The Biorefiner

Annual Magazine

2017

IBEST´s Growing Outreach

Editorial letter

Amazonic biorefinery experience

A glance at a leading 2nd generation biorefinery

Welcome from the RSC ♦ UK-India Workshop on Energy ♦ IBEST @ Malaysia ♦ IBEST @ Mexico ♦ Publication insights! ♦ Research showcase ♦ New Biorefiner

Advancing cross-disciplinary knowledge and education in Biorefinery Engineering

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The **IBEST** is the Institution of Biorefinery Engineers, Scientists and Technologists, a network of biorefinery researchers and practitioners for advancing cross-disciplinary knowledge and education in Biorefinery Engineering.

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Anaerobic digestion equipment demonstration at the 1st International Forum.

Editorial letter

IBEST´s Growing Outreach

After its foundation 2 years ago, the growth of the IBEST has been sustained, adding new individual (100+ total) and organisational (80+ total) members. This is thanks to the engagement through the various events carried out and to the research projects which have strengthen the links among Biorefiners. And now, is expanding even more with the forthcoming UK-India Workshop at the Indian Institute of Petroleum on October (page 7). In fact, many of the research showcases in this issue come from the participants who will be presenting at this workshop dedicated to Energy for Economic Development and Welfare. We are grateful for the continuous support from the Newton Fund through the Researcher Links programme and the partner funding organisations in Mexico, Malaysia and India. The Royal Society of Chemistry is also supporting the workshop in India. We would also like to thank the Royal Academy of Engineering for their support for Newton Collaborative project "Economic Value Generation and Social Welfare in Mexico by Waste Biorefining" concluded this year. Sections reporting the outcomes of this project and from the Malaysia workshop are included. The new section on Publication Insights! is where members can introduce their recent journal or book chapter publications.

The 1st International Forum on Bioenergy, Biorefinery and Bioeconomy took place at University of Surrey in March this year. It is noteworthy to see an increased engagement of the industrial members who participated in this Forum and others will present in the UK-India workshop and have become members of the IBEST. Some of them are featured in the New Biorefiner section and we also extend a warm welcome to all our new members. The Biorefiner editors have also participated in other events such as the EUBCE, AIChE meeting, and other workshops in Kazakhstan and Brazil. The visit to one of the most advanced biorefineries located in Brazil is featured in this issue. The report is a reminder that the dream of a Biorefiner to see a biorefinery concept becoming a reality is possible; with the right policies, scientific research and engagement with all stakeholders, and, of course, the right context and country.

Sincerely yours,

The editors

ROYAL SOCIETY OF CHEMISTRY

Welcome from the Royal Society of Chemistry

The Royal Society of Chemistry is proud to be a partner in this British Council Newton Fund Researcher Links Workshop.

The aims of the British Council Researcher Links programme strongly align with our international strategy. Working with partners around the world to ensure a flourishing future for global chemistry is central in our mission to advance excellence in the chemical sciences.

Through our operational alliance with the British Council, we are very proud to be one of the organisations involved in co-funding the Newton Fund Researcher Links programme.

In 2016 we supported six workshops in India, on topics such as antimicrobial resistance, biomaterials for water purification, catalysis for sustainability, and nanomaterials for energy and air pollution. In 2017 we are supporting nine.

The Royal Society of Chemistry is the world's leading chemistry community, advancing excellence in the chemical sciences. With over 54,000 members and a knowledge business that spans the globe, we are the UK's professional body for chemical scientists, supporting and representing our members and bringing together chemical scientists from all over the world.

Tackling the Emergence of Antimicrobial Resistance: Increasing Awareness and Facilitating Research Networks, Chandigarh, November 2016

Urban Air Pollution in Indian and UK Cities: Characterization and Prediction of Chemically Reactive Air Pollutants, Delhi, December 2016

A not-for-profit organisation with a heritage that spans 175 years, we have an ambitious vision for the future. We invest in educating future generations of scientists. We raise and maintain standards. We partner with industry and academia, promoting collaboration and innovation. We advise government on policy. And we promote the talent, information and ideas that lead to great advances in science.

We are tremendously proud of our association with Indian science. Many Indian scientists sit on our journal editorial and advisory boards, and India is the second highest contributor to our journals.

We have an active member community, strong relationships with academia, government and industry, and staff members in our Bangalore office committed to supporting our many activities here.

Please do contact us if you would like to learn more about the many ways in which you can benefit from membership of the Royal Society of Chemistry, including international funding opportunities.

In a complex and changing world, chemistry and the chemical sciences are essential. They are vital in our everyday lives and will be vital in helping the world respond to some of its biggest challenges.

We wish you a successful and enjoyable workshop, and hope that it will lead to new friendships, opportunities and collaborations.

India, UK researchers join hands over Nano materials

TRIBUNE NEWS SERVICE

MANDI, OCTOBER 4

To explore the benefits of advanced Nano materials for energy, health and sustainability, scientists of India and the UK have come together to exchange their views.

It is for the first time that 17 researchers of the UK rom top universities have isited IIT-Mandi to partic- pate in four-day workshop ver Nano-materials search work, which gan yesterday and will ntinue till October 6.

alking to reporters her ay, acting director of IIT BD Chaudhari "The institute is ing over advanced nology of Nano mate- o make its maximum use for the growth of people in our society."

The workshop is an effort between IIT Mandi and the University of Nottingham, the UK.

The workshop will focus on chemical science works in the field of health, e ronment, sustainab and energy. It will pro a unique opportunit sharing research expe and networking bet Indian and researchers.

