Renewable Energy Research Initiative

Title :

The Smart Cities Project: A Pilot Study to Produce Bioenergy and Fertilizer from UC's Food Waste

A short abstract of presentation:

A pilot renewable energy project is to convert food wastes from the University of Cincinnati's (UC) cafeterias into usable energy, including gases, liquid and solid fuels, as well as fertilizer solids. UC is currently generating approximately 1800 kg of food waste per week of which the majority is landfilled. Food waste is the single largest category of solid waste (MSW) being landfilled comprising > 15% of total MSW in the U.S. The technical approach is to build a pilot-scale off-campus dry anaerobic digester coupled with an algae photobioreactor that will result in significant volumes of near-pipeline quality methane along with the production of biodiesel and solid fuels from the growth of algae. The pilot unit is designed to handle ~ 90 kg per week of food wastes. The technical advantages of this approach include:

– Provides a source of methane that could be used as a replacement for natural gas that is obtained from fracking;
– Potential for the use for carbon dioxide from the biogas to grow algae for the production of solid fuels, biodiesel, food products, and other products;
– Utilizes waste carbon sources in a manner that reduces the water requirement for energy production;
– Reduces climate change by recycling and utilizing huge amounts of methane and carbon dioxide which would otherwise be released into the atmosphere from landfills;
– Reduces the potential for groundwater and surface water contamination from landfills;
– Potential for producing biosolids that can be used as fertilizers; and,
– The concept could be developed for implementation at other universities or organizations with large volumes of food waste in any city or locale regardless of location, or local climatic conditions.

The project commences as a pilot study and the funds obtained from this renewable energy initiative are leveraged by seeking funds from industrial partners and other internal UC sources, as well as State of Ohio and Federal sources.

Names of people involved in this research and their affiliations (in alphabetical order):

Pablo Campo-Moreno, PhD: Research Assistant Professor, Department of Biomedical, Chemical, and Environmental Engineering;

Role in project: Digestate characterization including solids and liquid characterization.

San-Mou Jeng, PhD; Professor, Department of Aerospace Engineering;
Role in project: Biogas and biofuels evaluation; heating values; combustion characteristics; applicability for gas turbine use.

Tim Keener, PhD: Professor, Department of Biomedical, Chemical, and Environmental Engineering;
Role in project: Algae system design and development; system evaluation and optimization; lipid evaluation and biofuels development.

Drew McAvoy, PhD: Adjunct Professor, Department of Biomedical, Chemical, and Environmental Engineering;
Role in project: Anaerobic digester design and development; system evaluation and optimization.

Existing and potential funding sources:

For this initial pilot project we are requesting as follows:

1. Renewable Energy Research Initiative ($35K);
2. Department of Biomedical, Chemical, and Environmental Engineering Interdisciplinary Seed Grant Application ($25K);
3. URC ($20K).

Going forward: State of Ohio; US EPA, DOE and DOA.

Duration of the existing effort (when started and until when funded);

Project duration will be 12 months commencing when sufficient funding has been obtained.

A 5-page project description follows this page.

The Smart Cities Project:
A Pilot Study to Produce Bioenergy and Fertilizer from UC's Food Waste

A Proposal Submitted to the

Renewable Energy Research Initiative

Participants
(In alphabetical order):

San-Mou Jeng, PhD
Professor, Department of Aerospace Engineering

Tim Keener, PhD
Professor, Department of Biomedical, Chemical, and Environmental Engineering

Drew McAvoy, PhD
Adjunct Professor, Department of Biomedical, Chemical, and Environmental Engineering

George Sorial, PhD
Professor, Department of Biomedical, Chemical, and Environmental Engineering

