Environment and Natural Resources Trust Fund
2017 Request for Proposals (RFP)

Project Title: **ENRTF ID: 140-E**

Low Cost and Efficient Biomass Based Electricity Generation

Category: E. Air Quality, Climate Change, and Renewable Energy

Total Project Budget: $ 450,000

Proposed Project Time Period for the Funding Requested: 3 years, July 2017 - June 2020

Summary:

The objective of this project is to provide a new low cost and efficient technology for generating electricity from biomass feedstocks in the state of Minnesota.

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Sponsoring Organization: U of MN

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Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

The map shows the pathway from biomass feedstocks to renewable eletricity generation using the proposed technology.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: Low Cost and Efficient Biomass Based Electricity Generation

I. PROJECT STATEMENT

The objective of this project is to provide a low cost and efficient technology for generating electricity from biomass and solid waste that could lead to large scale adoption of biomass based electricity production in Minnesota. Producing electricity from renewable sources is a key priority for the nation and the state of Minnesota. Biomass feedstocks are not only renewable, but also can be used as an energy storage to complement other renewable sources such as solar and wind due to their intermittence. The challenges for large scale adoption of biomass based electricity generation include the cost competitiveness of the biofuels and the cost and efficiency of converting biofuels into electricity. This project is aimed at offering a low cost solution for the above challenges by combining biomass gasification with a free piston engine linear generator (FPELG). Developing a free piston engine linear generator that is efficient and sufficiently robust to handle variabilities in energy content and chemical properties of producer gas from gasification of different biomass feedstocks can help achieve this objective. Such a technology will enable the use of inexpensive biomass and reduce the cost of the biomass to fuel conversion process by allowing significant variabilities in the end products (producer gas). The FPELG is able to convert various producer gases into electricity in a clean and efficient fashion. It can also be started quickly (less than a second) and can therefore complement other renewable electricity generation methods, such as solar and wind. The FPELG concept can be sized for either individual home use or for a power plant. Therefore it is suitable for both distributed power generation and electricity generation at power plants.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Design and modeling of gasification and free piston engine linear generator Budget: $ 200K

Gasification of typical Minnesota based biomass resources will be modeled and analyzed. Minnesota has two major sources of biomass feedstocks: agricultural biomass and forestry biomass. Agricultural biomass includes both primary on-farm byproducts of growing crops, such as crop residues, and secondary sources from facilities processing ag-based products, such as oat hulls and pea pods. Similarly, primary forest products include virgin wood material from lumber and paper harvest operation and secondary products from activities such as lumber milling and cabinet building. A free piston engine linear generator will be designed to convert the biomass based producer gas into electricity. The producer gas will be premixed with air and supplied to the FPELG. This configuration has the potential to significantly increase the conversion efficiency from biomass to electricity. Specifically, the engine efficiency can be improved with less friction due to the elimination of the crankshaft and variable compression ratio which enables the implementation of homogeneous charge compression ignition (HCCI). The dynamic and modular nature of the free-piston engine linear generator makes it very attractive for distributed power generation or complementing the intermittence of other renewable energy sources such as solar or wind. The FPELG also has less moving parts compared with a conventional internal combustion genset. This helps reduce the cost and maintenance. This activity will design, model and simulate the proposed FPELG based on gasification of biomass feedstocks.

Outcome	Completion Date
1. Modeling and analysis of gasification of Minnesota biomass feedstocks	*3/31/2018*
2. Design of FPELG	*12/31/2018*
3. Modeling, simulation and analysis of FPELG with producer gas from biomass	*6/30/2020*

Activity 2: Non-contact piston position measurement for the FPELG Budget: $ 200K

The FPELG does not have a crankshaft attached as in conventional engines. This “frees” the piston motion from the crankshaft. However, the piston position needs to be controlled actively and this requires a precise position sensor for real-time feedback. Traditionally, researchers have used LVDT sensors to measure the positions of the pistons in the FPE. While this is a good temporary measure for conducting research, LVDTs are not the desired solution. This is because an LVDT incorporates a thin rod that constitutes a moving core which couples two side-by-side transformers. Continuous movement of this thin rod under real-life side loads may eventually result in fatigue failure of the sensor. Further, an LVDT is itself expensive with a cost at least $500 for each sensor. This activity therefore proposes exploiting the inherent magnetic fields of the oscillating components inside the FPELG for estimating the position of each piston. The proposed sensor has the following advantages: No internal sensor components are required inside the FPELG; No sensor components need to be connected between the moving piston and the ground; The cost of magnetic field measurement chips and associated electronics is low (sub - $50) and can lead to a very low-cost solution for position measurement.

Outcome	**Completion Date**
1. Model of the magnetic field of the FPELG	*3/31/2018*
2. Design and fabrication of the sensor	*3/31/2019*
3. Algorithm development and testing of the sensor	*6/30/2020*

Activity 3: Life cycle assessment **Budget: $ 50K**

In order to assess efficiency of the gasification and FPELG genset system, an exploratory life cycle assessment (LCA) will be conducted. The LCA will examine the life cycle carbon and fossil fuel implications of using the system to make electricity. An attributional LCA will be performed using two distinct functional units, the life cycle impacts per ton of biomass and per kW of electricity produced. The boundaries for the LCA work focus on the background system, items not associated with power production, and the foreground system, items that directly relate to gasification and power production.

