	**$394,060**
Amount Spent:	**$ 0**
Balance:	**$394,060**

Activity Completion Date:

Outcome	**Completion Date**	**Budget**
1. *Develop and optimize oil recovery, conversion, and upgrading processes; Streamline processes and design the complete system.* Specific outcomes include: 1.1. The trans/esterification process will be developed and optimized for conversion of low grade oil to biodiesel. 1.2. A supercritical methanol based conversion method will be developed and optimized for conversion of low grade oil to biodiesel. 1.3. The new conversion methods will be compared with the conventional AD process 1.4. Scale-up process parameters will be developed.	6/30/2015	$110,000
2. *Fabricate and install the system at demonstration site.* Specific outcome include: Based on the information provide in task 1, a scum to biodiesel demonstration system will be developed according to the optimized parameters. An estimated capacity of 300 ton biodiesel/year facility or smaller system will be developed.	12/31/2016	$180,000

A complete scum to biodiesel production system will be designed and then bided for contract-fabrication.		
3. *Test the system and collect mass and energy balance data; conduct technoeconomic analysis (TEA) and life cycle assessment (LCA).* <u>Specific outcome includes</u>: The environmental and economic impacts of the technologies developed will be quantified and reported.	03/31/2017	$80,000
4. *Demonstrate the systems to stakeholders*. <u>Specific outcome includes</u>: Demonstration of the technologies developed to the stakeholders will be carried out by the end of the project.All demonstration schedules will be discussed with LCCMR office and announced to the stakeholders through UMN and LCCMR's channels.	06/30/2017	$24,060

Project Status as of December 31, 2014:

Project Status as of June 30, 2015:

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Project Status as of June 30, 2016:

Project Status as of December 31, 2016:
Final Report Summary:

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ACTIVITY 2: Develop and demonstrate centrate to algae fuel system
Description:

The second wastewater stream of interest to this project is "centrate", which is generated from centrifuging of activated sludge. Centrate contains highest amount of ammonia nitrogen and active phosphorus among several wastewaters at different stages in a municipal wastewater treatment plant, which could be a suitable growth medium for microalgae for the dual purposes of removing nutrients and obtaining a feedstock for biofuel production.

Our previous research shows that algae consume organic carbon source in the centrate quickly while relatively large amount of N and P remain in the culture broth. In order to completely utilize and remove N and P from the wastewater to meet discharge standards, carbon source may be replenished through addition of glycerol from the scum to biodiesel conversion process, process water from hydrothermal treatment of algae, and CO_2 from fMAP and fMAG processes. The goal of this section is to use byproducts derived from scum to biodiesel process and waste gas from sludge to bio-fuels process to improve nutrients removal efficiency and obtain maximal algal biomass feedstock for biofuels application, and demonstrate a pilot-scale centerate to algae fuel system.

The specific objectives of centrate are (1) to evaluate and optimize the concentration of crude glycerol as sole carbon source for fast growth; (2) to develop and optimize best cultivation growth conditions for fast mixotophic growth; (3) to develop a mixotro-autotrophic two-stage cultivation strategy for improved nutrient removal and enhanced lipid production; (4) to develop a pilot-scale centrate to bio-fuels demonstration system based on the optimized process.

Specific tasks will be:

1. Evaluate and optimize the concentration of crude glycerol for maximal algal biomass production. Different facultative heterotrophic microalgae strains will be evaluated and different concentration of crude glycerol will be added to meet the requirements of enhanced algal biomass accumulation and improved nutrient removal efficiency.
    a. Evaluate and compare the capability of different facultative heterotrophic strains to utilize the purify and crude glycerol derived from scum-biodiesel process directly for fast growth;
    b. Optimize the concentration of crude glycerol in batch-scale experiment.
2. Optimize CO_2 concentration for fast mixotophic growth. This task is intended to select appropriate CO_2 concentration to obtain high cell density and fast nutrient removal efficiency.
    a. CO_2 concentration levels of 1%, 2%, 5%, 10%, 15% (v/v) will be tested and optimized in batch-scale experiment.
    b. CO_2 rich-waste gases collected from fMAP and fMAG processes will also be analyzed and evaluated for the feasibility of replacing above CO_2 to stimulate algae growth;
    c. Effect of temperature, light intensity, glycerol and CO_2 concentration on algae growth and nutrient removal under mixotrophic cultivation mode will be evaluated and optimized through Box-Wilson Central Composite design (CCD).
3. Develop a mixotro-autotrophic two-stage cultivation strategy for improved nutrient removal and enhanced lipid production. At the first mixotrophic dominated stage, both glycerol and CO_2 will be used to support the mixotrophic growth, the supernatant will be reused as culture media in the second autotrophic dominated stage and CO_2 will be injected to provide inorganic carbon source.
    a. A lab-scale two-stage cultivation system using 1-L PYREX Roux culture bottle as bioreactor will be used for process development and optimization;
    b. Investigate the effects of temperature, light intensity, glycerol and CO_2 concentration on biomass accumulation and nutrient removal in the two-stage cultivation system.
    c. The two-stage system will be further scaled up and the process will be optimized.
4. Develop a pilot-scale centrate to bio-fuels demonstration system based on the optimized process.
    a. A pilot-scale two-stage system based on multi-layer bioreactors will be developed and constructed.
    b. Light intensity, Temperature, pH, and glycerol and CO_2 concentration were further optimized in large-scale cultivation system.
    c. The 3M Building Illumination & Photo Voltiac (BIPV) power modules provided through a grant from the 3M Foundation will be incorporated into the system to provide power for pumping and mixing.
    d. Demonstrate the pilot-scale centrate to bio-fuels demonstration system.
5. Environmental impacts analysis (Optional). Our analysis will follow the LCA standards created by International Organization for Standardization (ISO): ISO 14040 and ISO 14044. The LCA analysis will include all direct impacts and upstream impacts of chemicals and energy inputs. The process simulation models combined with existing modeling software will be applied in developing life cycle inventory. Software for modeling efforts, including Excel, GREET, GaBi, and Ecoinvent database, are currently owned by the research group. The LCA will include of environmental impact of fossil fuel use (MJ) and GHG emissions (kg CO2 eq.) and final results of centrate to algae technology will be compared with previous cultivation models.

Summary Budget Information for Activity 2:

ENRTF Budget:	**$172,060**
Amount Spent:	**$ 0**
Balance:	**$172,060**

Activity Completion Date:

Outcome	Completion Date	Budget
1. Develop and optimize algae growth and nutrient removal involving crude glycerol; design the complete processes.	6/30/2015	$50,000

Specific outcomes include: 1.1. High performance facultative heterotrophic microalgae strains and optimal concentration of crude glycerol added to meet the requirements of enhanced algal biomass accumulation and improved nutrient removal efficiency will be determined. 1.2. Optimal CO_2 concentration for fast mixotophic growth, high cell density, and fast nutrient removal efficiency.will be determined 1.3. A mixotro-autotrophic two-stage cultivation strategy for improved nutrient removal and enhanced lipid production will be developed 1.4. Scale-up process parameters will be developed.		
2. *Design and construct a greenhouse based algae based wastewater treatment facility.* Specific outcomes include: 2.1. A pilot-scale two-stage system based on multi-layer bioreactors will be developed and constructed. 2.2. Light intensity, Temperature, pH, and glycerol and CO_2 concentration will be further optimized in large-scale cultivation system. 2.3. The 3M Building Illumination & Photo Voltiac (BIPV) power modules provided through a grant from the 3M Foundation will be incorporated into the system to provide power for pumping and mixing.	12/31/2016	$70,000
3. *Test the facility and collect mass and energy balance data; conduct TEA and LCA.* Specific outcome includes: The environmental and economic impacts of the technologies developed will be quantified and reported.	03/31/2017	$27,060
4. *Demonstrate the systems to stakeholders.* Specific outcome includes: Demonstration of the technologies developed to the stakeholders will be carried out by the end of the project. All demonstration schedules will be discussed with LCCMR office and announced to the stakeholders through UMN and LCCMR's channels.	06/30/2017	$25,000

Project Status as of December 31, 2014:

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ACTIVITY 3: Develop and demonstrate sludge to bio-fuels system

Description:

The third waste steam of interest to the project is sludge, a solid biomass from primary and secondary settling processes. The sludge typically contains around 70% organic matter. Landfilling, land application and incineration are the common disposal processes for sludge. It is possible and beneficial to capture the energy contained in sludge biomass through thermochemical conversion because we not only capture the economic value, but also minimize pollutants associated with sludge. Thermochemical conversion (e.g., pyrolysis and gasification) of sludge to produce bio-oil, syngas and other products is an attractive solution to the sludge problems. However, the acceptance of this idea has been limited due to the low economic value of the products and the relative complexity of the processing equipment. Traditional gasification operated at temperature around 1,000C may not be able to destroy pollutants and toxic compounds such as dioxin. Therefore, we must improve the technology to enhance overall economic viability and environmental friendliness of the technology.

One of the major breakthroughs achieved in the endeavor to improve the microwave assisted pyrolysis process is the result of using properly designed microwave absorbents. Our research found that some microwave absorbents such as silicon carbide (SiC) are excellent in enabling rapid temperature rise, making fast pyrolysis and gasification feasible and efficient, and can achieve very efficient high temperature gasification, such as above 1,200C to avoid hazardous gas emission, therefore eliminating the need of expensive downstream gas treatment.

The goal of this activity is to use and compare fast microwave assisted pyrolysis and gasification processes for sludge conversion, and demonstrate a fast microwave assisted conversion system capable of providing processing conditions to meet fast pyrolysis and high temperature gasification requirements. While sludge will be the main feedstock, algal biomass harvested from Activity 4.2 can also be processed using this system.

The specific objectives of sludge to bio-fuels component are (1) to develop a cost effective sludge dewatering system, (2) to develop and optimize fast microwave assisted pyrolysis process, (3) to develop and optimize fast microwave gasification process, (4) to develop and optimize bio-fuel upgrading processes, and (5) develop a sludge to bio-fuels demonstration system based on the optimized process.

Specific tasks will be:

1. Develop a cost effective sludge dewatering system. As the sludge from primary and secondary settling processes still contains much water, this task is to develop a dewatering system to dry the sludge and meet the requirements of following processes.
    a. Compare different dewatering processes based on dewatering efficiency and the cost;
    b. Lab scale dewatering system development;
    c. Investigate the effect of feed rate on sludge dewatering efficiency.
2. Develop and optimize fast microwave assisted pyrolysis process. This task is intended to select appropriate microwave absorbents and develop a fast microwave assisted pyrolysis system to covert sludge or algal biomass to bio-oil, syngas, and bio-char.
    a. Develop a lab scale microwave assisted pyrolysis system and analyze the components of bio-oil, syngas, and bio-char;
    b. Investigate the effect of different microwave absorbents on heating rate and product distribution;
    c. Examine the effects of temperature, catalyst and catalyst to feed ratio on the yield of bio-fuels.

3. Develop and optimize fast microwave assisted gasification process. This task is to produce syngas from sludge or algal materials using a fast gasification system.
    a. Lab scale system development;
    b. Investigate the effects of temperature, catalyst, catalyst to feed ratio and steam addition on syngas yield and quality;
    c. Study the stability of catalyst during gasification process using X-ray Diffraction (XRD) technique.
4. Develop and optimize bio-fuel upgrading processes. This task is to upgrade the products of bio-oil, syngas, and bio-char for direct application.
    a. Develop a catalytic upgrading process to treat the bio-oil and make it mixable with gasoline for fuel;
    b. Introduce syngas into centrate system mentioned in 4.2 and CO_2 will be utilized and consumed by algae. Compare this novel system with traditional syngas conditioning processes based on CO_2 removal efficiency. Remove hydrocarbons from raw syngas by steam conditioning;
    c. Develop processes to separate bio-char from catalyst and further improve the quality of the bio-char to meet the requirements of soil amendment agent or activated carbon.
5. Development of a continuous sludge to bio-fuels demonstration system. Based on the data obtained from the above tasks, a pilot scale continuous fast microwave assisted conversion system with capacity estimated at about 25 kg/h will be designed and fabricated. The key features of the system is expected to include fast heating, high temperature, mechanisms for easy feeding of feedstock and discharge of solid residues, a motor-driven mixer/conveyer, air cooled condensers, integrated gas turbine power generator, multiple-point temperature detection, and automatic and accurate temperature control. The Pilot testing and demonstration facilities will be carried out in MCES St. Paul Wastewater Treatment Plant and/or FreightMasters/Minnesga Inc. Warehouse in Eagan. The space in FreightMasters/Minnesga Inc. warehouse is also appropriate for future potential commercial operations.
6. Environmental impacts analysis (Optional). Our analysis will follow the LCA standards created by International Organization for Standardization (ISO): ISO 14040 and ISO 14044. The LCA analysis will include all direct impacts and upstream impacts of chemicals and energy inputs. The process simulation models combined with existing modeling software will be applied in developing life cycle inventory. Software for modeling efforts, including Excel, GREET, GaBi, and Ecoinvent database, are currently owned by the research group. The LCA will include environmental impact of fossil fuel use (MJ) and GHG emissions (kg CO_2 eq.) and final results of fast microwave assisted sludge to bio-fuels technology are supposed to compare with conventional pyrolysis and gasification processes.

