Title of the project: Renewable Gasoline from Waste Biomass

Focus Area: Energy, climate change, and the environment

Collaborative Team:

Country	Organization	Match	Type of Match
United States	Texas A&M University	$83,202	Salary
Great Britain	University of Aberdeen	$10,700	Salary
Brazil	Universidade Federal de Pernambuco (UFPE)	$70,000	Salary & Equip.
United States	Earth Energy Renewables	$300,000	Feedstock
	Total	$463,902	

Vision

Global population is growing at a rate of 1.14% per year. The United Nations estimates that we reached 7 billion in 2011 and we will reach 8 billion in 2024, only 13 years later. [1] In addition to a growing population, the global standard of living continues to improve. According to the World Bank, global per capita GDP was $6,700 in 2004 and it increased to $10,500 in 2013. [2] Some impacts of these statistics are to increase demand for energy while simultaneously increasing production of wastes.

This project focuses on developing the MixAlco process, which converts biodegradable wastes (e.g., municipal solid waste, sewage sludge, manure, agricultural residues) into "green" gasoline for a selling price of about $2/gallon. [3] Because the feedstock is biological in origin, combustion of "green" gasoline does not accumulate carbon dioxide in the atmosphere; the emitted carbon dioxide is fixed by photosynthesis and is converted to more plant matter. This technology has the potential to benefit the economy (domestic jobs, inexpensive transportation fuels), security (less dependence on foreign oil), and the environment (recycle wastes, reduce global warming).

A promising biofuel technology, the MixAlco process has received the Presidential Green Chemistry Challenge Award (1996) from the president and vice president of the United States, the McGraw-Hill Environmental Champion Award (1997), the Sigma Xi Walston Chubb Award for Innovation (2006), and the Odebrecht Award for Sustainable Development (2014).

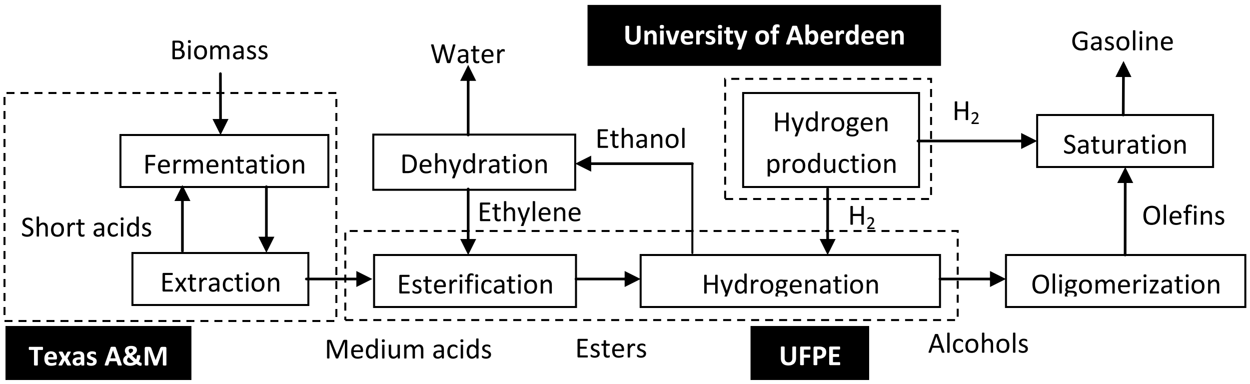

Figure 1. Schematic of MixAlco process.

Process Description

Figure 1 shows a schematic diagram of the MixAlco process. In principle, any biodegradable biomass can be employed. In this case, we will use waste food scraps because their putrid nature makes them a significant disposal problem. On a continuous basis, the biomass is fermented to carboxylic acids ranging from acetic acid (two carbons) to octanoic acid (eight carbons). To prevent conversion of acids to methane – a low-value product – methanogen inhibitors such as iodoform are added periodically. To maintain pH neutrality, a buffer is added to react with the carboxylic acids to form the corresponding salt. The microorganisms in the fermentor are a mixed culture derived from marine soil, so selected because they are well adapted to a salty environment. The fermentation broth is filtered to remove solid debris so the liquid can contact an immiscible extractant that has high affinity for medium-chain carboxylic acids (four to eight carbons) but low affinity for short-chain carboxylic acids (two to three carbons). The short-chain acids are returned to the fermentor where they continue to elongate.

The extracted medium-chain carboxylic acids react with ethylene to make esters, which are subsequently hydrogenated to make primary alcohols. Ethanol is recovered from the alcohol mix and is dehydrated to ethylene, which is recycled. The higher alcohols are oligomerized to olefins using a zeolite catalyst. The olefins are hydrogenated to form gasoline.

The two hydrogenation steps must be supplied with hydrogen. In the near term, the hydrogen can be supplied from standard technology (reformed natural gas); however, this process emits carbon dioxide. Eventually, a more sustainable low-carbon source of hydrogen must be found. A promising alternative is thermal water splitting, such as the sulfur-iodine cycle [4], which employs high-temperature heat (>850°C) to split water into hydrogen and oxygen. The high-temperature heat can be derived from a solar furnace or Generation IV nuclear reactors.