October 15, 2013

ABSTRACT

A pilot renewable energy project is to convert food wastes from the University of Cincinnati's (UC) cafeterias into usable energy, including gases, liquid and solid fuels, as well as fertilizer solids. UC is currently generating approximately 1800 kg of food waste per week of which the majority is landfilled. Food waste is the single largest category of solid waste (MSW) being landfilled comprising > 15% of total MSW in the U.S. The technical approach is to build a pilot off-campus dry anaerobic digester coupled with an algae photobioreactor that will result in significant volumes of near-pipeline quality methane along with the production of biodiesel and solid fuels from the growth of algae. The pilot unit is designed to handle ~ 90 kg per week of food wastes. The technical advantages of this approach include:

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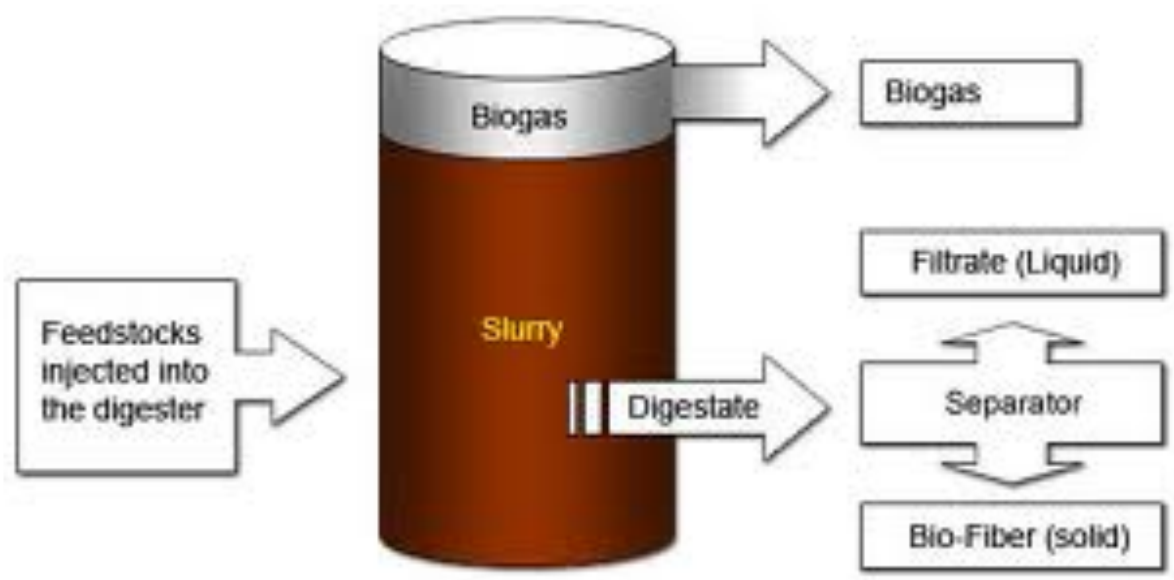
BACKGROUND

Food waste represents one of the greatest opportunities for the generation of renewable fuels and also one of the least utilized of all organic waste materials. A report[1] from the United Nations' Food and

[1] http://www.weather.com/news/science/environment/wasted-food-makes-climate-change-much-worse-20130917

Agriculture Organization shows that global food waste is the world's third-biggest emitter of greenhouse gases from landfills, behind only the United States and China, releasing the equivalent of more than 3.6 billion tons of carbon dioxide into the atmosphere from the release of methane. Only about 2.5% of food waste is currently recycled in the U.S. and the principal technology is composting, which does provide an alternative to landfilling food waste, but requires large land area, produces smog precursor VOCs, emits carbon dioxide to the atmosphere, and consumes energy. Diverting food waste from landfills can contribute to producing significant quantities of renewable fuels while achieving USEPA, State of Ohio and local solid waste diversion goals.

