Environment and Natural Resources Trust Fund

2021 Request for Proposal

General Information

Proposal ID: 2021-290

Proposal Title: Efficient Production and Clean Combustion of Renewable Biofuels

Project Manager Information

Name: Suo Yang

Organization: U of MN - College of Science and Engineering

Office Telephone: (612) 625-4520

Email: suo-yang@umn.edu

Project Basic Information

Project Summary: This proposal develops new technologies for efficient production and clean combustion of biofuels derived from Minnesota agriculture, and also performs a lifecycle assessment of the environmental benefits of the technologies.

Funds Requested: $681,000

Proposed Project Completion: 2023-06-30

LCCMR Funding Category: Air Quality, Climate Change, and Renewable Energy (E)

Project Location

What is the best scale for describing where your work will take place?

Statewide

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

During the Project and In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Renewable sources of energy such as wind and solar energy are highly intermittent, requiring significant energy storage capacity. Hydrocarbon/chemical fuels remain the primary option with sufficiently high energy density. Therefore, combustion-based power generation is expected to remain a dominant energy source. However, net CO2 emissions can be alleviated using renewable fuels derived from biomass. With high biomass potential (agriculture, forest management), Minnesota is the 4th largest producer of ethanol (1247 mgal per year) and the 8th largest producer of biodiesel (77 mgal of B100 per year) in the nation. However, there are several technical challenges that prevent widespread adoption of biofuels:

1. Current biofuel production technologies are not cost-competitive. Further, the heating value and flame stability of biofuels are lower than fossil fuels. Therefore, in practice, each biofuel is usually blended with a fossil fuel or another biofuel. However, this leads to undesirable phenomena such as puffing and micro-explosion. This necessitates further refining, increasing cost.
2. Cheaper liquid products from biomass (e.g., waste glycerol from biodiesel production, 'black liquor' from paper mills) have a high energy content. Nevertheless, their high viscosity renders them hard to spray into a fine mist necessary for clean combustion with current burner designs.

What is your proposed solution to the problem or opportunity discussed above? i.e. What are you seeking funding to do? You will be asked to expand on this in Activities and Milestones.

1. Instead of trial-and-error to arrive at optimum blends, we will use fundamental research (computation and experimental diagnostics) to optimize the formula of biofuel blends, in terms of cost, power, stability, and emission. The optimized formula will be tested in Minnesota power plants using biofuels. Lifecycle analysis will be conducted to evaluate the overall environmental impact.
2. We propose two solutions to reduce the cost of biofuels:
   a. In order to directly use the existing combustors/burners for fossil fuels, biomass feedstocks (e.g., liquified corn, vegetable oils, black liquor from paper mills) can be converted to petroleum-like biofuels (e.g., syn-gas, ethanol, biodiesel, biomethanol, bioDME) through the gasification or distillation process; however the high viscosity of these feedstocks prevents the formation of fine droplets and reduces evaporation rates of volatile components. Currently these processes require higher energy input to attain temperatures (>900 oC), often produced by burning natural gas. We propose to reduce the energy input by facilitating high performance atomization of these viscous feedstocks.
   b. Completely remove the pre-treatment costs involved in producing low viscosity gasoline/diesel-like liquid biofuels, through efficient atomization of cheaper, viscous liquid fuels, facilitating clean combustion with extremely low emissions.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

1. Optimized formulas of biofuel blends to allow the state to be less reliant on fossil fuels, and more reliant on renewable and clean biofuels (zero PAH/soot), to improve the air quality and reduce the impacts on human health and the environment.
2. Technologies for biofuel producers to reduce their cost and for power plants to utilize relatively inexpensive biofuels, which will support the efficient and sustainable use of the state's natural resources, while effectively reduce the greenhouse gas emissions and mitigating climate change.
3. Larger markets of biofuels and supplement the state's agricultural income.