Process Advantages

The advantages of the MixAlco process follow:

- *No sterility* – The fermentation employs a mixed culture of microorganisms derived from soil. Literally, dirt is added to the fermentor, so there is no need for sterile operating conditions. This greatly simplifies processing because contamination is not an issue.
- *No enzyme addition* – The mixed culture of microorganisms make their own enzymes, so the addition of expensive enzymes is not required.
- *Versaltile* – The mixed culture of microorganisms can ferment a wide variety of biomass components (e.g., cellulose, hemicellulose, starch, sugar, polysaccharides, gums, lipids, proteins, nucleic acids), so a wide variety of biomass wastes can be employed.
- *Wet processing* – Wet biomass feedstocks can be employed without the need for drying.
- *Scalable* – At small scale, the process is economical when making industrial chemicals, which are more valuable than fuel. This is an essential stepping stone in the path to commercialization.
- *Distributed processing* – The fermentations can be scaled down to process wastes produced by municipalities and farmers' co-ops. The product acids can be shipped to centralized facilities, such as conventional oil refineries, where they are upgraded to gasoline. In essence, the mixed acids are an infinitely renewable "bio-crude."
- *Compatible fuels* – Current transportation fuels employ energy-dense hydrocarbons. Our products are perfectly compatible with the current fuel infrastructure and require no special handling, such as are required by ethanol or hydrogen fuels.

Participating Organizations

As shown in Figure 1, the MixAlco process has the following three key steps: (1) fermentation of biomass to carboxylic acids, (2) production of hydrogen, and (3) reaction of hydrogen with carboxylic acids to produce gasoline. Each university is responsible for one of the steps, so each plays a vital role in the project as described below:

Texas A&M University

Role – Texas A&M will focus on fermenting biomass to carboxylic acids. Using a mixed culture of microorganisms derived from marine sediment, waste food scraps will be fermented to carboxylic acids. The medium-chain acids (four to eight carbons) will be extracted and the short-chain acids (two to three carbons) will be returned to the fermentor to continue being elongated.

Background – Since 1991, Texas A&M University has been developing the MixAlco process. The research program has involved 36 masters students, 30 PhD students, five post-doctoral students, and three faculty totaling over 270 person·years. The process is being commercialized by Earth Energy Renewables, which has a demonstration plant in Bryan, TX.

Collaboration – Texas A&M is located 90 miles from Houston, the "Energy Capital of the World." Many of its graduates find employment in the energy industry, so Texas A&M seeks collaborations with universities that have a similar profile.

University of Aberdeen

Role – Currently, industrial hydrogen is produced from natural gas, which forms carbon dioxide as a byproduct that is released into the atmosphere and thereby increases global warming. To overcome this problem, the University of Aberdeen will investigate thermochemical production of hydrogen (i.e., water splitting) from Generation IV high-temperature nuclear reactors (HTR). Rather than conduct experiments, the studies will focus on the following: (1) evaluate the literature to determine the most suitable heat source (gas-cooled or molten-salt based nuclear reactors, or solar radiation power plants) and (2) initial simulations of heat recovery in hypothetical HTRs.

Background – Since 2001, Dr. Gomes has been actively engaged in nuclear research. Most recently, investigations have focused on safety assessment of two Generation IV reactor designs: very-high temperature reactor (VHTR) and gas-cooled fast reactor (GFR). Gasses reach temperatures of 1000–1300°C, which can be readily used in steam generators. These temperatures are ideally suited to water-splitting. Advanced thermo-hydraulic models developed by Dr. Gomes will be used to assess reactor safety and will help design efficient heat extractors to split water.

Collaboration – The University of Aberdeen is located near the North Sea oilfields and is located in the "Energy Capital of Europe." In 2009, Dr. Mark Holtzapple of Texas A&M University presented seminars on sustainability at the University of Aberdeen. Recognizing that both institutions graduate students who serve the energy industry, they have negotiated a collaborative agreement that involves both student exchanges and research collaboration.

Universidade Federal de Pernambuco (UFPE)

Role **–** Mixed-acid samples produced in the demonstration plant of Earth Energy Renewables will be sent to the Universidade Federal de Pernambuco where they will be chemically processed into esters, alcohols, olefins, and gasoline using the chemical steps described in Figure 1. In this project, the focus will be the optimization of the first two steps: esterification and hydrogenation using heterogeneous catalysts. Experiments will be performed initially with reagent-grade carboxylic acid as a model compound representative of the acid extract. After optimization, the reactions will be performed with the acid extracts provided by Earth Energy Renewables, our commercialization partner.

Background – Since 1990, the Universidade Federal de Pernambuco (UFPE) has been actively engaged in chemical engineering research related to the production of chemicals by hydrogenating sugars. Since 2004, UFPE has done research on biofuel production from the conversion of biomass residues, lignocellulose, and vegetable oil with support from Petrobras. Jose Pacheco (UFPE) and Rafael Holanda (TAMU) have researched the energy integration of crude oil refining.

Collaboration – In 2012, Texas A&M created an alliance with Brazilian universities that share common goals and serve similar student bodies.

Project Management

Texas A&M is the lead institution and will be responsible for all reporting and fiduciary requirements of the grant. Texas A&M has a well-developed management infrastructure that manages about $800 million in research annually. The three universities will be in constant contact via e-mail. On a monthly basis, conference calls will be held via Skype. On an annual basis, the researchers will meet at an international conference to present the results of their research and to discuss the project face-to-face.

As shown in Figure 1, the research responsibilities are clearly delineated by the steps each university is investigating. The break points were selected to manage the project in a rational manner. Texas A&M will focus on the biological steps, UFPE will focus on chemical transformation of the acids to create esters and alcohols (key intermediates to form gasoline), and the University of Aberdeen will focus on hydrogen production. Within each domain, faculty members will manage the activities of their students, which is a natural line of authority.