Professors from UK address the media during a workshop at IIT Kamand in Mandi on Tuesday. PHOTO: JAI KUMAR

Advanced Nanomaterials for Energy, Health and Sustainability, Mandi, October 2016

UK-India Workshop on Energy

Under the Researcher Links scheme offered within the Newton Fund, British Council and Royal Society of Chemistry provides opportunities for early career researchers from the UK and internationally to interact, learn from each other and explore opportunities for building long-lasting research collaborations.

Workshop Title: Energy for Economic Development and Welfare: Promoting International Collaboration, Innovation and Sustainability

UK Coordinator: Dr Jhuma Sadhukhan

India Coordinator: Dr Thallada Bhaskar

Discipline: Engineering, Chemistry and Science (Energy focus)

Dates & Venue: 23-27 October, 2017, Indian Institute of Petroleum (IIP), Dehradun, India

The workshop will provide a unique opportunity for sharing research expertise and networking. During the workshops early career researchers will have the opportunity to present their research in the form of a poster/short oral presentation and discuss this with established researchers from the UK and partner countries. There will be a focus on building up links for future collaborations and participants selected on the basis of their research potential and ability to build longer term links.

Summary of the workshop:

India is one of the fastest growing economies in the world albeit amongst the lowest per capital energy consuming nations in the world. Indigenous energy production and security by integrated solutions are the needs of the hour. The aim of this workshop is finding sustainable solutions and systems by bringing together bright minds and stakeholders from our two nations. An objective is to identify and evaluate the highest efficiency integrated cradle-to-grave solutions of energy systems closing the gap between local availability and demand profiles and communicate findings to policy and decision makers. An objective also includes research and design of approaches for resource recovery strategies for decentralised renewable clean energy systems. Effective utilisation of locally available non-fossil resources, solar, wind, biomass, hydro and geothermal is a key strategy for fulfilling local demands and for cleanest and sustainable processing. The event will provide opportunities for the exchange of ideas and expertise between disciplines, industrial, academic and government bodies and private and public sectors from both nations. Outputs from the workshop include evaluations of technologies in the context of whole systems and their correlations to socio-economic growth, e.g. the target set by The Energy and Resources Institute, India, by 8% in the next decade. These will be disseminated to government bodies, policy makers, industries and institutions. A Journal Special Issues (SI), e.g. on Sustainable energy resources and systems in Bioresource Technology of Elsevier, will be dedicated for publication of selected papers from the workshop.

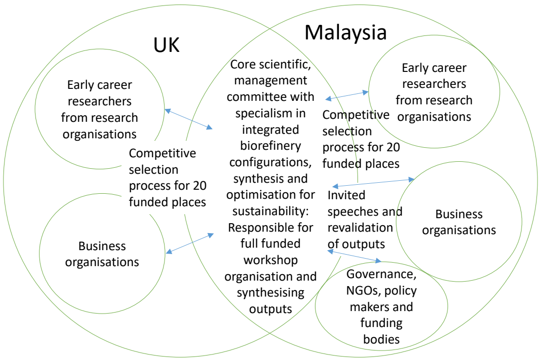
IBEST @ Malaysia

Since its creation in May 2015 supported by the Newton funding scheme and UK Research Councils, the Institution of Biorefinery Engineers, Scientists and Technologists (IBEST), a world-wide network of professionals, has grown considerably to include over one hundred member organisations. We do support biorefinery research activities that have an important role in extreme poverty elimination, socio-economic welfare generation and fostering living with dignity.

A Strategic Pathway for Sustainable Biorefinery Development in Malaysia

Followed from the UK-Malaysia British Council & Akademi of Sains supported Researcher Links Workshop, “Bioenergy, Biorefinery and Bioeconomy: Promoting Innovation, Multidisciplinary Collaboration and Sustainability”, Kuala Lumpur, 30 May – 3 June, 2016. <http://www.theibest.org/malaysia-workshop-material>

A publication has been made: Sadhukhan, J., Martinez-Hernandez, E., Murphy, R.J., Ng, D.K.S., Hassim, M.H., Ng, K.S., Kin, W.Y., Jaye, I.F.M., Hang, M.Y.L.P. and Andiappan, V., 2017. Role of bioenergy, biorefinery and bioeconomy in sustainable development: Strategic pathways for Malaysia. *Renewable and Sustainable Energy Reviews*. In press.



Framework for stakeholders’ engagement for output synthesis via a Newton funded UK-Malaysia Researcher Links workshop.

The research focus was to scope out a whole range of bioenergy and biorefinery technologies and systems relevant for Malaysia and developing countries, as follows, in creating a bio-based circular economy and their roles in meeting Sustainable Development Goals.

Mature	Developed	Developing
• Bioenergy • Fermentation-Bioethanol • Transesterification-Biodiesel • Anaerobic digestion- Biogas	• Pyrolysis- Bio-oil • Gasification-Syngas • Hydrothermal liquefaction- Fuel • Algae- Biofuel	• Catalytic (hydro)processing-Chemical and Fuel • CO_2 reduction or reuse- Fuel and Chemical • Resource recovery from waste-Functional products

Researchers

Sadhukhan J.[1], Martinez-Hernandez E.[2], Murphy R.J.[1], Ng D.K.S.[3], Hassim M.H.[4], Ng K.S.[1], Kin W.Y.[5], Jaye I.F.M.[1], Hang M.Y.L.P.[1] and Andiappan V[6].
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Lignocellulosic biorefinery development across the technology readiness level (TRL). Indigenous industries tend to target products of low-risk and high demand, such as bioenergy, which primarily rely on regulatory incentives, while economic proposition is to produce chemical and material, with niche market, still serving substantial human needs, in conjunction with bioenergy and biofuel generation, replacing petrochemicals and petroleum. It is envisaged that bio-based products, food and pharmaceutical ingredients, fine, specialty and platform chemicals, polymers, alongside biofuel and bioenergy can be produced from alternative waste resources for overall sustainability and closing the loop.