Outcome	**Completion Date**
1. Data collection	*6/30/2019*
2. Life cycle analysis	*6/30/2020*

III. PROJECT STRATEGY

A. Project Team/Partners

Prof. Zongxuan Sun from Mechanical Engineering will serve as the PI. He has extensive experience on the design, control and testing of free piston engines. He has developed a unique control methodology (US patent pending) based on a "virtual crankshaft" that enables the precise and robust operation of the free piston engine and demonstrated the control on a hydraulic free piston engine. PI Sun will be responsible for the design and modeling the proposed free piston engine linear generator (activity 1). Prof. Rajesh Rajamani from Mechanical Engineering is responsible for the development of a non-contact position sensor needed for the FPELG (activity 2). Dr. Joel Tallaksen from the University West Central Research and Outreach Center is responsible for conducting the LCA of the proposed technology (activity 3). Co-PI Tallaksen has over 30 years experience in agricultural and plant production systems.

B. Project Impact and Long-Term Strategy

The long term goal of this work is to use the more efficient and lower cost technology being proposed in this project to increase the use of biomass energy capabilities in Minnesota. As a scalable, biomass-based renewable electricity production technology, the FPELG genset is a very good fit for Minnesota's rural electric cooperatives, businesses and residents in biomass rich regions of the state. The information generated by this work will put the researchers in a good position to continue the work with funds from other sources that would allow building a deployable prototype based on the FPELG technology, which could be tested in Minnesota communities with biomass resources. Recently the US DOE started a new program "OPTIMA" targeting the co-optimization of fuel and energy conversion devices, which would fit this later stage prototype development.

C. Timeline Requirements

The project duration is 36 months, 7/1/2017-6/30/2020. Activities 1 and 2 will proceed in parallel but with close collaborations. Activity 3 will start in year 2 and gather data based on the results from activities 1 and 2.

2017 Detailed Project Budget

Project Title: Low Cost and Efficient Biomass Based Electricity Generation

IV. TOTAL ENRTF REQUEST BUDGET: 3 years

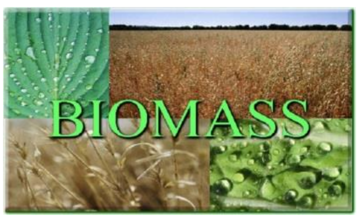
BUDGET ITEM	AMOUNT
Personnel:	$ -
Zongxuan Sun, PI (4.3 weeks (0.11FTE)+ fringe 33.8% fringe) for three years	$ 52,482
Rajesh Rajamani, (2 weeks (0.05FTE)+ fringe 33.8% fringe) for three years	$ 34,223
Joel Tallaksen, (27 weeks (0.5FTE)+ fringe 33.8% fringe)	$ 40,218
2 Graduate research assistants 50% FTE for three years	$ 282,878
Equipment/Tools/Supplies:	$ -
Lab supply (Sun)	$ 6,079
Lab supply (Rajamani)	$ 24,338
Lab supply (Tallaksen)	$ 6,732
LCA software/computer updtae (Tallaksen)	$ 1,250
Travel: Tallaksen	$ 1,800
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 450,000

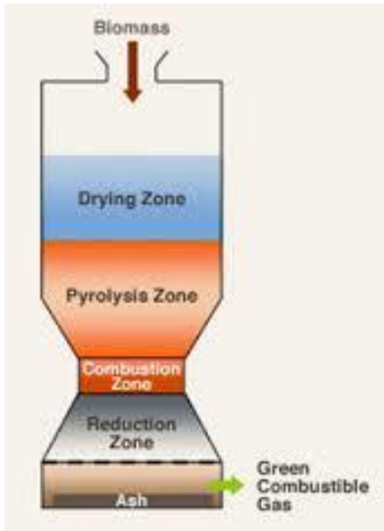
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period: N/A	$ -	
Other State $ To Be Applied To Project During Project Period: N/A	$ -	
In-kind Services To Be Applied To Project During Project Period: *N/A*	$ -	
Funding History: CCEFP for development of a hydraulic free piston engine	$ 643,049	secured
Remaining $ From Current ENRTF Appropriation: N/A	$ -	

Sun, Rajamani, and Tallaksen, University of Minnesota

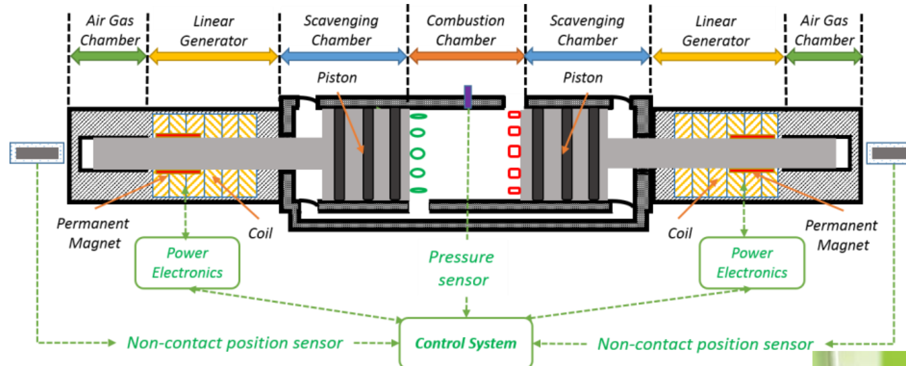
Low Cost and Efficient Biomass Based Electricity Generation