Program Activities

Texas A&M

The fermentations will be conducted in plastic centrifuge bottles that are incubated at 40^{o}C, a temperature that is known to favor the formation of medium-chain carboxylic acids. The fermentations will be conducted in a countercurrent train employing a series of fermentors, typically four per train. Biomass is added to Fermentor 1 (F1) and water is added to Fermentor 4 (F4). Every second day, the contents of each bottle are centrifuged. The excess liquid is passed from F4 to F3, and so on. Excess solids are passed from F1 to F2, and so on. A buffer (e.g., sodium bicarbonate) is added periodically to maintain near-neutral pH. The liquid exiting F4 has concentrated carboxylic acids and their salts.

The product will be recovered by contacting with ion exchange resins, which are convenient to use at the laboratory scale. We have already performed preliminary batch fermentations using ion exchange resins, which in some cases have proven to double product yields compared to no-resin batch fermentations. Further, ion exchange resins have proven to selectively remove medium-chain carboxylic acids, which allows the short-chain acids to recycle to the fermentor and elongate. In an industrial setting, the solid ion exchange resins will be replaced with liquid extractants that have similar abilities to selectively remove medium-chain carboxylic acids.

The ultimate objective of the research is to study operational parameters (e.g., solid feed rate, liquid feed rate, product concentration) on fermentation rates, yields, and product spectrums. These data are essential to perform economic evaluations.

University of Aberdeen

Thermal water splitting involves the use of chemicals that react with water at low temperature. When the chemicals are heated to high temperatures, hydrogen and oxygen evolve, thus regenerating the chemicals so they can be recycled and used again. The most famous example is the sodium-iodine cycle [4]; however, other cycles have been explored as well. For example, the University of Colorado has recently developed a process to use solar energy to thermally split water using ZnO. [5]

The focus of this study is to evaluate the water splitting literature to determine which technologies are most suitable for our application. A major goal is to determine if solar or nuclear energy is the best option. Further, to perform economic assessments, the cost of the hydrogen must be estimated so it can be compared to conventional technology (steam reforming of methane).

Universidade Federal de Pernambuco (UFPE)

UFPE has well-equipped laboratories that include Parr reactors and gas chromatographs. All the chemical processing steps shown in Figure 1 can be performed using existing equipment. Appropriate catalysts and operating conditions are selected for each reaction performed in the Parr reactors. Appropriate columns and operating conditions are selected to measure the product spectrum produced in the reaction.

The first series of experiments will be performed with reagent-grade carboxylic acid as a model compound. The second series of experiments will be performed with liter quantities of industrial-quality mixed acids provided by Earth Energy Renewables, our commercialization partner. The acids will be processed sequentially according to the steps shown in Figure 1. Each step requires separate optimization of operating conditions.

Program Evaluation

Texas A&M

The fermentations are evaluated based on the following criteria: yield (g acids produced/g dry biomass fed), conversion (g biomass digested/g dry biomass fed), selectivity (g acids produced/g biomass digested), product concentration (g/L), and product spectrum (wt % of each acid). The fermentor operating conditions – solid loading rate (g/(L·d), liquid residence time (d) – will be explored to determine their impact on the above criteria.

University of Aberdeen

The literature will be evaluated to select the most promising thermal water-splitting technologies. The following criteria will be used to evaluate the various options: required temperature (^{o}C), materials of construction, chemical make-up requirements, safety, operability, market readiness, and suitability for solar or nuclear heat source. Ultimately, the appropriate technology will be selected based on the cost of hydrogen ($/kg).

Universidade Federal de Pernambuco (UFPE)

The chemical conversions will be based on the following criteria: reaction rates (g product/(L reactor volume·day)), conversion (g reacted/g fed), yield (g product/g fed), and selectivity (g product/g reacted). The reactor operating conditions – temperature (^{o}C), pressure (kPa), and catalyst type – will be explored to determine their impact on the above criteria.

Measures of Sustainability

Expected Outcomes

The process described in Figure 1 is the latest embodiment of the MixAlco process and is different than previous versions. In earlier versions, we recovered short-chain carboxylic acids, which were converted to secondary alcohols (e.g., isopropanol). Via oligomerization, the alcohols were converted to gasoline using zeolite catalysts at fairly aggressive operating conditions that can coke the catalyst. The impact is loss of product and reactor downtime, both of which negatively impact process economics. Even so, our economic evaluations indicated that gasoline could be sold for about $2/gal. [3] The new embodiment shown in Figure 1 employs more gentle operation conditions, which should eliminate coking. Further, the use of primary alcohols results in significantly higher product yields.

A further benefit of the latest embodiment is that products are extracted from the fermentors, which allows for low product concentrations and thereby reduces product inhibition. The impact is that the fermentors should be able to operate with more throughput, which will lower costs.

Previous economic evaluations were performed using hydrogen produced from undigested biomass residues. This required gasification and gas clean-up, all of which were expensive causing the hydrogen to cost about $3/kg. Should thermal water splitting produce hydrogen at a lower cost, process economics will be improved further.

The combined impact of improved performance of the biological and chemical processing steps is to lower operating costs, which should reduce the required selling price of the gasoline product, potentially below $2/gal.

Expected Benefits to Research Capacity

Until now, the primary focus of MixAlco development has been in the United States; however, the technology can be applied globally. Gasoline is required everywhere and wastes are produced everywhere. This proposed project will allow US researchers to collaborate with international researchers and thereby help diffuse the technology around the world.