Anaerobic digestion (AD) is the biological degradation of organic matter in the absence of oxygen yielding two products, biogas and digestate. Benefits of AD include being a renewable energy source, reduction in greenhouse gas emissions (compared to landfilling), reduction in water pollution, and the generation of a valuable revenue stream. Biogas is comprised of 60-70% methane and 30-40% carbon dioxide, and



Basic Anaerobic Digestion Process

digestate consists of water and biosolids which are high in nutrient content and can be filtered and used as a fertilizer or soil conditioner. Anaerobic digestion is a better alternative to landfilling food waste because it results in significant waste volume reductions and provides for the creation of these beneficial end products. Food waste is an excellent candidate for anaerobic digestion due to its high moisture and organic content. While anaerobic digestion is commonly used in wastewater treatment, there are few examples of U.S. food waste digesters. Biogas is capable of operating most devices intended for natural gas, although the carbon dioxide content reduces the heat available from the gas. Typically, when the biogas is used as a combustion fuel, the carbon dioxide is simply sent along with the methane and it passes back into the atmosphere unused.

Microalgae species are aquatic organisms that produce complex organic compounds from simple inorganic molecules using carbon dioxide (CO_2) as their carbon source, and energy primarily from sunlight (photosynthesis). They produce lipids which are organic compounds containing fats, oils, and related substances that, along with proteins and carbohydrates, are the structural components of living cells. Some species of algae consist of as much as 80% of their mass as lipid content. They have rapid growth rates and can double in mass every 24 hours. A byproduct of their metabolic and reproduction cycles is the production of oxygen (O_2) and hydroxyl ion (OH^-) which increases the solution pH with time if not neutralized with the addition of absorbed CO_2. This coupled with their rapid growth rates makes them ideal candidates for the production of alternative fuels (biofuels), especially biodiesel and solid fuels, from the biomass media. In addition, algae contains ~23,500 kJ/kg, has no chlorine, little or no sulfur or heavy metals, is non-toxic, and its biofuel is highly biodegradable. In addition, researchers have recently reported that a life-cycle analysis[2] of pilot-scale operations at an algae-to-fuel facility show that substantial reductions in greenhouse gases will be achieved over petroleum based fuels along with a sustainable energy return when algaeculture (the commercial production of algae) is fully developed. They also found that algae-based fuels from the pilot plant are on par with commercial-scale, first-generation biofuels. The study concluded that greenhouse gas reductions and energy returns are set to increase significantly once economies of scale in production take hold.