Activities and Milestones

Activity 1: Efficient Distillation and Gasification for Biofuel Production

Activity Budget: $227,000

Activity Description:
We target to improve the energy efficiency of two specific processes in the biofuel production: (i) the distillation process in the production of ethanol and biodiesel from corn and soybean; (ii) the gasification process in the production of biomethanol and bio-dimethyl ether (BioDME) from the 'black liquor' generated by the pulp and paper industry (e.g., Sappi). Barr Engineering Co. will procure samples of intermediate biomass before the distillation/gasification process to be used for University of Minnesota (UMN) testing. Barr can help to quantify the energy cost and efficiency of the current distillation and gasification processes. UMN researchers will then develop a new distillation/gasification technology based on our novel injector design for the atomization of highly viscous biomass to produce very fine sprays for fast evaporation such that we can minimize the energy requirement for distillation/gasification and hence minimize the consumption of natural gas. If the testing is successful, Barr will evaluate the feasibility of the future design, implementation and testing of a distillation/gasification technology in a biofuel production site. As part of the testing, Barr can evaluate the improvement of energy efficiency and emissions associated with the optimization.

Activity Milestones:

Description	Completion Date
Quantification of the energy cost and efficiency of the current distillation and gasification processes	2021-12-31
Developing a new distillation/gasification technology to minimize the required energy cost	2022-12-31
On-site test of the new distillation/gasification technology in the biofuel production sites	2023-06-30

Activity 2: Effective Atomization of Highly Viscous Liquid Biofuels

Activity Budget: $227,000

Activity Description:
Barr Engineering Co. can help to procure samples of highly viscous biofuels for experimentation. Based on the samples, the University of Minnesota (UMN) researchers will conduct laboratory-scale experiments for identifying high temperature/pressure processes that are inexpensive and yield products with similar chemical characteristics as fossil fuels but with less stringent physical properties (viscosity, density). Specifically, we plan to test the direct-firing of corn or soybean oil with di-ethyl ether (DEE). UMN researchers will then conduct experiments (2 graduate students, one at Twin Cities and one at Duluth) and simulations (1 graduate student at Twin Cities) on fuel spray production, and the dependence of spray parameters on injector design. Use standard fluid dynamic techniques to measure droplet size and distribution as a function of injector geometry and liquid biofuel viscosity. Finally, the nozzle technology will be modified from laboratory prototypes to designs that are suitable for scale-up and operation in existing power plants, such as Ever-Green Energy and Duluth Steam, who have expressed interest in discussion. Barr can help to evaluate the improvement of energy efficiency and emissions associated with the optimization.

Activity Milestones:

Description	Completion Date
Characterization of inexpensive processes to produce highly viscous liquid biofuels	2021-12-31
Developing a new fuel injection technology to enable efficient evaporation of highly viscous liquid biofuels	2022-12-31
On-site test of the new fuel injection technology in selected power plants	2023-06-30

Activity 3: Optimization of Biofuel Blend Formula for Clean, Stable, and Inexpensive Combustion

Activity Budget: $227,000

Activity Description:

Barr Engineering Co. can help procure samples for biofuel blending (could include biomass-based diesel, di-ethyl ether DEE, and petroleum diesel). Barr can prepare sample blends for experimentation. University of Minnesota (UMN) researchers will then investigate the production of DEE from ethanol for use as a fuel supplement in diesel engines, running petroleum diesel or biomass diesel, in order to increase the fuel's cold weather properties for Minnesota utilization. UMN researchers will also conduct laboratory-level experiments and simulations to document the spray combustion properties of different formulas of biofuel blends, as well as scaling up experiments and simulations for addressing eventual industrial adoption. The spray combustion properties to be investigated include evaporation and flame stability, ignition heat release rate, thermal/combustion efficiency and emission. After the optimized formula is obtained, Barr and UMN will coordinate with potential biofuel blend users to evaluate the before and after emissions/impacts associated with the fuel change from petroleum fuels to the optimized biofuel blend, under peaking, stand-by, and emergency conditions. Finally, Barr can conduct a lifecycle assessment that tracks impacts starting from extraction of raw materials, through processing, manufacturing, transportation and end-of-life treatment/final disposal.