Great Britain is an example of a developed nation with high population density. The biomass wastes will primarily be municipal solid waste and sewage sludge. Brazil is an example of a developing nation that has a high population density in urban areas, but also has abundant agricultural waste such as sugarcane bagasse. Introducing MixAlco technology to researchers in these nations will allow for a more diverse and sustainable funding base, including both public and private funding.

Anticipated Knowledge Transfer

Since 1991, various versions of the MixAlco process have been explored and documented in the literature. The MixAlco process is not a static technology; rather, it evolves as knowledge improves. By directly involving researchers from other nations, it will "stir" the technology allowing for cross-fertilization of ideas.

Broader Institutional Collaboration

Once the benefits of the MixAlco technology are realized by direct collaboration with international researchers, it is anticipated that the relationships will continue. As new research solicitations are released in each country, the team that has already formed will be well-prepared to respond to the solicitations and hence perpetuate the relationships.

Conclusions

The MixAlco process can transform any biodegradable waste biomass into gasoline at a selling price of about $2/gallon, and therefore is an economical solution to both energy and waste problems. The proposed research project has the potential to lower processing costs. This collaborative effort involves researchers in North America, South America, and Europe, which will enhance technical exchanges and thereby enhance the rate of commercial implementation.

References

[1] http://www.worldometers.info/world-population/#growthrate

[2] http://data.worldbank.org/indicator/NY.GDP.PCAP.CD/countries?display=graph

[3] V. Pham, M. El-Halwagi, and M. Holtzapple, Techno-economic analysis of biomass to fuel conversion via the MixAlco process, *Journal of Industrial Microbiology and Biotechnology*, 37(11): 1157–1168 (2010).

[4] http://en.wikipedia.org/wiki/Sulfur%E2%80%93iodine_cycle

[5] http://www.nrel.gov/hydrogen/pdfs/development_solar-thermal_zno.pdf

Work Plan

	2015			2016				2017
Task	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
Texas A&M								
Batch Fermentation 1								
Fermentation Train 1								
Batch Fermentation 2								
Fermentation Train 2								
Batch Fermentation 3								
Fermentation Train 3								
Economic evaluation								
University of Aberdeen								
Literature search of thermal water splitting								
Comparison of competing technologies								
Initial assessment of energy requirement								
Economic evaluation of preferred technologies								
Universidade Federal de Pernambuco (UFPE)								
Esterification with reagent-grade acids								
Esterification with industrial-grade mixed acids								
Hydrogenation with reagent-grade esters								
Hydrogenation with industrial-grade mixed esters								
Economic evaluation								

Budget Narrative

Texas A&M University

The Texas A&M budget will be used to provide salary for one graduate. Laboratory costs include expendable supplies (e.g., gas cylinders, CG columns, rubber gloves, syringe needles, filters) and maintenance (e.g., pipette calibration). Funds are provided for one trip per year to an international conference. Faculty salary is cost shared.

University of Aberdeen

The University of Aberdeen budget will be used to provide salary for one graduate student, one undergraduate student (summer replacement), and modest faculty support. The students will support the research and perform numerical simulations. Funds are provided for one trip per year to an international conference. The majority of faculty salary is cost shared.

Universidade Federal de Pernambuco (UFPE)

The UFP budget will be used to provide salary for one graduate student. Laboratory costs include expendable supplies (e.g., gas cylinders, CG columns, rubber gloves, syringe needles, filters) and maintenance (e.g., pipette calibration). Funds are provided for one trip per year to an international conference. Faculty salary and some equipment costs are cost shared.

DIVISION OF RESEARCH
Office of the Vice President for Research

TEXAS A&M UNIVERSITY

October 31, 2014

Ms. Morgan Clark
Institute of International Education
809 United Nations Plaza, 7^{th} Floor
New York, NY 10017

Dear Ms. Clark:

On behalf of Texas A&M University (Texas A&M), I wish to express the institution's support for the proposal entitled, *Renewable Gasoline from Waste Biomass*, as submitted to the Institute of International Education Global Innovation Initiative by Dr. Mark T. Holtzapple. This proposal is a collaboration between Texas A&M University of the United States, the University of Aberdeen of Great Britain, and the Universidade Federal de Pernambuco of Brazil.

To convert waste biomass into industrial chemicals and fuels, the proposed project employs the MixAlco process, which has been developed at Texas A&M. The American university's effort will focus on fermenting waste biomass into carboxylic acids (e.g., acetic to octanoic acid) and their subsequent recovery. The downstream processing that converts the carboxylic acids to industrial chemicals and fuels will be performed by the collaborating universities.

Dr. Holtzapple's abilities and proven record as a researcher and an educator make him exceptionally qualified to lead this international initiative for our institution. It is anticipated that this project will benefit the partnering universities and their nations through economic development (jobs, inexpensive transportation fuels), security (less dependence on foreign oil), and environmental preservation (recycle wastes, reduce global warming).

Texas A&M University is a leader in education and research among the U.S. institutions. With a annual research expenditure exceeding $820M, it is also a leader among U.S. institutions as to research collaborations with international partners and sponsors. In Fiscal Year 2013, Texas A&M University performed research in the amount of $49.6 million dollars in collaboration with foreign sponsors (non-profits, industries, government and universities). Additionally, there are numerous teaching partnerships throughout the world in which Texas A&M University participates including a branch campus at Doha, Qatar.