The Pilot testing and demonstration facilities will be carried out in MCES St. Paul Wastewater Treatment Plant and/or FreightMasters/Minnesga Inc. Warehouse in Eagan. The space in FreightMasters/Minnesga Inc. warehouse is also appropriate for future potential commercial operations.

Summary Budget Information for Activity 3: **ENRTF Budget: $433,880**
Amount Spent: $ 0
Balance: $433,880

Activity Completion Date:

Outcome	**Completion Date**	**Budget**
1. *Develop cost effective dewatering process; design microwave absorbent device; optimize catalytic bio-oil upgrading process.* <u>Specific outcomes include:</u> 1.1. A cost effective sludge dewatering processes will be developed. 1.2. Fast microwave assisted pyrolysis process will be developed	6/30/2015	$70,000

and optimized for conversion of sludge and algal biomass to bio-oil, syngas, and bio-char. 1.3. Fast microwave assisted gasification process will be developed for conversion of sludge and algal biomass to syngas. 1.4. Refining processes will be developed and optimized for upgrading of bio-oil and syngas to high quality products. 1.5. Scale-up process parameters will be developed.		
2. *Design and construct a complete facility for dewatering and conversion of sludge to bio-oil and syngas; the facility is expected to be fully or partially self-powered.* <u>Specific outcome includes:</u> Based on the data obtained from the above tasks, a pilot scale continuous fast microwave assisted conversion system with capacity estimated at 50 kg/h will be designed and fabricated. The key features of the system is expected to include fast heating, high temperature, mechanisms for easy feeding of feedstock and discharge of solid residues, a motor-driven mixer/conveyer, air cooled condensers, integrated gas turbine power generator, multiple-point temperature detection, and automatic and accurate temperature control.	12/31/2016	$320,000
3. *Test the facility and collect mass and energy balance data; conduct TEA and LCA.* <u>Specific outcome includes:</u> The environmental and economic impacts of the technologies developed will be quantified and reported.	03/31/2017	$23,880
4. *Demonstrate the systems to stakeholders.* <u>Specific outcome includes:</u> Demonstration of the technologies developed to the stakeholders will be carried out by the end of the project. All demonstration schedules will be discussed with LCCMR office and announced to the stakeholders through UMN and LCCMR's channels.	06/30/2017	$20,000

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V. DISSEMINATION:

Description:

The findings will be disseminated through:

1. On site demonstration as described in the activities
2. Public seminars
3. Progress update on www.biorefining.cfans.umn
4. Presentations at national and international technical conferences
5. Communications with interested entrepreneurs
6. Peer reviewed papers
7. Collaboration with UMN extension

The technologies, if demonstrated successfully, may be implemented to many MWTPs in the State of Minnesota and beyond. Any intellectual properties and related revenues as a result of the program will be shared between UMN and LCCMR.