Activity Milestones:

Description	Completion Date
Characterization of candidate biofuels and blends	2021-12-31
Optimization of biofuel blend formula for clean, stable, and inexpensive combustion	2022-12-31
Life-cycle assessment of environmental impacts of biofuel power generation	2023-06-30
Stack testing to evaluate the before and after emissions/impacts associated with the fuel change	2023-06-30

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Chandler P. Taylor	Barr Engineering Co.	Project Partner	Yes
Alison Hoxie	University of Minnesota-Duluth	Co-PI	Yes
Vinod Srinivasan	University of Minnesota-Twin Cities	Co-PI	Yes

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this be funded?

The project will develop and demonstrate novel technologies that allows for broader utilization of sustainable biofuels with high energy efficiency and lower greenhouse gas emissions than fossil fuel alternatives. Any intellectual property developed during this project will be owned by the University of Minnesota. The long-term goal is to commercialize the technologies, and promote more biofuel producers and power plants to utilize them to supplement farm income, both in Minnesota and in other states. Licenses granted to Minnesota companies for the use of the technologies may generate jobs and bring in royalty that can be used to offset ENRTF funding.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Development of Clean Energy Storage Systems for Farms	M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 07a	$650,000

Project Manager and Organization Qualifications

Project Manager Name: Suo Yang

Job Title: Richard & Barbara Nelson Assistant Professor

Provide description of the project manager's qualifications to manage the proposed project.

Dr. Suo Yang is the Principle Investigator and Project Manager of the proposed project. Dr. Suo Yang is currently a Richard & Barbara Nelson Assistant Professor of Mechanical Engineering at the University of Minnesota - Twin Cities (UMN), and the Director of the Computational Reactive Flow and Energy Lab (CRFEL). Within UMN, Dr. Yang is also serving as a faculty member of Institute for Engineering in Medicine (IEM) and Particle Technology Laboratory (PTL). During 2017-2018, he was a Postdoctoral Research Associate in Mechanical and Aerospace Engineering at Princeton University. He received Ph.D. (2017) and M.Sc. (2014) degrees in Aerospace Engineering, and another M.Sc. degree in Computational Science & Engineering (2015), all from Georgia Institute of Technology. He received a B.Sc. degree in Mathematics & Applied Mathematics from Zhejiang University, China in 2011. Dr. Yang is currently serving on the American Institute of Aeronautics and Astronautics (AIAA) Propellants and Combustion Technical Committee, and he is also an active member of Combustion Institute, American Society of Mechanical Engineers (ASME), American Physical Society (APS), and Institute for Liquid Atomization and Spray Systems (ILASS).

Dr. Yang is a leading expert on the modeling and simulation of reacting flows, including clean combustion, turbulence,

plasma physics, particulate and multiphase flows (e.g., atomization, sprays, and evaporation), and their multiscale interactions, many of which are critical for the proposed project. Dr. Yang has an extensive experience in computational fluid dynamics (CFD) and high-performance parallel computing (HPC). As the Project Manager, Dr. Yang will work closely with Dr. Vinod Srinivasan (Mechanical Engineering, University of Minnesota) and Dr. Alison Hoxie (Mechanical Engineering, University of Minnesota-Duluth) and collaborators at the Barr Engineering Co. (Chandler P. Taylor) and biofuel supplies/users to direct all aspects of the project.