Due to the importance of these collaborations, Texas A&M University and the Department of Chemical Engineering will contribute support to the partnership by providing 1.5 months per year of Dr. Holtzapple's salary and fringe costs. Additional support is provided by Earth Energy Renewables, which will provide liter quantities of industrial-quality mixed carboxylic acids for downstream processing.

As the Vice President for Research Texas A&M, I wholeheartedly support the goals and objectives of this initiative and Dr. Holtzapple in pursuit of this international partnership.

Sincerely,

Dr. Glen A. Laine
Vice President for Research

1112 TAMU
College Station, TX 77843-1112
Tel. 979.845.8585 Fax. 979.845.1855
http://vpr.tamu.edu

1495
UNIVERSITY OF ABERDEEN

School of Engineering
College of Physical Sciences
Fraser Noble Building
King's College
Aberdeen
AB24 3UE
Scotland
United Kingdom
Tel: +44 (0) 1224 272820
Fax: +44 (0) 1224 272497
www.eng.abdn.ac.uk

31 October 2014

To whom it may concern:

Re: Institute of International Education, Global Innovation Initiative

I am writing on behalf of the University of Aberdeen to outline our support for the proposal led by Professor Mark Holtzapple of Texas A&M University for the project titled 'Renewable Gasoline from Waste Biomass', to the Institute of International Education of the USA in the area of Energy, climate change and the environment. The University's participation in the project will be led by Dr Jefferson Gomes.

This project is very pertinent to the research direction of our University, the School of Engineering and in particular to the Energy Theme. The experience of our multidisciplinary teams across the University includes modelling, simulation and experiments towards better understanding of the underlying science and technology challenges in the energy sector. The proposed project has a potential to address key-challenges in the production of gasoline with near-zero net carbon emissions, and will gather world-class scientists from three key institutions on the fields of chemical engineering, energy technologies and computational physics.

As a demonstration of our commitment to the project, the University undertakes to provide 117 hours of Dr Gomes' time, which is equivalent to a contribution of USD 10.7k.

Please do not hesitate to contact me should you require any additional information.

Yours sincerely

Professor Igor Guz
Head of School of Engineering
University of Aberdeen

Departamento de Engenharia Química
Centro de Tecnologia e Geociências
UFPE

Letter of Commitment

The Universidade Federal de Pernambuco is committed to support and participate in the execution of the project "Renewable Gasoline from Waste Biomass", for the period from April 2015 to April 2017, to be submitted to the request for proposal from the Institute of International Educational of the United States of America in the area of Energy, climate change and the environment.

To that end, the Universidade Federal de Pernambuco will provide laboratory facilities of the Department of Chemical Engineering for the use of equipment for performing chemical reactions. Our University will provide cost share for staff and faculty time, laboratory facilities and use of equipment for catalyst characterization as described below.

Team member	Role of team member	Time dedicated
Jose Geraldo de Andrade Pacheco	Principal Investigator	6 hours/week
Celmy Maria Bezerra Menezes Barbosa	Researcher	4 hours/week
Cesar Moraes de Abreu	Researcher	2 hours/week
Jose Marcos Francisco Silva	Researcher	3 hours/week

Cost from salaries (two years): USD53,000.00 (R$ 126000.00)
Cost from equipment (two years): USD17,000.00 (R$ 40800.00)
Total cost: USD70,000.00 (R$ 166800.00)

Recife, Brazil, September 29 2014

Prof. Alexandre Ricardo P. Schuler
Diretor
Centro de Tecnologia e Geociências
Escola de engenharia de Pernambuco
UFPE

Alexandre Ricardo Pereira Schuler
Diretor do Centro de Tecnologia e Geociencias
Universidade Federal de Pernambuco

De acordo com a solicitação.
Em, 29/10/2014

Prof. Nelson Medeiros de Lima Filho
Chefe do Departamento
de Engenharia Quimica
SIAPE: 1283004

Earth Energy Renewables

6150 Mumford Rd. Bryan, TX 77807
979-778-0033

October 29, 2014

Dr. Mark Holtzapple
Department of Chemical Engineering
3122 TAMU
Texas A&M University
College Station, TX 77843-3122

Dear Dr. Holtzapple:

Earth Energy Renewables is pleased to support your proposed research project entitled *Renewable Gasoline from Waste Biomass*.

To allow you to conduct studies with realistic industrial-quality mixed acids, we will provide you with 3 liters of product from our pilot plant. As you are well aware, pilot-scale production is very expensive and includes not only the capital cost of the pilot plant, but also labor. The pilot plant is operated by PhD chemists and chemical engineers, all of whom command a high salary. Further, there are significant expenses associated with operating the pilot plant, such as chemical analysis, utilities, maintenance, overhead, and taxes. In our estimation, the cost of producing the mixed acids is $100,000 per liter; thus, our in-kind contribution to your research project is valued at $300,000.

In exchange for our contribution, we request the following:

- You provide us with periodic updates on progress
- You provide us with a copy of the final report

We are very excited by this project and look forward to the possibility of working with you.