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Final Report Summary:

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Explanation
Personnel:	$507,364	• Roger Ruan, PI/PD, 1%, 3 years, including 33.6% benefits, leading and managing project, overlooking R&D, leading demonstration, supervising postdocs and RA ($4,963) • Paul Chen, co-PI, 10%, 3yrs, including 33.6% benefits, project coordination, conducting R&D, project evaluation, progress report ($33,168) • 2 research associate 100%, 3yrs, including 33.6% benefits, conducting R&D, operations, demonstration, data analysis ($347,381) • 1 Graduate Research Assistants, 50%, 3yrs, including 15.7% benefits plus tuitions, conducting R&D, operation, demonstration ($121,852)
Professional/Technical/Service Contracts:	$30,000	Salary/fees for a consultant, helping with

		engineering design and development of demo system for scum to algae conversion
Supplies:	$56,454	Laboratory supplies including: • chemicals $2,454) • analytical supplies ($500) • microwave absorbents ($700) • catalysts ($500) • glassware ($1,000) • containers ($500)
Capital Expenditures over $5,000:	$400,000	• Pilot scale biodiesel conversion demo system including oil extraction device, reaction tank, storage tanks, separation tanks, fractional rectifier, pumps, heaters, heat exchangers, control ($100,000) • Algae cultivation and harvesting demo system including multi-layer photobioreactors, greenhouse, circulation equipment, harvest equipment, dewatering equipment ($40,000) • Fast microwave assisted pyrolysis demo system including auto-feeder, magnitrons, reaction chamber, microwave absorbent bed, condenser, syngas scraper, gas turbine power generator ($260,000)
Travel Expenses in MN:	$6,182	Mileage for researchers to travel between campus and demonstration site over the 3yrs project period
TOTAL ENRTF BUDGET:	**$1,000,000**	

Explanation of Use of Classified Staff: None.

Explanation of Capital Expenditures Greater Than $5,000:
Capital expenditures are planned for development and demonstration of three technologies in the project. All these demo systems will be custom-designed. The fabrication may require sourcing the components from multiple suppliers. US Contractors will be selected through UMN bidding process.

- Pilot scale biodiesel conversion demo system: This system will be developed for converting scum to biodiesel. This system is essential for the completion of project objectives. It will be used for demonstration and collection of data for TEA and LCA. The system will consist of mainly oil extraction device, reaction tank, storage tanks, separation tanks, fractional rectifier, pumps, heaters, heat exchangers, and control panel. While the system is in a small demo scale, it will be capable of processing all the scum generated in MCES St. Paul Wastewater Treatment Plant.
- Algae cultivation and harvesting demo system: This system will be developed for growing microalgae on the centrate with supplement of glycerol, a byproduct of scum to biodiesel process. This system is essential for the completion of project objectives. It will be used for demonstration and collection of data for TEA and LCA. The system includes multi-layer photobioreactors, greenhouse, circulation equipment, harvest equipment, and dewatering equipment.
- Fast microwave assisted pyrolysis demo system: This system will be developed for converting sludge to system gas and biofuels. This system is essential for the completion of project objectives. It will be used for demonstration and collection of data for TEA and LCA. The system will consist of an auto-feeder,

magnitrons, reaction chamber, microwave absorbent bed, condenser, syngas scraper, gas turbine power generator

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 7.83

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 1.5

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
MCES	$49,999		Developing scum to biodiesel process
Gift fund	$80,000	$	Developing scum to biodiesel and sludge utilization processes
State			
Project Unrecovered (UMN unpaid F&A as in-kind support)	$286,638	$	Developing algae cultivation and microwave assisted conversion processes.
TOTAL OTHER FUNDS:	**$415,638**	**$**	

VII. PROJECT STRATEGY:

A. Project Partners:

Project Partners Not Receiving Funds:

- *MCES St. Paul Wastewater Treatment Plant*
- *FreightMasters/Minnesga Inc.*

B. Project Impact and Long-term Strategy:

The purpose of the project is to demonstrate innovative technologies to utilize and treat wastewater streams. Specifically, research will be conducted to optimize processes and develop demo systems for converting oily scum, sludge, and centrate to renewable bio-fuels. The essential qualities of the proposed research lie in the following features: (1) the project appropriately and timely addresses the needs of wastewater treatment industry to utilize various waste streams for renewable fuels and energy production, to reduce environment impact and treatment cost; (2) the project is largely built on the excellent outcomes from the previous research funded by LCCMR and others; (3) the project involves strong academic and industry partnership; and (4) the project is loaded with high impact and achievable objectives. The success of the project is expected to reduce landfill, improve water quality, reduce GHG emission, produce renewable energy, create revenue for wastewater treatment operators, and lower the overall wastewater treatment costs.