Organization: U of MN - College of Science and Engineering

Organization Description:
The University of Minnesota (UMN) is a land grant research university which is highly ranked in public research and offers a wide range of undergraduate and graduate programs. The University is dedicated to its mission of promoting access to higher education and collaborating to advance knowledge benefiting communities, the state and the world. There is one project partner organization in this project: Barr Engineering Co. (Barr) is a project-oriented consulting service organization that is focused on helping clients develop, manage, process, and restore natural resources. Barr has contacts with biofuel producers, biofuel trade organizations, paper mills and power plants in Minnesota, including Sappi, Ever-Green Energy, and Duluth Steam. Barr has been identified by UMN researchers to coordinate with industry partners, to procure samples for testing, and to help UMN researches evaluate the energy and life-cycle emissions impacts of using biofuels in new applications. Barr's capabilities also include emissions testing. As appropriate, Barr can also provide engineering services for translating UMN test results to practical applications.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Dr. Suo Yang		PI (Salary: $20,831 Fringe: $7,603. UMN FY21 fringe benefit rate for faculty is 36.5% of salary)			26.74%	0.16		$28,434
Dr. Vinod Srinivasan		Co-PI (Salary: $21,926 Fringe: $8,007. UMN FY21 fringe benefit rate for faculty is 36.5% of salary)			26.74%	0.16		$29,943
Dr. Alison Hoxie		Co-PI (Salary: $19,711 Fringe: $7,195. UMN FY21 fringe benefit rate for faculty is 36.5% of salary)			26.74%	0.16		$26,906
Research Assistant (U of M-Duluth)		Combustion experiment. (Salary: $45,663 Fringe: $42,109. UMN FY21 fringe benefit rate for Graduate Research Assistants is 19.9% health benefits and $21.06/hr x 780 hrs for tuition remission). Salary pro-rated based on proposal dates/fiscal year rate changes.			47.97%	2		$87,772
Research Assistant (U of M-Twin Cities)		Spray modeling and simulation. (Salary: $61,705 Fringe: $45,301. UMN FY21 fringe benefit rate for Graduate Research Assistants is 19.9% health benefits and $21.06/hr x 780 hrs for tuition remission. Salary pro-rated based on proposal dates/fiscal year rate changes.)			42.34%	2		$107,007
Research Assistant (U of M-Twin Cities)		Spray experiment. (Salary: $61,705 Fringe: $45,301. UMN FY21 fringe benefit rate for Graduate Research Assistants is 19.9% health benefits and $21.06/hr x 780 hrs for tuition remission. Salary pro-rated based on proposal dates/fiscal year rate changes.)			42.34%	2		$107,007
Research Assistant (U of M-Twin Cities)		Combustion modeling and simulation. (Salary: $61,705 Fringe: $45,301. UMN FY21 fringe benefit rate for Graduate Research Assistants is 19.9% health benefits and $21.06/hr x 780 hrs for tuition remission. Salary pro-rated based on proposal dates/fiscal year rate changes.)			42.34%	2		$107,007
							Sub Total	**$494,076**
Contracts and Services								
Barr Engineering Co.	Professional or Technical Service Contract	Project Management/Partner Coordination, Emissions Estimates/Characterization, Mechanical Engineer Consultation, Stack Tests, Life-Cycle Analysis				0.04		$53,840

Barr Engineering Co.	Professional or Technical Service Contract	Biofuels Producer Information and Samples				0.02		$10,000
							Sub Total	**$63,840**
Equipment, Tools, and Supplies								
	Tools and Supplies	LCCMR Lab Materials & Supplies to perform experiments. Atomization experiments require a long-working distance microscope ($7K), gear pumps to feed particulate suspensions such as black liquir ($4K x2=$8K) to the nozzle, laser optical components for image acquisition ($4K), optical rails, breadboards ($6K), compressed gas cylinders ($2K), nozzle fabrication costs ($5K), gas cabinets and air handling ($8K), camera ($3K), misc supplies such as lab tools, tubing, wiring ($6K), liquid property characterization ($3K). Combustion Experiments require: $10K for sensors, laser optics and mounts and vented fuel storage container. $15K lab system plumbing, mass flow meter, combustion facility modification, and electrical supplies, modification to combustion facility for spray combustion experiment ($5K)	Experiments to demonstrate improved atomization, combustion and emissions					$81,483
	Tools and Supplies	Dedicated high performance computing service from Minnesota Supercomputing Institute (MSI): the unit cost is $3,420 per node (each node contains 128 AMD cores and 256 GB memory) per year, and we need 5 nodes for 2 years. See more details in the MSI website: https://www.msi.umn.edu/content/dedicated-computing	Conduct computational research					$34,200
							Sub Total	**$115,683**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								