Sincerely,
EE-Terrabon Biofuels LLC
dba Earth Energy Renewables

Jeffrey J. Wooley,
Manager

Mark T. Holtzapple

Artie McFerrin Department of Chemical Engineering, Texas A&M University

3122 TAMU, College Station, TX 77845

m-holtzapple@tamu.edu

http://research.che.tamu.edu/groups/holtzapple

979-845-9708

PROFESSIONAL PREPARATION

Institution	Major/Area	Degree	Date
Cornell University	Chemical Engineering	B.S.	1978
University of Pennsylvania	Chemical Engineering	Ph.D.	1981

APPOINTMENTS

1998–	Professor, Chemical Engineering, Texas A&M University
1991–1998	Associate Professor, Chemical Engineering, Texas A&M University
1986–1991	Assistant Professor, Chemical Engineering, Texas A&M University
1983–1985	Lecturer, Chemical Engineering, Tufts University

SELECTED PAPERS (134 TOTAL)

KW Golub, AK Forrest, ME Wales, AJM Hammett, JL Cope, HH Wilkinson, MT Holtzapple, Comparison of three screening methods to select mixed-microbial inoculum for mixed-acid fermentations, *Bioresource Technology*, 130: 739–749 (2013).

S Taco-Vasquez, MT Holtzapple, Biomass Conversion to Hydrocarbon Fuels Using the MixAlco™ Process, *Oil & Gas Science and Technology – Revue D IFP Energies Nouvelles*, 68(5): 861–873 (2013).

KW Golub, SR Golub, DM Meysing, MT Holtzapple, Propagated fixed-bed mixed-acid fermentation: Effect of volatile solid loading rate and agitation at near-neutral pH, *Bioresource Technology*, 124:146–156 (2012).

M. Falls, J. Shi, M.A. Ebrik, T. Redmond, B. Yang, C.E. Wyman, R. Garlock, V. Balan, B.E. Dale, V. R. Pallapolu, Y.Y. Lee, Y. Kim, N.S. Mosier, M.R. Ladisch, B. Hames, S. Thomas, B.S. Donohoe, T.B. Vinzant, R.T. Elander, R.E. Warner, R. Sierra-Ramirez, M.T. Holtzapple, Investigation of enzyme formulation on pretreated switchgrass, *Bioresource Technology*, 102(24): 11072–11079 (2011).

C.E. Wyman, V. Balan, B.E. Dale, R.T. Elander, M. Falls, B. Hames, M.T. Holtzapple, M.R. Ladisch, Y.Y. Lee, N. Mosier, V.R. Pallapolu, J. Shi, S.R. Thomas, R.E. Warner, Comparative data on effects of leading pretreatments and enzyme loadings and formulations on sugar yields from different switchgrass sources, *Bioresource Technology*, 102(24): 11052–11062 (2011).

Jefferson Luís Melo de Almeida Gomes

Contact Information

University of Aberdeen
School of Engineering
E-mail: jefferson.gomes@abdn.ac.uk
Fraser Noble Building, Aberdeen, UK AB24 3UE

Mobile: +44 (0)7877675780
Tel.: +44 (0)1224 272988

Research Interests

Computation multi-fluids dynamics, multi-physics modelling, industrial and environmental fluid flows, nuclear criticality, heat and mass transfer, thermodynamics, finite element methods and computational optimisation.

Education

PhD
Department of Earth Science and Engineering, Imperial College London (1999-2004)

MSc in Applied Mathematics
State University of Rio de Janeiro, Brazil (1997-1999)

BSc in Chemical Engineering
Federal University of Rio de Janeiro, Brazil (1991-1996)

Academic Appointments

University of Aberdeen
- **Lecturer in Engineering** — December 2012 – today

Imperial College London
- **Research Fellow** — May 2006 – November 2012
- **Scientific Consultant with ICON** — January 2002 – November 2012

Journal Editor

Associate Editor of the Brazilian Journal of Chemical Engineering since May 2011.

Measures of Esteem, Visibility and Professional Activities

- Keynote Speaker (November 2013) at the 'XVI Conference on Computational Modelling, Ilheus, Brazil.
- Invited Speaker (April 2009) at the 'Todai Forum 2009: Role of Nuclear Energy for Sustainable Development', London, UK.
- Invited Speaker (March, 2008) at the 'Asian Monsoon and Climate Change Workshop' Guangzhou, China.

Awards

- Imperial College Research Excellence Award (award to all AMCG's scientists, 2011);
- Institution of Nuclear Engineers Pinkerton Award for the article 'Safety and Performance of Innovative Reactors' published at the Journal of the British Nuclear Energy Society (award to all scientists involved in the KNOO/EPSRC programme, 2008);

Grants Recently Completed

MBase: Molecular Basis of Advanced Nuclear Fuel Separations — 2010-2013
- Title: Criticality and Fission in the Solution State (Co-I)
- ◇ Funded by EPSCR (£132k)

Thermohydraulics for Innovative Nuclear Systems (THINS) — 2010-2013
- Title: Development of Novel Discretisation Methods for Multiphase Flows (Co-I)
- ◇ Funded by EC-FP7 (€68k)

Gas-Fast Reactors (GoFastR) — 2010-2013
- Title: Modelling and Simulation of Core-Melting in PWR (Co-I)
- ◇ Funded by EC-FP7 (€125.5k)

Technology Proof of Concept — 2010-2012

- Title: Computational Framework for Multi-Scale Environmental Modelling (Co-I)
- ◇ Funded by NERC (£191k)

EPSRC Follow-on Fund 2010-2011

- Title: Realising the Commercial Potential of the Multi-Physics and Multi-Scale FETCH Technology for Nuclear Safety Applications (CoI)
- ◇ Funded by EPSRC (£106k)

Energy Grant 2006-2007

- Title: Numerical Investigation of Biomass Gasification (CoI)
- ◇ Funded by the Brazilian Research Council CNPq (∼ £45k)