Better functional or quality and greener product, faster marketability, and least production cost are the key to success of the businesses.

Research Showcase

The optimum energy system designed under Malaysian techno-economic and policy scenario generates 472 kW of net electricity from sago barks (10.2 odt/d) (odt: oven dry tonne) from sago starch extraction process (SSEP) with the starch production capacity of 12 t/d. The payback period is 3.5 years. 8.5 tonne CO_2 equivalent/d can be decreased.
In an integrated sago-based bioethanol plant (SBP) in Malaysia, a total of 4.75 t/d of bioethanol and 35.3 kW of net electricity can be produced from 20.8 tonnes (wet basis) or 10.2 tonnes (dry basis) of sago barks, and 16.9 tonnes (wet basis) or 6.5 tonnes (dry basis) of sago fibres, generated from the SSEP operating at a starch production capacity of 12 t/d. The process is associated with a saving of 16.32 tonne CO_2 equivalent/d. The payback period of the integrated SBP with on-site enzyme production and using available labor from SSEP is estimated to be 6.6 years.
Novozymes© have their own enzymatic cocktail to make biodiesel from oils, in Malaysia. Their enzymatic, yeast and nutrition recipe enables palm kernel cake (PKC) (e.g. 1000 kg) conversion into palm kernel oil (PKO) (35 kg), bioethanol (237 kg) and palm kernel protein (PKP) (555 kg), respectively.
Roundtable of Sustainable Palm Oil (RSPO) for certifying sustainable palm oil production and use. RSPO enabled more than 13 million tonnes of RSPO Certified Sustainable Palm Oil produced from more than 3 million hectares production area around the world. This figure translates to 20% of the global crude palm oil (CPO) production certification to date. The palm oil industry in Malaysia today grows oil palm plantation in brownfields and low carbon stock areas and free from claims by other stakeholders. The sustainable palm oil producers operate within the boundary of the law, particularly with regard to land ownership, labor rights and environmental conservation.
1 tonne of CPO production is associated with 9 tonne of biomass production, if all of which is used for energy production, e.g. via biogas in anaerobic digestion (AD) they can fulfil 80% of energy need of Malaysia. It has been shown that a high grade biogas (>96% methane by volume) can save 0.0793 kg CO_2 equivalent / MJ if injected to natural gas grid or 0.12 kg CO_2 equivalent / MJ if utilized in energy generation by the replacement of natural gas. AD co-produces bio-fertilizer, which gives a saving of 0.44-0.77 kg CO_2 equivalent / kg bio-fertilizer replacing fossil derived fertilizer in agricultural application.
Three main policies are relevant for bioenergy, biorefinery and bioeconomy development in Malaysia: Renewable Energy Policy & Act; National Biotechnology Policy; and Green Technology Policy.
The Feed-in-Tariff (FiT) scheme gives leverage on biomass-derived / renewable electricity price applicable to biogas to electricity and biomass to electricity generation schemes. The FiT rates in RM-Sen/kWh valid for following 16 years after operation, are dependent on installed capacity, up to 4 MW, 4-10 MW, 10-30 MW; and gas engine performance: e.g. above 40% efficiency, locally manufactured or assembled gas engine technology, additional FiT for landfill or sewage gas usage. Main renewable energy sources identified are biomass: CPO biomass, wood / forestry / sawmill, MSW, rice husk and straws and sugarcane bagasse and molasses; hydro-power, and solar thermal and photovoltaic.
However, policy incentives will not mitigate environmental emissions and impacts. Landfill taxes and waste disposal costs are needed for a serious effort in stopping environmental emissions.
Despite the sharp economic development in Malaysia, solid waste management is relatively poor. It is projected that municipal solid waste (MSW) production can reach 30,000 tonnes by 2020. MSW constitutes of domestic (49%), industrial (24%), commercial (16%), construction (9%) and miscellaneous (2%) by mass, respectively. Malaysia generated 5.5 MW