							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	Six meetings between PI/Co-PIs at Minneapolis): (280 miles round-trip, one night, three meals) = $375 *6 = $2250; One trip by PI/Co-PIs to Brewster, MN plant producing biodiesel (340 mi round-trip, one night, three meals)= $800; One trip by PIs/co-PIs to Sappi paper mill in Cloquet (200 miles, two meal) = $200	Project progress discussion; on-site discussion and testing with biofuel producers and power plants					$3,250
							Sub Total	**$3,250**
Travel Outside Minnesota								
	Conference Registration Miles/ Meals/ Lodging	Each PI/Co-PI will attend one academic conference per year, with an estimated cost of $692 per conference (~$292 for flights and ~$400 for lodging). So the total cost is ~$692/conference * 3 people * 2 years = ~$4,151	Attend academic and professional conferences to present the outcomes of proposed research					$4,151
							Sub Total	**$4,151**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$681,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
Cash	American Chemical Society (Effects of non-Newtonian Rheology on Atomization)	Conduct fundamental spray research to support the technology development in the proposed project	Secured	$110,000
			Non State Sub Total	**$110,000**
			Funds Total	**$110,000**

Attachments

Required Attachments

Visual Component

File: c7a1d271-c02.pdf

Alternate Text for Visual Component

This graphic shows the distribution of ethanol and biodiesel producing plants in Minnesota. Also shown is a process for converting black liquor generated in the pulp and paper industry, to syn-gas or motor fuel. Our innovation can enable cleaner, more efficient production of these biofuels in the biomass gasifier/distillator, as well as producing better combustion of the resulting fuels.

Optional Attachments

Support Letter or Other

Title	File
Support Letter from U of MN Sponsored Projects Administration	463e20f9-f9e.pdf
Support Letter from Barr Engineering Co.	a179d4e9-bd2.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have patent, royalties, or revenue potential?

Yes,

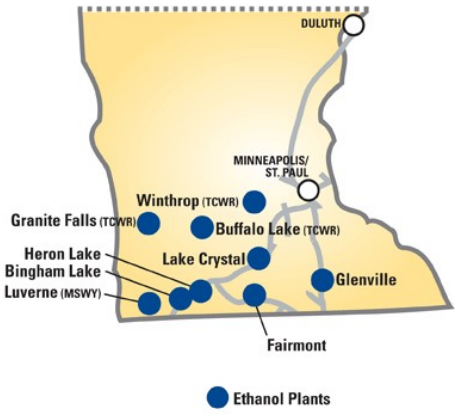
- Patent, Copyright, or Royalty Potential

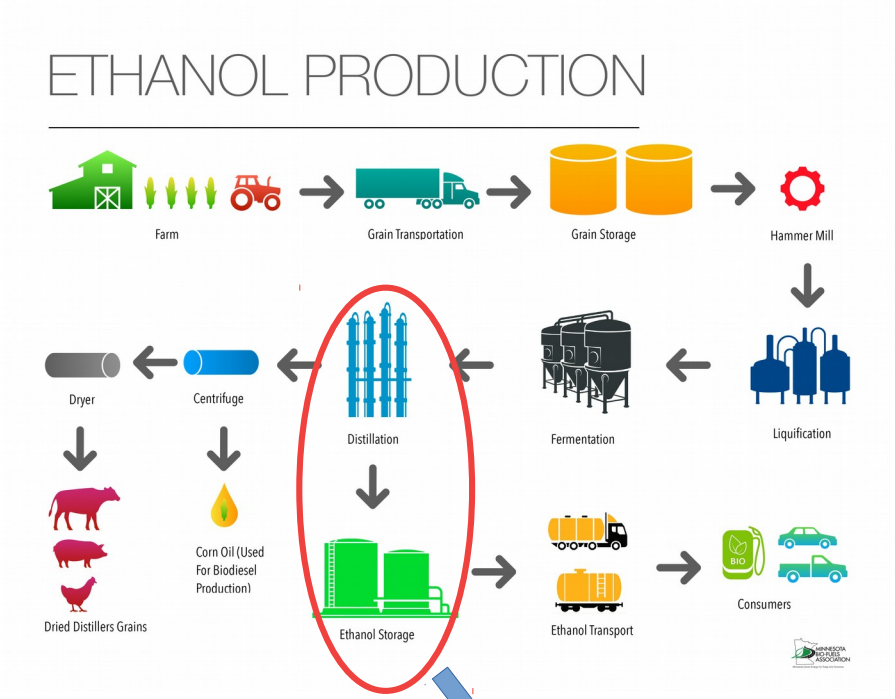
Does your project include research?