Refereed Journal Publications (last 3 years)

Jackson, M.D., **Gomes, J.L.M.A.**, Mostaghimi, P., Percival, J., Tollit, B., Pavlidis, D., Pain, C.C., El-Sheikh, A.H., Muggeridge, A.H., Blunt, M.J. Reservoir Modeling for Flow Simulation Using Surfaces, Adaptive Unstructured Meshes, and Control-Volume-Finite-Element Methods. *2013 SPE Reservoir Simulation Symposium*, 2013. doi:http://dx.doi.org/10.2118/163633-MS

Buchan, A., Pain, C. C., Tollit, B.S., **Gomes, J.L.M.A.**, Eaton, M. D., Gorman, G.J., Cooling, C.M., Goddard, A.J.H., Nygaard, E.T., Angelo, P.L., Smith, P.N. Spatially Dependent Transient Kinetics Analysis of the Oak-Ridge Y12 Plant Criticality. *Progress in Nuclear Energy*. 63:12-21. 2013.
doi:10.1016/j.pnucene.2012.09.006

ElSheikh, A.H., Pain, C.C, Fang, F., **Gomes, J.L.M.A.**, Navon, I.M. Parameter Estimation of Subsurface Flow Models using Iterative Regularized Ensemble Kalman Filter. *Stochastic Environmental Research and Risk Assessment*. 27:877-897. 2013.
doi:10.1007/s00477-012-0613-x

Ferrat, M., Langmann, B., Cuia, X., **Gomes, J.L.M.A.**, Weiss, D. Numerical Simulations of Dust Fluxes to the Eastern Qinghai-Tibetan Plateau: Comparison of Model Results with a Holocene Peat Record of Dust Deposition. *Journal of Geophysical Research – Atmospheres*. 2013.. doi:http://dx.doi.org/10.1002/jgrd.50275

Buchan, A., Pain, C.C., **Gomes, J.L.M.A.**, Eaton, M.D., Gorman, G.J., Cooling, C., Goddard, A.J.H., Nygaard, E.T., Glenn, D.E. Simulated transient dynamics and heat transfer characteristics of the water-boiler nuclear reactor – SUPO, with cooling coil heat extraction. *Annals of Nuclear Energy*. 48:68-83. 2012.
doi:10.1016/j.anucene.2012.03.027

Gomes, J.L.M.A., Pain, C.C., Eaton, M.D., Tollit, B., Goddard, A.J.H., Piggott, M.D., Ziver, K. and Yamane, Y. Coupled neutronics-fluids modelling of criticality within a MOX powder system. *Progress in Nuclear Energy*. 53(5):523-552. 2011.
doi:10.1016/j.pnucene.2011.01.011

García, X., Pavlidis, D., Gorman, G.J., **Gomes, J.L.M.A.**, Piggott, M.D., Aristodemou, E., Mindel, J., Latham, J.P., Pain, C.C. and ApSimon, H. A two-phase adaptive finite element method for solid-fluid coupling in complex geometries. *International Journal for Numerical Methods in Fluids*. 66(1):82-96. 2011.
doi:10.1002/fld.2249

Book Chapters

Gomes, J.L.M.A., Tollit, B., Miles, B. and Pain, C.C. Multi-Physics Flow Modelling for Nuclear Applications. In: *Fluidization Engineering Practice*. ISBN: 978-0-9919117-0-7. 2012.

Gomes, J.L.M.A. and Henderson, N. Vapour-Liquid Equilibria in Polymer Solutions – A Non-Linear Optimisation Problem (*in Portuguese*). In: *Computational Modelling in Material Science*, Moura-Neto, F., Platt, G., Bastos, I. (Eds.), Ciência Moderna. 2010.

JOSE GERALDO DE ANDRADE PACHECO

Current Position: Associate professor (Since 2005)
Universidade Federal de Pernambuco
Department of Chemical Engineering
Av. Artur de Sa SN, Cidade Universitaria. 50570521, Recife, PE, Brazil.
Tel.: 55-81-21268997; Cell Ph# 55-81-87069329
jose.pacheco@ufpe.br and geraldo.ufpe@gmail.com
Detailed Curriculum Vitae at: www.lattes.cnpq.br/6315186407922891

Academic
Chemical Engineering at Universidade Federal de Pernambuco
Safety Engineer at Universidade Federal da Bahia, 1997.
Doctor Science at COPPE/ Universidade Federal do Rio de Janeiro, 1995.

Experience

- Petrobras/Transpetro, Safety, Health and Environment Consultant, Mar. 2012 – Dec. 2013. Improving health, safety and the environment in the laboratory analysis of fuels in transportation fuels terminals.

- Universidade Federal da Bahia, Professor, Oct. 1992 – Oct. 1994. Professor of Transport Phenomena and Thermodynaics.

- Braskem/Copene Petrochemistry at Camaçari, BA, R&D Engineer, Feb. 1897 - Apr. 1992. Design and operation of pilot unit for catalytic hydrogenation processes of pyrolysis gasoline. Evaluation of industrial zeolite catalysts for disproportionation of toluene and xylene isomerization. Economic assessment of alternative processes for the production of olefins from natural gas.

Technological Research Projetcs on Cleaner Technologies in Industry (concluded)

- Water and Wastewater Minimization in Braskem, (Basic Petrochemicals Unit, UNIB). Mar. 2002 - Dec. 2004. Finantial support: FINEP and Braskem. Survey of effluents and consumers of water at UNIB and propose process modifications aiming the minimization of water and wastewater.