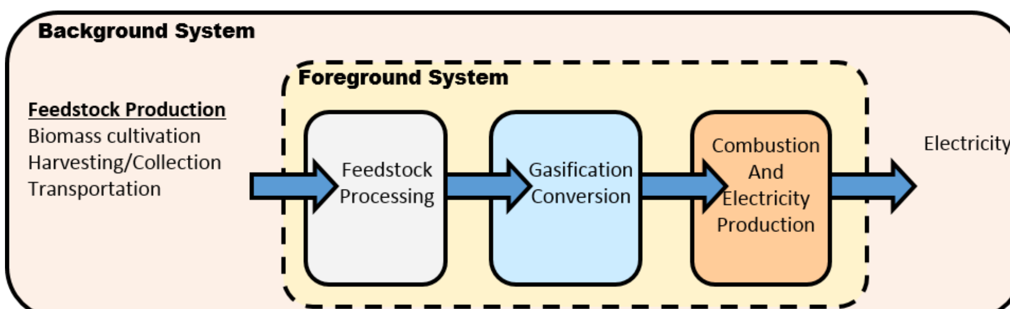
Gasification

Free piston engine linear generator



Non-contact sensor

Renewable electricity



Life cycle analysis

Project Manager Qualifications & Organization Description

Zongxuan Sun received the M.S. and Ph.D. degrees in Mechanical Engineering from the University of Illinois at Urbana-Champaign in 1998 and 2000 respectively, and the B.S. degree in Automatic Control from Southeast University, Nanjing, China, in 1995. He is currently Associate Professor of Mechanical Engineering at the University of Minnesota and Co-Deputy Director of the NSF Engineering Research Center of Compact and Efficient Fluid Power. He was a staff researcher (2006-2007) and a senior researcher (2000-2006) at General Motors Research and Development Center in Warren, MI. His research interests include controls and mechatronics with applications to the energy conversion systems. Dr. Sun has published over one hundred referred technical papers and received nineteen US patents.

Rajesh Rajamani obtained his M.S. and Ph.D. degrees from the University of California at Berkeley in 1991 and 1993 respectively and his B.Tech degree from the Indian Institute of Technology at Madras in 1989. Dr. Rajamani is currently Professor of Mechanical Engineering at the University of Minnesota. His active research interests include sensors and estimation systems. Dr. Rajamani has co-authored over 110 journal papers and is a co-inventor on 9 patent applications. He is the author of the popular book "Vehicle Dynamics and Control" published by Springer Verlag. Dr. Rajamani has served as Chair of the IEEE Technical Committee on Automotive Control and on the editorial boards of the IEEE Transactions on Control Systems Technology and the IEEE/ASME Transactions on Mechatronics. He is a Fellow of ASME and has been a recipient of the CAREER award from the National Science Foundation, the Ralph Teetor Award from SAE, and the 2007 O. Hugo Schuck Award from the American Automatic Control Council.

Joel Tallaksen is a Renewable Energy Scientist at the University of Minnesota, West Central Research and Outreach Center (WCROC). As an applied scientist, Dr. Tallaksen blends the most up-to-date science with new technologies or in new applications that meet the region's economic, environmental, and social needs. Currently, he is using life-cycle analysis as a tool to evaluate agricultural products, including biomass, for energy systems and for other uses. His focus is on setting up systems to use locally available resources to replace imported fossil fuels. Dr. Tallaksen's agricultural upbringing has played an important role in how he approaches developing biomass energy for the improvement of the environment and rural economies. He has BS degrees in Plant Sciences and Genetics & Cell Biology from the University of Minnesota, as well as a Ph.D. from the University of Minnesota in Plant Biological Sciences.

PI Sun has extensive experience on the design, control and testing of free piston engines. He has developed a unique control methodology based on a "virtual crankshaft" that enables the precise and robust operation of the free piston engine and demonstrated the control on a hydraulic free piston engine. PI Sun will oversee the whole project and be responsible for the design, modeling and analysis of the proposed free piston engine linear generator (FPELG) system. Co-PI Rajamani is responsible for the development of a non-contact position sensor needed for the FPELG. The proposed sensor will be a non-contact non-intrusive magnetic transducer located entirely outside the engine cylinder. Compared to the standard LVDT sensor, the proposed position estimation technology has significant advantages of cost and robustness. Co-PI Tallaksen is responsible for analyzing various feedstocks of biomass and conducting the life cycle analysis (LCA) of the complete system. The exploratory LCA will examine the life cycle carbon and fossil fuel implications of using biomass gasification with the more efficient FPELG.