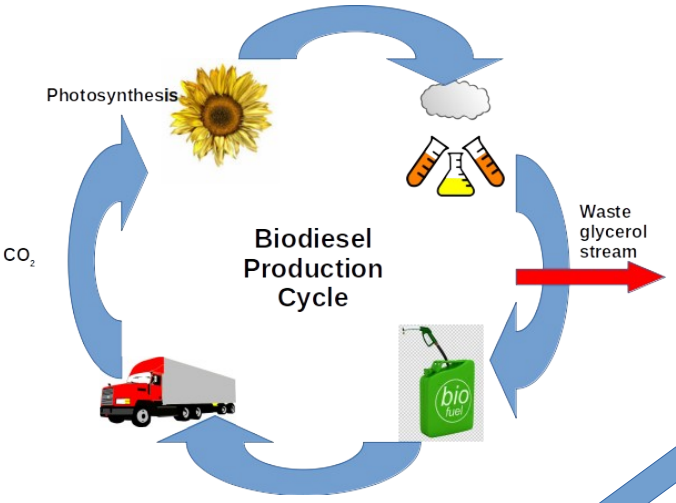
Yes

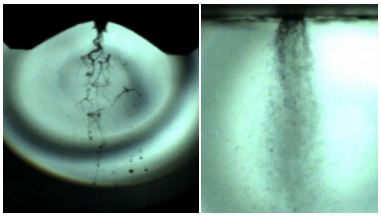
Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration



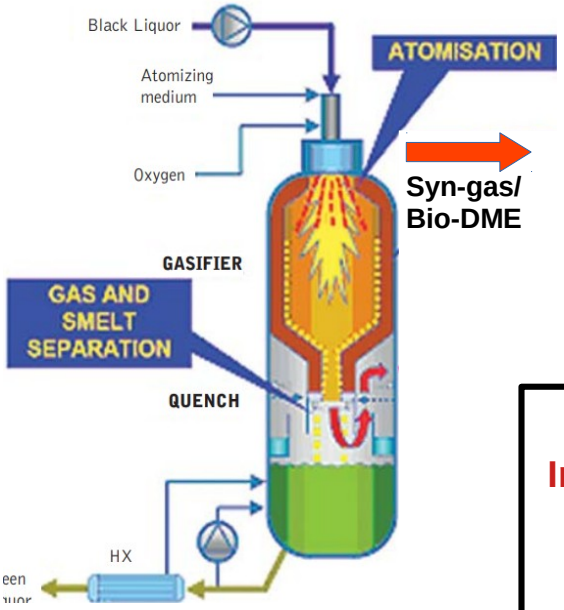


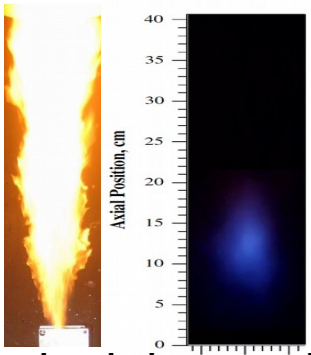




Atomization of a viscous liquid using (left) commercial nozzle, (right) UMN nozzle

Black Liquor Gasification Process





Soot production during vegetable oil combustion with (left) conventional and (right) enhanced atomization

Outcome

Improved Atomization and Oxidation of Viscous Liquids (Liquified Corn Mash, Black Liquor, Glycerol) Leads to Higher Conversion Efficiency and Throughput of Biofuel