Results of a forward looking biorefinery system

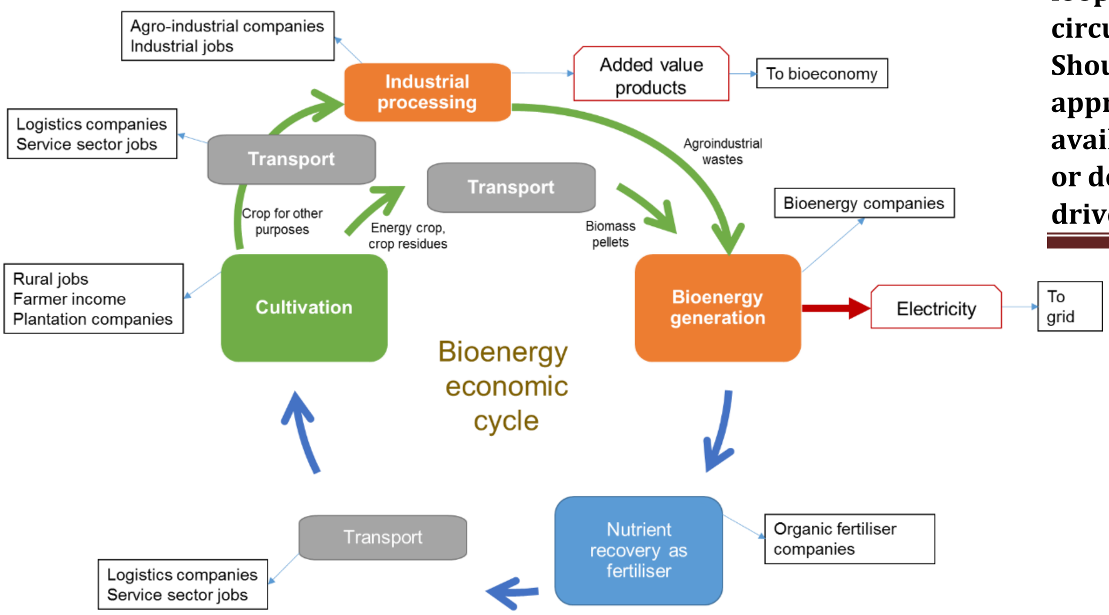
Wood, garden and food wastes are the primary source of organics. The mixed stream can be treated by steam explosion or supercritical hot water extraction, called pulping process that separates the curbside-type recyclables from the lignocellulosic fraction of MSW. The lignocellulosic fraction of MSW goes through a primary wash for ash removal and cellular disruption for yield maximization combined with a sterilization stage – fractionation of this lignocellulosic stream of MSW is then carried out by the controlled acid hydrolysis process for eventually producing levulinic acid via chemical conversion. The integrated biorefinery has char separation, levulinic acid extraction/purification by methyl isobutyl ketone solvent, acid / solvent and by-product recovery. The by-product and pulping effluents can be anaerobically digested into biogas and bio-fertilizer. Produced biogas and char can be combusted, heat recovered into steam generation in boiler; on-site heat/steam demand is met; balance of steam is expanded into electricity in steam turbines. A yield of Levulinic acid by only 5 weight% of recycle free MSW gives 1.5 fold increase in profitability from the incineration case.

of electricity from MSW in August 2009 and it is expected that, with the policies adopted by the Government, the total installations will rise to 360 MW by 2022. However, source segregation strategies have to be enforced to ensure that the non-combustible constituents exist in various streams of MSW, post-combustion, do not end up as emissions to the environment. Source segregation is necessary for clean technology and processing for remedying environmental pollution, albeit at a higher capital investment, which needs process integration that can unlock the value of organic waste via added value products and a total site utility system optimisation.

Microbial oxidation of organic wastes, wastewaters, lignocellulosic hydrolysates and organic streams from industrial systems as anode substrates using biotic anode harvests electron, releases proton and produces hydrogen, carbon dioxide, pyruvate, formate and fatty acids, as species, which can be subjected to reduction reaction in cathode for chemical, bioplastic and biofuel productions. In the cathode chamber, carbon dioxide in the form of carbonic acid is reduced into products. The cathode can be biotic or abiotic. The process is versatile in terms of the ability to process mixed stillage streams, containing metals, organics, inorganics, e.g. wastewaters from metal and mineral industries and hydrolysate streams from dilute acid / alkali hydrolysis or pretreatment of lignocellulose, into the recovery of metals, bioplastics, biofuel and biochemical. Homoacetogenesis by *Clostridium thermoaceticum* converting hydrogen and carbon dioxide into acetate; succinate formation from glycerol by *Actinobacillus succinogenes*; reverse β oxidation for chain elongation of ethanol and acetate to *n*-butyrate; and ethanol and *n*-butyrate to *n*-caproate by *Clostridium kluyveri* are proven cathode carboxylation reactions.

In Malaysia, 15 kilo tonnes of food are wasted daily including a fifth still fit for consumption. This amount is enough to feed 7.5 million people daily. Foods, especially meat and dairy products have the highest carbon footprint. Food waste must be avoided, from environmental and ethical considerations. Strategies for sustainable lifestyle by adopting to "Sustainable Development Goal (SDG) 12: sustainable consumption and production" must feature in the National Plan.

"How to close the loop and achieve a circular economy? Should the approach be availability-driven or demand-driven?"



Biorefinery value chain.

A key proposition here is to decouple demand from waste generation *via* circular economy principle of transforming what would otherwise have been 'waste' into resources for reuse/redeployment. Sustainable lifestyle must embark upon elimination of wastage in particular consumable food waste and embrace SDGs, in particular, SDG3: good health & wellbeing.

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UK-Mexico Biorefinery Workshop
18-22 May 2015, Mexico City
Instituto Mexicano del Petróleo

IBEST @ Mexico

Followed from the UK-Mexico Workshop supported by the Council of Science and Technology of Mexico and the British Council's Researchers Links programme, a Royal Academy of Engineering funded Newton Research Collaboration Programme "Economic Value Generation and Social Welfare in Mexico by Waste Biorefining" was successfully delivered in March, 2017.