TECHNICAL DETAILS

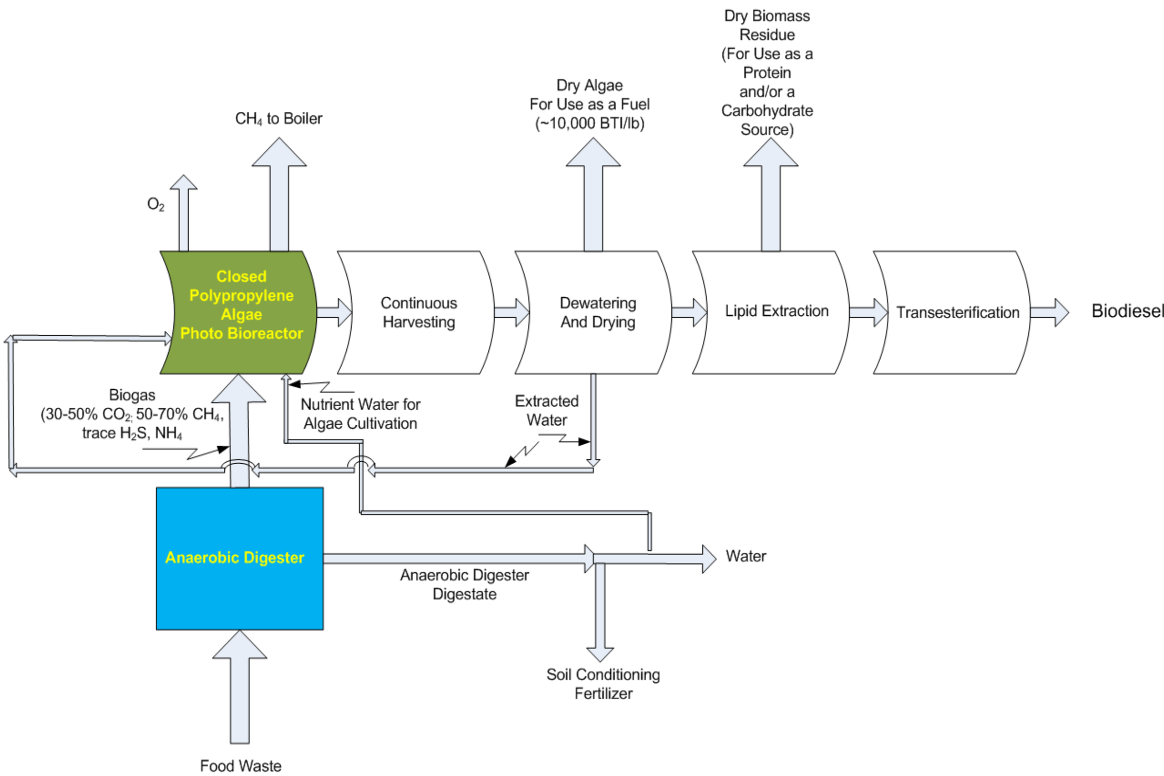
An off-campus site is chosen for the location of the combined system of an anaerobic digester (AD) coupled with an algae photobioreactor. AD technologies consist of wet (3-10% solids) or dry (> 15% solids) systems. We utilize dry digestion as it significantly reduces the volume of the AD reactor and saves on the digestate post processing costs by minimizing the amount of volume that has to be handled. Water is added to food waste for wet digestion, but not for dry digestion. Another major advantage of dry

[2] http://www.biomassmagazine.com/articles/9533/algae-fuel-passes-another-crucial-test

systems is that they can be built to scale-up (batch/modular units) easily as more waste becomes available, and they require less space than wet systems.

A novel algae reactor system with an extremely small footprint will utilize the CO_2 portion of the biogas. CO_2 scrubbing is accomplished with a unique gas separation system developed by the PIs producing scrubbed effluent gas, which consists of methane and water vapor and has the characteristics of pipeline natural gas. The algae harvests continuously for further processing using techniques which have been developed by the PIs.

A schematic flow diagram of the system is shown in Figure 1, which is not drawn to scale. The processed food waste enters the anaerobic digester via an air seal where it has a residence time of approximately ~15 days. After steady state conditions is achieved, biogas consisting of 60-70% methane and 30-40% carbon dioxide is



Food Waste Processing Flow Diagram

continuously generated. The volumetric flow rate of the gas depends on the amount of volatile material in the waste, and the waste mass flow rate into the reactor. The biogas is conveyed to a scrubber where an algae solution at a suitable pH will absorb the CO_2 into the aqueous solution forming dissolved carbonate species and this solution is conveyed to a closed, polypropylene photobioreactor where the dissolved carbonate is utilized by the algae as their carbon source in the presence of sunlight. As methane is essentially insoluble, it passes through the scrubber unchanged in molar volumetric flow rate, and only have the addition of water vapor whose concentration is a function of the scrubber operating temperature. The pH of the influent scrubber solution is approximately 8.0 and the effluent solution is approximately 6.8. The methane is conveyed to a holding tank for further use.

The algae solution is continuously pumped to a separation unit where a portion of the algae is separated for processing. This fraction is conveyed to a dewatering and drying step where the extracted water is recirculated to the photobioreactor. The dried algae has a heat content of ~23,500 kJ/kg and can be used in pelletized form as a direct substitute for coal or other solid fuels in fluidized bed combustors, or spreader stokers, or injected as a dry solid into pulverized coal combustors. If desired, the lipid content from the algae can be extracted, and process via transesterification reactions to produce biodiesel.