- Mass and Energy Integration Network in a Linear Polyethylene Plant at Braskem/Politeno. Oct. 2002 - Mar. 2004. Finantial support: Politeno Co. Conceptual design for retrofitting the linear polyethylene plant aiming the energy integration with minimizing the consumption of utilities.

Research Projetcs on Catalytic Process (concluded)

- Oxidative Desulfurization of Model Diesel Using Hydrogen Peroxyde and Heterogeneous Catalysts. Jul. 2003 – Jun. 2005. Finantial support: FINEP and Petrobras/Cenpes.

- Degradation of Polymer Residues to Produce Olefins and Gasoline. Mar. 2004 – Mar. 2006. Finantial support: FAPESB, BA. The objective is to study the degradation of post-consumer polymers in the presence of zeolites and mesoporous catalysts.

- Continuous Reactor for Biodiesel Production with Real Time Monitoring the Yield. Jul. 2007 - Jun. 2011. Finantial support: FINEP. Development of a continuous reactor for esterification of fatty acids from high acidic feedstocks with real time monitoring the yield by infrared specrtoscopy analysis.

- Catalytic Pyrolysis of Biomass Residues. Aug. 2009 - Jul. 2014. Finantial support: Petrobras/Cenpes. The objective of this project is to study micro scale catalytic fast pyrolysis of sugarcane bagasse and straw and its fractions cellulose, hemicellulose and lignin.

- Effluent Treatment via Oxidation Processes for Water Reuse in Industry. INCT- EMA - USP. Oct. 2014 – Sep. 2014. Finantial support: CNPq. The objective is to apply the techniques of advanced oxidation processes for treatment of industrial effluents from petrochemical, textile and pharmaceutical sector, aiming at water reuse.

Current Research Projetcs on Catalytic Process

- Obtaining terephthalate bis (hydroxy-ethylene) monomer (BHET) from the chemical recycling of poly (ethylene terephthalate) (PET). Dec. 2013 – Dec. 2016. Finantial support: Petrobras/Cenpes. The objective is to develop heterogeneous catalysts for chemical recycling of post-consumer PET plastics to obtain the monomer BHET.

Recent publications

Souza TPC, Stragevitch L, Knoechelmann A, Pacheco JGA, Silva JMF. Simulation and preliminary economic assessment of a biodiesel plant and comparison with reactive distillation. Fuel Process Technol. 2014 ; 123 : 75-81.

Frety, R.; Santos, M.R.; Padilha, J.F.; Azevedo, A.F.; Brandao, S.T.; Pontes, L.A.; Pacheco, J.G.A. Flash pyrolysis of model compounds adsorbed on catalyst surface: Amethod for screening catalysts for cracking of fatty molecules. J. Anal. Appl. Pyrolysis, 109 (2014) 56-64.

Costa, M. J. F.; Chellappa, T.; Araujo, A. S.; Fonseca, V. M.; Fernandes Jr, V. J.; Nascimento, R. M.; Pacheco, J. G. A. Characterization and Acidic Properties of AlMCM-41 Prepared by Conventional and Post-Synthesis Alumination. Aust J Chem. 2014. Accepted for publication.

Holanda, R.W.; Oliveira, P.E; Dias ,F.F.; Arcanjo ,A.P.C.; Pessoa, F.P.; Pacheco, J. G.A. Energy integration in unit desalting and atmospheric distillation refining of heavy oil. Petro & Química 356 (2014) 60-63.

Dantas, D.C.P.; Napoleão, D.C.; Pacheco, J.G.A.; Barbosa, C.M.B.M.; Benachour, M.; Silva, V.L. Kinetic Modeling of the Hydrogenation of Soybean Oil Aiming Biofuel Production. Scientia Plena, 10 (3), (2014) 034202-1 - 8. Available online at www.scientiaplena.org.br/sp/article/view/1707/946

Silva, K.S.; Zaidan, L.E.M.C.; Napoleão, D.C.; Dias, F.F.S.; Brandão, Y.B.; Pacheco, J.G.A.; Barbosa, C.M.B.M.; Benachour, M.; Silva, V.L. Analysis of the Degradation and Mineralization of Phenol Via Advanced Oxidative Process for Reuse of Wastewater in Petroleum Industry. Scientia Plena, 10 (7), (2014) 074201-1 - 9. Available online at www.scientiaplena.org.br/sp/article/view/1843

Dias, F. F. S.; Lira, R. J.; Chiavone-Filho, O.; Carvalho, F. O. Pacheco, J. G. A. Degradation of Reactive Black 5 dye by photo-Fenton process in a PTC reactor with modeling and optimization using ANN. Scientia Plena, 9 (10), (2013) 104201-1 - 12. Available online at www.scientiaplena.org.br/ojs/index.php/sp/article/viewFile/1286/896

Baydum, V.P.A.; Dantas, R.F.; Teixeira, A.; Pacheco, J.G.A.; Silva, V.L. Pre-treatment of Propranolol Effluent by Advanced Oxidation Processes. Afinidad, 69 (2012) 559.

Costa, M. J. F.; Araujo, A. S.; Silva, E. F. B.; Farias, M. F.; Fernandes Jr., V. J.; Santa-Cruz, P. A.; Pacheco, J. G. A. J. G. A. Model-free kinetics applied for the removal of CTMA+ and TPA+ of the nanostructured hybrid AlMCM-41/ZSM-5 material. J Therm Anal Calorim 106 (2011) 767–771.