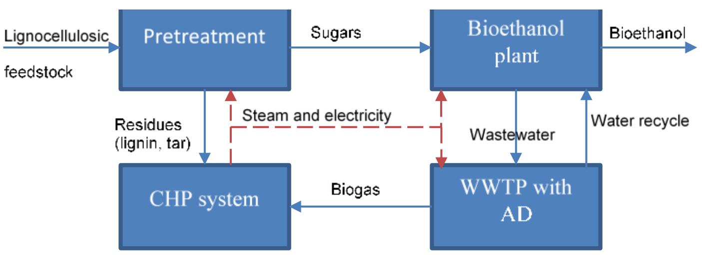
Biomass and Biorefinery Analyses in Mexico

The objectives of i) analysing agricultural and forestry biomass in Mexico for energy and biofuel/chemical products; ii) investigating supercritical upgrading technology and iii) development of integrated fermentation based biorefinery systems utilising biomass available in Mexico; iv) techno-economic and environmental footprint analyses and v) evaluation of synthesis and retrofit design options have been successfully completed by research exchange visits between Mexico and UK.

Biomass physical attributes that determine bioenergy and biorefinery feasibility in Mexico have been determined. The spatial distributions of available agricultural and forestry biomass in Mexico have been created using geographic information system for 2457 Mexican municipalities and 31 states. Assessed biomass has a potential of contributing 6.85% of the total energy production in Mexico. This is an enhancement from identified prospect of bioenergy by 4.14% by the SENER.

Wet analysis including compositions of constituents of hemicellulose, cellulose, lignin, ash and moisture has been collated for 19 forestry and 13 agricultural lignocelluloses in Mexico and used as input variables to the models for techno-economic and carbon footprint analyses of their conversions into the products. Lignocelluloses included in the analyses, pinus and wood species, agave, sugarcane and apple bagasse, rice and barley husks, wheat straw, grass species, coffee pulp, corn stover and sweet sorghum stalks, are selected on the basis of yields, accessibility, land availability and ease of collection.

Currently there is no large-scale biofuel production in Mexico but there are several bioethanol industrial projects using first generation biomass such as sugarcane, and sorghum. In April 2015, PEMEX signed contracts with four companies to supply anhydrous ethanol for blending with gasoline at 5.8 % vol. in the states of Veracruz, Tamaulipas and San Luis Potosí. Despite the focus on first generation feedstock for bioethanol production, there is a huge potential of lignocellulosic residues as feedstock to bioethanol production, in Mexico. It has been estimated that 75.73 million tonnes of residues dry matter are generated from 20 crops, with 79.4% coming from crop residues (corn, sorghum and wheat straws, sugarcane tops/leaves) and the rest from agroindustrial residues (sugarcane bagasse, corncobs, maguey bagasse and coffee pulp), with potential for electricity and bioethanol production. Bioethanol production from lignocellulose is needed for sustainability and to add value to residues that currently cause pollution as they are burned on field or dumped in open lands. However, their feasibility in commercial establishment needs to be holistically evaluated for sustainability.



Conceptual integrated lignocellulosic biorefinery scheme producing bioethanol.

Contact Us

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Publication insights!

The University of Surrey and Mexican Institute of Petroleum would like to report recent publications on MSW valorisation that will be of interest to IBEST members (see Figures 1 and 2 and Table 1). The second paper listed is more on sustainable pathways for Malaysia, written with the various partners in Malaysia. The last section reports submitted manuscripts co-authored by researchers from Surrey and IMP.

1. http://www.sciencedirect.com/science/article/pii/S0960852417309823

Sadhukhan, J. and Martinez-Hernandez, E., 2017. Material Flow and Sustainability Analyses of Biorefining of Municipal Solid Waste. *Bioresource Technology*. 243, 135-146.

"This paper presents material flow and sustainability analyses of novel mechanical biological chemical treatment system for complete valorization of municipal solid waste (MSW). It integrates material recovery facility (MRF); pulping, chemical conversion; effluent treatment plant (ETP), anaerobic digestion (AD); and combined heat and power (CHP) systems producing end products: recyclables (24.9% by mass of MSW), metals (2.7%), fibre (1.5%); levulinic acid (7.4%); recyclable water (14.7%), fertiliser (8.3%); and electricity (0.126 MWh/t MSW), respectively. Refuse derived fuel (RDF) and non-recyclable other waste, char and biogas from MRF, chemical conversion and AD systems, respectively, are energy recovered in the CHP system. Levulinic acid gives profitability independent of subsidies; MSW priced at 50 Euro/t gives a margin of 204 Euro/t. Global warming potential savings are 2.4 and 1.3 kg CO_2 equivalent per kg of levulinic acid and fertiliser, and 0.17 kg CO_2 equivalent per MJ of grid electricity offset, respectively."

2. http://www.sciencedirect.com/science/article/pii/S1364032117309450

Sadhukhan, J., Martinez-Hernandez, E., Murphy, R.J., Ng, D.K., Hassim, M.H., Ng, K.S., Kin, W.Y., Jaye, I.F.M., Hang, M.Y.L.P. and Andiappan, V., 2017. Role of bioenergy, biorefinery and bioeconomy in sustainable development: Strategic pathways for Malaysia. *Renewable and Sustainable Energy Reviews*. In press.