From an analysis of typical food wastes available in the literature it is possible to generate ~6 m^3 of methane and 0.75 liters of biodiesel per day per 45 kg (100 lb) of as-received food waste. This will represent a potential generation of 240 m^3 of methane and 30 liters of biodiesel per week for the 1800 kg of food waste currently being generated at UC. However, we are building an integrated system to be able to handle ~90 kg per week which will be enough to generate 12 m^3 of methane and 1.5 liters of biodiesel per day. This is sufficient to provide us with adequate data necessary for scale-up in order to propose to build a larger system capable of handling all of the University's food wastes in the future.

PATH GOING FORWARD

Energy sustainability means using less carbon from fossilized sources such as natural gas, coal and petroleum, and utilizing and recycling biologic forms of carbon that already exist in the environment. The coupling of anaerobic digestion with carbon dioxide utilization via algaculture will represent a giant step forward in achieving this goal. The success of the pilot plant here will allow the PIs to seek funding from both State of Ohio and Federal sources in order to reproduce this concept not only at other universities but also in large urban areas where cities are seeking to think green, which requires them to think smart. This project will also generate substantial positive public relations as it will represent a renewable energy "first." The PIs have as their ultimate goal to use this project as an initiator of a Smart Cities Center located at UC where concepts such as this can be developed and tested.

PROJECT BUDGET

We are seeking partial funding support from the Renewable Energy Research Initiative and will seek additional funds from internal sources, as well as industrial support. The pilot project will be conducted for one year. The overall project budget for the pilot plant is as follows:

Student Stipend Support:	$44,000
Equipment:	$26,000
Supplies:	$10,000
Total Overall Project Budget:	**$80,000**

Funds requested from the Renewable Energy Research: $35,000

Faculty Participants' Biographical Information

Pablo Campo-Moreno, Ph.D.

Research Assistant Professor
Environmental Analysis Service center, Director
Department of Biomedical, Chemical and Environmental Engineering
College of Engineering and Applied Science
University of Cincinnati
Cincinnati, OH 45221

Biographical Sketch
Dr. Pablo Campo is a Research Assistant Professor in the Department of Biomedical, Chemical and Environmental Engineering; his appointment includes the supervision of the Environmental Analysis Service Center (EASC) of this Department. Dr. Campo has a B.S. in Chemistry from the University of Valladolid, Spain. In 2009, he obtained his Ph.D. in Environmental Science from the University of Cincinnati, where he held a postdoctoral fellowship from 2009 to 2011. His research experience centers on the treatment and reuse, by biological and physical-chemical means, of wastewaters resulting from residential uses, industrial activities, and energy production. As EASC director, Dr. Campo supports the application of instrumental and bioanalytial techniques in the field of environmental science and engineering.

Dr. Campo is currently involved in two studies concerning the sustainable treatment of domestic wastewater funded by Ohio's Water Technology Innovation Cluster. The first project explores the optimization of the BCR design so that an effective process of wastewater reuse is achieved, whereas the second one deals with the thermo-oxidation of municipal sludge for obtaining class A biosolids. He also participates in a U.S. EPA study on the treatment of hydraulic fracturing wastewaters with conventional biological systems.

San-Mou Jeng, Ph.D.

Department of Aerospace Engineering and Engineering Mechanics
University of Cincinnati
Cincinnati, OH 45221

Biographical Sketch
Dr. Jeng received his BS in Power Mechanical Engineering at the National Tsing-Hua University in 1977, his MS in Mechanical Engineering from the Pennsylvania State University in 1982, and his PhD in Mechanical Engineering from the Pennsylvania State

University in 1984. He started his teaching career with the University of Tennessee Space Institute (UTSI) in 1985. During his six year tenure at the UTSI, he focused his research on “Space and Rocket Propulsion”. Dr. Jeng expanded his research area into gas turbine combustion after he joined the University of Cincinnati, 1992. Over the last twenty years, he has successfully secured funding from NASA, DOD, GEAE, Parker Hannifin, and Ohio Aerospace Institute in fuel injector and combustor related research. He has also established a well-equipped laboratory for research, test and evaluation in liquid fuel injectors, single cup combustors and deposits in fuel supply system at the University of Cincinnati. The research foci of the laboratory are emissions from the combustor, liquid fuel atomization, air/fuel mixing, fuel lean ignition limit, fuel thermal stability alternative fuels and fuel injectors.