The proposed project, built on our existing technologies, does not need additional investment other than the requested ENRTF support to complete. However, further development and demonstration leading to eventual technology transfer and commercialization will be our long-term goal and will require additional funding. Next level commercial scale-up pilot facilities demonstrations may be necessary with federal, state, and private funding before the technologies can be commercialized.

C. Spending History:

Funding Source	M.L. 2008 or FY09	M.L. 2009 or FY10	M.L. 2010 or FY11	M.L. 2011 or FY12 &13	M.L. 2013 or FY14
USDA	1,025,676				
MCES Metro Council	484,999				
MECC/IREE	143,192				

LCCMR			899,999		
Corn Growers				7991	
SDSU/DOE	613,235				
IREE	601,552				

VIII. ACQUISITION/RESTORATION LIST:

IX. VISUAL ELEMENT or MAP(S):

X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET:

XI. RESEARCH ADDENDUM:
Enclosed

XII. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted no later than September 2014, March 2015, September 2015, March 2016, September 2016, and March 2017. A final report and associated products will be submitted between June 30 and August 15, 2017.

Environment and Natural Resources Trust Fund
M.L. 2014 Project Budget

Project Title: *Demonstrating innovative technologies to fully utilize wastewater resources*
Legal Citation: *M.L. 2014, Chp. 226, Sec. 2, Subd. 08c*
Project Manager: *Roger Ruan*
Organization: *University of Minnesota*
M.L. 2014 ENRTF Appropriation: $*1,000,000*
Project Length and Completion Date: *3 Years, June 30, 2017*
Date of Report: *Januray 15, 2014*

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	***Develop and demonstrate scum to biodiesel process and system***			***Develop and demonstrate centrate to algae fuel system***			***Develop and demonstrate sludge to bio-fuels system***				
Personnel (Wages and Benefits)	$240,000		$240,000	$120,000		$120,000	$147,364		$147,364	$507,364	$507,364
Roger Ruan, PI/PD, 1%, 3 years, including 33.6% benefits, leading and managing project, overlooking R&D, leading demonstration, supervising postdocs and RA ***($4,963)***											
Paul Chen, co-PI, 10%, 3yrs, including 33.6% benefits, project coordination, conducting R&D, project evaluation, progress report ***($33,168)***											
2 research associate 100%, 3yrs, including 33.6% benefits, conducting R&D, operations, demonstration, data analysis ***($347,381)***											
1 Graduate Research Assistants, 50%, 3yrs, including 15.7% benefits plus tuitions, conducting R&D, operation, demonstration ***($121,852)***											
Professional/Technical/Service Contracts											
Salary/fees for a consultant, helping with engineering design and development of demo system for scum to algae conversion	$30,000		$30,000			$0			$0	$30,000	$30,000
Equipment/Tools/Supplies			$0			$0			$0	$0	$0
Laboratory supplies including chemicals, analytical supplies, microwave absorbents, catalysts, glassware, containers	$22,000		$22,000	$10,000		$10,000	$24,454		$24,454	$56,454	$56,454
Capital Expenditures Over $5,000											
Pilot scale biodiesel conversion demo system including oil extraction device, reaction tank, storage tanks, separation tanks, fractional rectifier, pumps, heaters, heat exchangers, control	$100,000		$100,000			$0			$0	$100,000	$100,000
Algae cultivation and harvesting demo system including multi-layer photobioreactors, greenhouse, circulation equipment,			$0	$40,000		$40,000			$0	$40,000	$40,000
Fast microwave assisted gasification demo system including auto-feeder, magnitrons, reaction chamber, microwave			$0			$0	$260,000		$260,000	$260,000	$260,000
Travel expenses in Minnesota	$2,060		$2,060	$2,060		$2,060	$2,062		$2,062	$6,182	$6,182
Milleages for researchers to travel between campus and demonstration sites											
COLUMN TOTAL	**$394,060**	**$0**	**$394,060**	**$172,060**	**$0**	**$172,060**	**$433,880**	**$0**	**$433,880**	**$1,000,000**	**$1,000,000**