"Malaysia has a plethora of biomass that can be utilized in a sustainable manner to produce bio-products for circular green economy. At the 15th Conference of Parties in Copenhagen, Malaysia stated to voluntarily reduce its emissions intensity of gross domestic product by upto 40% by 2020 from 2005 level. Natural resources e.g. forestry and agricultural resources will attribute in achieving these goals. This paper investigates optimum bio-based systems, such as bioenergy and biorefinery, and their prospects in sustainable development in Malaysia, while analyzing comparable cases globally. Palm oil industry will continue to play a major role in deriving products and contributing to gross national income in Malaysia. Based on the current processing capacity, one tonne of crude palm oil (CPO) production is associated with nine tonnes of biomass generation. Local businesses tend to focus on products with low-risk that enjoy subsidies, e.g. Feed-in-Tariff, such as bioenergy, biogas, etc. CPO biomass is utilized to produce biogas, pellets, dried long fibre and bio-fertilizer and recycle water. It is envisaged that co-production of bio-based products, food and pharmaceutical ingredients, fine, specialty and platform chemicals, polymers, alongside biofuel and bioenergy from biomass is possible to achieve overall sustainability by the replacement of fossil resources. Inception of process integration gives prominent innovative biorefinery configurations, an example demonstrated recently, via extraction of recyclable, metal, high value chemical (levulinic acid), fuel, electricity and bio-fertilizer from municipal solid waste or urban waste. Levulinic acid yield by only 5 weight% of waste feedstock gives 1.5 fold increase in profitability and eliminates the need for subsidies such as gate fees paid by local authority to waste processor. Unsustainable practices include consumable food wastage, end-of-pipe cleaning and linear economy that must be replaced by sustainable production and consumption, source segregation and process integration, and product longevity and circular economy."

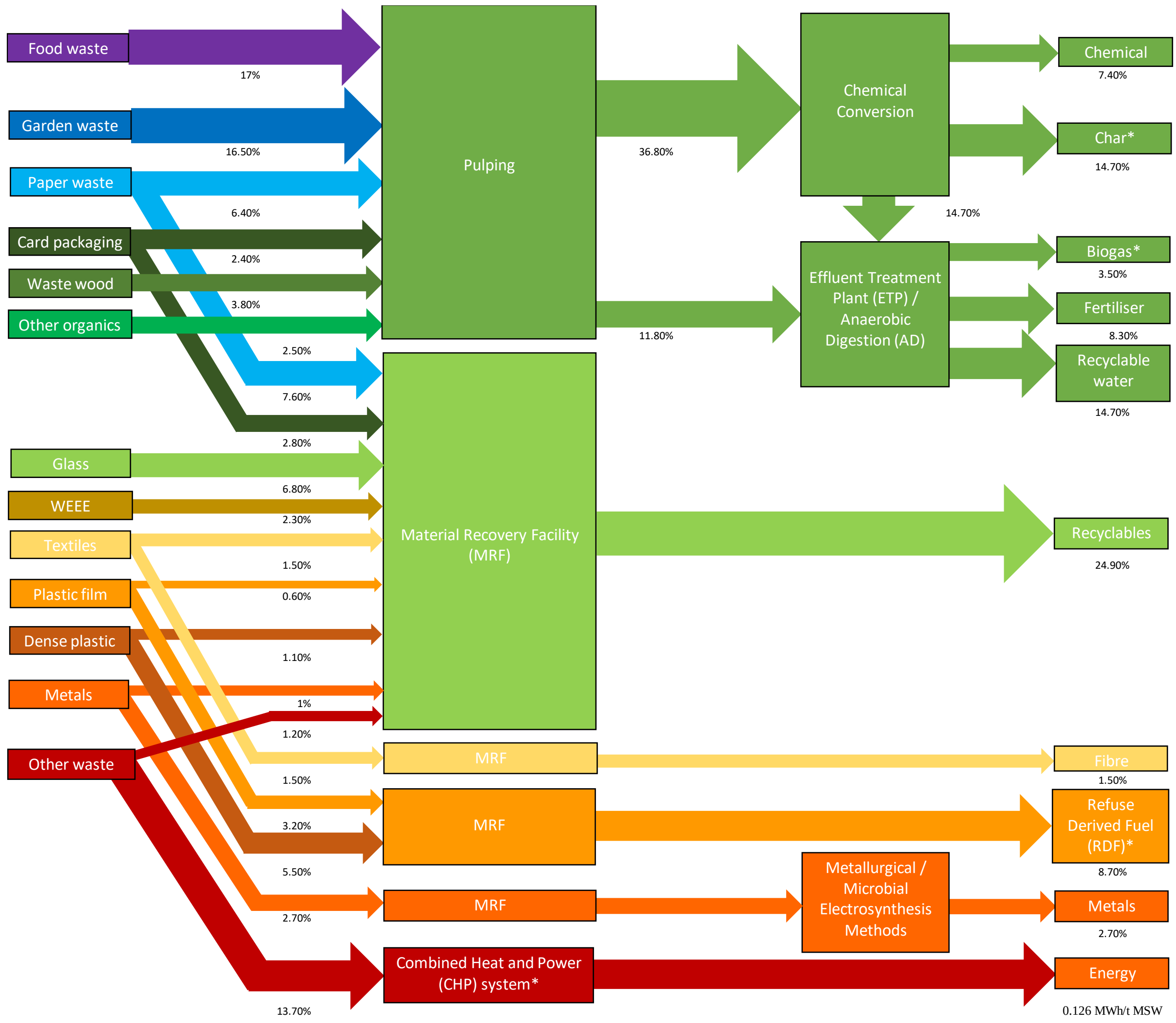

Figure 1 Material Flow diagram of the integrated biorefining system of MSW.