Drew C. McAvoy, Ph.D.

Adjunct Professor
Department of Biomedical, Chemical, and Environmental Engineering
College of Engineering and Applied Science
University of Cincinnati
Cincinnati, OH 45221

Biographical Sketch
Dr. McAvoy is an Adjunct and Research Professor in the Environmental Engineering Program within the College of Engineering and Applied Science. He received his Ph.D. from the University of Massachusetts (Environmental Engineering), M.S. from the University of Iowa (Civil & Environmental Engineering), and B.S. from the University of Iowa (Civil Engineering). Previous employers include The Procter & Gamble Company (Principal Research Engineer), Syracuse University (Research Associate), and Metropolitan Waste Control Commission (Water Quality Engineer) in St. Paul, MN. His teaching responsibilities include courses on physical and biological wastewater treatment, numerical methods and environmental modeling, and environmental sustainability. His research interests are in the areas of biological wastewater treatment, biogas generation from organic waste, fate of contaminants in engineered and natural systems, and sustainable systems development and evaluation.

Dr. McAvoy has published over 65 peer reviewed journal articles, presented more than 80 papers at scientific meetings, and holds two patents. He has been recognized for his accomplishments with awards from the Water Environment Federation (Willem Rudolf Medal - 1997), Environmental Science & Technology (Excellence in Review Award - 2003), the Engineers and Scientists of Cincinnati (Award for Engineer in Industry - 2007), and the University of Cincinnati (President’s Award for Outstanding Adjunct Faculty - 2012). He has also served on the Editorial Board of *Environmental Toxicology & Chemistry* (2000-2003, 2008-2010) and on the Research Council for the Water Environment Research Foundation (2003-2008). Dr. McAvoy has also served on several panels and committees for the U.S. Environmental Protection Agency, the

National Science Foundation, the U.S. Department of Agriculture, and the U.S. Department of Defense.

Tim C. Keener, Ph.D., P.E., QEP

Professor
Department of Biomedical, Chemical, and Environmental Engineering
College of Engineering and Applied Science
University of Cincinnati
Cincinnati, Ohio

Biographical Sketch

Dr. Keener obtained his PhD in Environmental Engineering from the University of Tennessee in 1982. He is a Professor and member of the faculty of the Department of Biomedical, Chemical, and Environmental Engineering in the College of Engineering and Applied Science. His research interests are in the areas of air pollution control, air quality management, and the development of sustainable energy production processes. He has mainly dealt with the prevention of the formation and control of pollutants from fossil-fueled fired power plants and other industrial sources. He has contributed to the developed of methods for the measurement and control of air pollutants, including sulfur dioxide, nitric oxides, VOCs, CO_2 and mercury. He is also currently involved in the development and evaluation of algae as a source of biodiesel.

Dr. Keener has published more than 200 publications and technical papers (including 102 peer-reviewed journal publications) on subjects dealing with air pollution control, combustion, influence of fuel properties on pollutant formation, emissions from industrial sources, climate change and air quality management. He holds five patents in these areas. Dr. Keener has been elected as a Fellow Member of the Air and Waste Management Association, and is a recipient of the Association's Lyman A. Ripperton Award for Excellence in Environmental Engineering. He has served on numerous national panels, committees and work groups for the Department of Energy, the National Science Foundation, and the U.S. Environmental Protection Agency. From 2003 - 2012, Dr. Keener served as the Technical Editor-In-Chief of the *Journal of the Air & Waste Management Association*.