PROJECT TITLE: Demonstrating innovative technologies to fully utilize wastewater resources
PI/PD: Roger Ruan, University of Minnesota

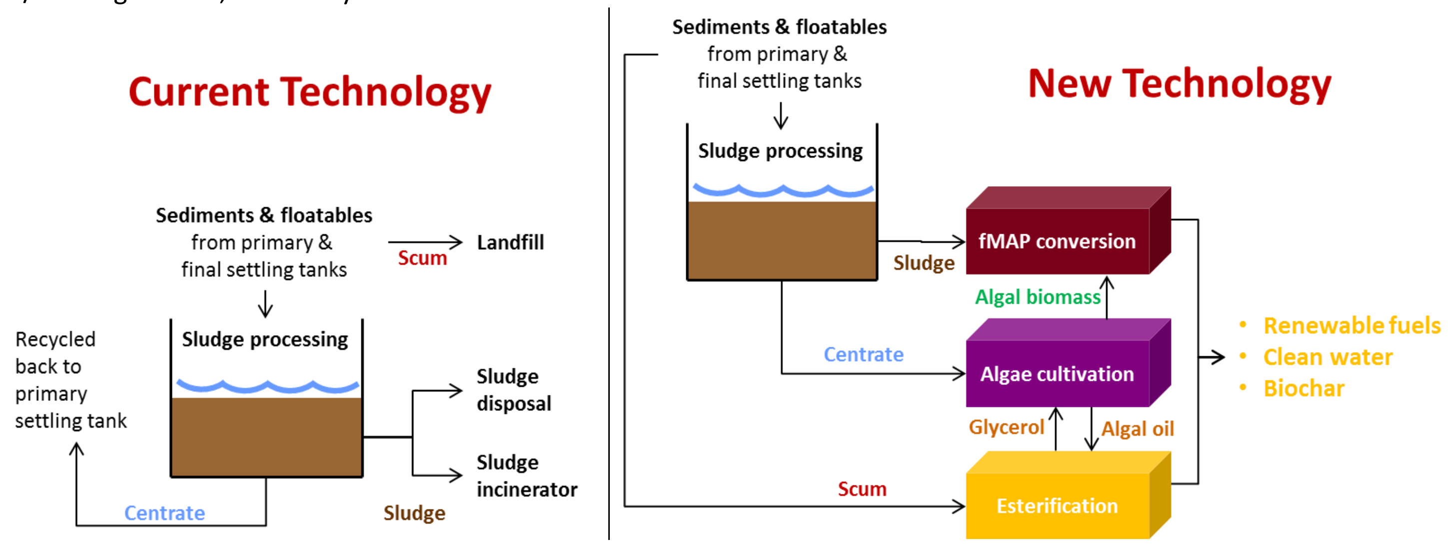

Figure 1. A comparison of waste stream pathways between the current and proposed new technologies

Figure 2. Pilot scale animal wastewater algae production facility in Rosemount, developed through previous LCCMR and other projects.

Figure 3. Pilot scale mobile MAP system developed through previous LCCMR and other projects; with incorporation of microwave absorbents, it becomes fMAP, a superior fast thermochemical conversion process.

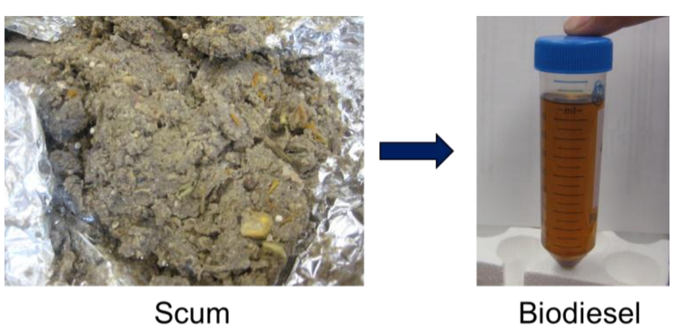

Figure 4. Converting scum to biodiesel