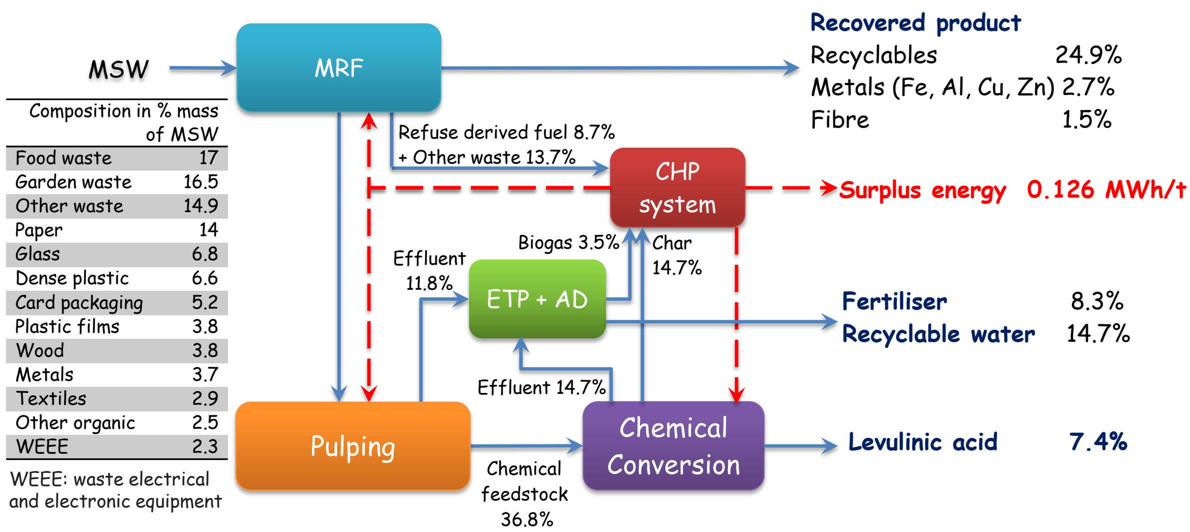

Figure 2 Overview of the mass and energy integrated biorefining system of MSW.

Table 1. MSW constituents and mass transfer in % mass of MSW to various production routes.

	Total	Recyclables	RDF	Recovered metal	Chemical feedstock	AD feedstock	Energy feedstock	Fibre
Food waste	17				8.5	8.5		
Garden waste	16.5				13.2	3.3		
Other waste	14.9	1.2					13.7	
Paper	14	7.6			6.4			
Glass	6.8	6.8						
Dense plastic	6.6	1.1	5.5					
Card packaging	5.2	2.8			2.4			
Plastic films	3.8	0.6	3.2					
Wood	3.8				3.8			
Metals	3.7	1.0		2.7				
Textiles	2.9	1.5						1.5
Other organic	2.5				2.5			
WEEE	2.3	2.3						
Total	100	24.9	8.7	2.7	36.8	11.8	13.7	1.5

Forthcoming publications

Out of the collaborative research project "Economic Value Generation and Social Welfare in Mexico by Waste Biorefining", the following paper and book chapters have been submitted for publication:

Sadhukhan, J., Martinez-Hernandez, E., Amezcua Allieri, M.A., Aburto Anell, J.A., Honorato S., J.A. **Techno-Economic and Environmental Footprint Analyses of Biochemical Conversion of Lignocelluloses in Mexico to Ethanol.** *Submitted*.

Martinez-Hernandez, E., Ng, K.S., Amezcua Allieri, M.A., Aburto Anell J.A., Sadhukhan, J. **Value added products from wastes using extremophiles in biorefineries – Process modelling, simulation and optimization tools.** In: Extremophilic Bioprocessing, Springer 2017, *In press*.

Elias Martinez-Hernandez, Jhuma Sadhukhan. **Process Integration and Design Philosophy for Competitive Waste Biorefineries.** In: Waste Biorefinery, Elsevier 2017, *In press*.

Amazonic biorefinery experience

Feature

A glance at a leading 2nd generation biorefinery

Churrascarias, football passion and caipirinha have as much in common with the Amazons as ethanol stations and biorefineries do: they are all widespread throughout Brazil. Streets full of ethanol or flexifuel cars, ethanol cheaper than gasoline and a prosperous biofuel and bioenergy industry are also characteristics of this tropical country.

Herein I would like to report what was an inspiring visit and amazing experience reassuring me as a "believer" (see Special Note by Prof Grant Campbell in the first issue) in the possibility of making The Biorefiner´s dream a reality. There it was, Raizen´s biorefinery in Piracicaba. As one arrives, from the outside, you can see the monstrous conveyors, the fermentation tanks, the bagasse power plant, and the colossal 20, 000 L ethanol storage tanks.

That was just the beginning, next to this 1st generation bioethanol plant is the 3 years old 2nd generation plant, a pioneering lignocellulosic biorefinery process converting the sugarcane bagasse and straws into more ethanol from both hexoses (C6 sugars) and pentoses (C5 sugars) using technology developed in alliance with Iogen.

Inside, at the quality assurance lab, a peek into the biorefinery streams is facilitated by the flasks containing samples from each process stage outlet.

The corporate presentation shows another impressive view of the tightly integrated supply chain, from soil preparation, plantation, cultivation and harvesting to the transportation and processing and points of sale. They showed the impressive high-precision agriculture technology used to detect the right time to harvest, and the harvesting machines designed to leave the right amount of residues to recover soil nutrients. The biorefiners working there, and the vision of Raizen, a joint venture between Shell and Cosan, are even more ambitious towards biorefinery integration. In one project, they are looking at integrating both the 1st generation and 2nd generation plants and also the combined heat and power unit to increase energy and water efficiency. Furthermore, plans for a gasification or anaerobic digestion unit to process wastewater is also highly encouraging for researchers working on biorefinery process technologies and their systematic process integration. A look through the control room windows also shows the highly advanced control system for the process which leaves no room for wasting time or feedstock.

Next stop was the icing on the cake, the almost brad-new lignocellulosic biorefinery, with its still shining hydrolysis and fermentation tanks (see cover and first picture of this section). Next to it is the yeast culture and enzyme preparation tanks. In front of the facility, a mountain of bagasse brought about by big trucks.

In numbers, the highly advanced integrated biorefinery is able to boost bioethanol production by up to 50%, in addition to the first-generation plant and without expanding cultivation land use. The use of bagasse and straws allows the biorefinery to continue production even off season for sugarcane harvest. The progressive scaling up has allowed producing 7 million litres in its first year, doubled to 14 million in 2017, and planned to reach a ground-breaking 40 million litres by 2018. The investment in the 2nd generation plant was R$ 237 million (~75 million USD). Furthermore, retrofitting 1st generation plants and adding seven more lignocellulosic ethanol plants are planned for the coming years. Plenty of work and jobs for biorefiners in Brazil.

Certainly, this was a breath-taking experience to see how advanced and highly integrated biorefineries are becoming a reality even in a context of recent decreased investment in biofuels and with the help of scientists, engineers and technologies, but also policy makers and the vision of a company who looks forward to the energy of the future. Many lessons to learn for other countries with enormous potential but less actions like this.

I would like to thank the Magalhaes Network, a bilateral initiative in the fields of higher education and scientific mobility. It promotes cooperation programs between leading European universities and Latin American and Caribbean institutions in the fields of engineering and architecture. As part of the network, the University of Bath supported this visit to the Workshop on Sustainable Energy, in Sao Paulo, 21-23 November 2016, at UNESP. I finalise with the picture of the great group of people that were in the same amazonic biorefinery adventure.

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Research Showcase

This section is dedicated to organisations and members showcasing their latest biorefinery research. It is useful for presenting your group or team at your organisation working on biorefinery related topics. After the successful biorefinery workshops in Mexico and Malaysia, the number of IBEST members have significantly grown to more than 80 organisations. This number is constantly growing as more and more researchers, engineers and technologists get to know the IBEST and its activities. Undoubtedly, spreading the word by active members has also contributed to an increase in the number of organisations that have become members.

In this issue we feature works to be presented by participants at the UK-India workshop in October 2017.

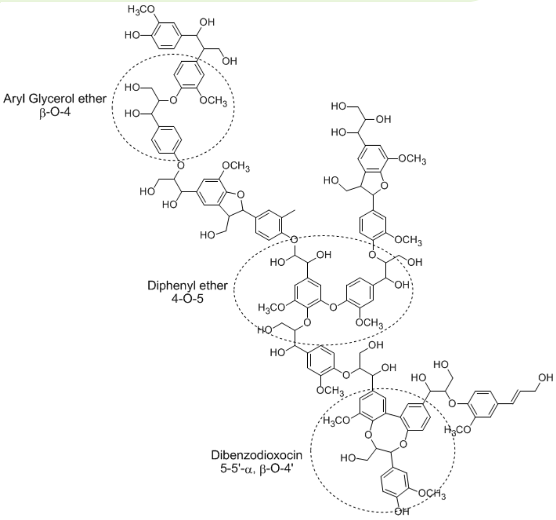
Instituto Mexicano del Petróleo

INSTITUTO MEXICANO DEL PETRÓLEO

The Mexican Petroleum Institute (IMP) is a national centre dedicated to basic and applied scientific research and is intended to develop technological solutions to the petroleum and energy industry challenges, form specialized human resources, and provide scientific, engineering and technical support to Petróleos Mexicanos (PEMEX) and new energy companies operating in Mexico. The IMP covers not only all value chains from exploration, production, logistics, refining, and petrochemicals, but also environmental issues and bioenergy. IMP worked on the UK-Mexico RAEng Newton Collaborative Grant "Economic Value Generation and Social Welfare in Mexico by Waste Biorefining".

Lignin pyrolysis: An approach on pyrolytic breakdown pathway.

Lignin pyrolysis proceeds through an extremely complex network of simultaneous and successive reactions, and its detailed mechanism and kinetics are not yet fully known. Different critical steps are involved in this multicomponent, multiphase and multiscale problem. Therefore, understanding the pyrolytic breakdown pathways of lignin from thermochemical and kinetic points of view is important to provide insightful information into the rational design and scaling-up of pyrolysis reactors.



Scheme 1. Representative structure of lignin.

Pyrolysis is a thermochemical conversion process that allows lignin pyrolytic breakdown using heat in the absence of oxygen and its use in the lignin valorisation has been widely tested and documented. The main goal of lignin valorisation is to breakdown the various linkages between its monomers to produce added-value compounds via thermal pathways. It is known that the main decomposition of lignin occurs within a wide temperature interval, and that several factors such as its origin, extraction method, particle size, type of feed, reaction temperature, residence time, heating rate, amongst many others, affect the amount and quality of products (liquid, gas and solid). Despite the significant success of the pyrolysis process in the valorisation of lignin, there is a lack of understanding of the fundamental mechanism of its thermochemical and kinetic performances over its entire operating range with the purpose of modulating the nature and yield of desired or high priority products.

Researchers

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Dr. J. Aburto (Scientific Researcher), Instituto Mexicano del Petróleo, C.P. 07730, Mexico City, México.
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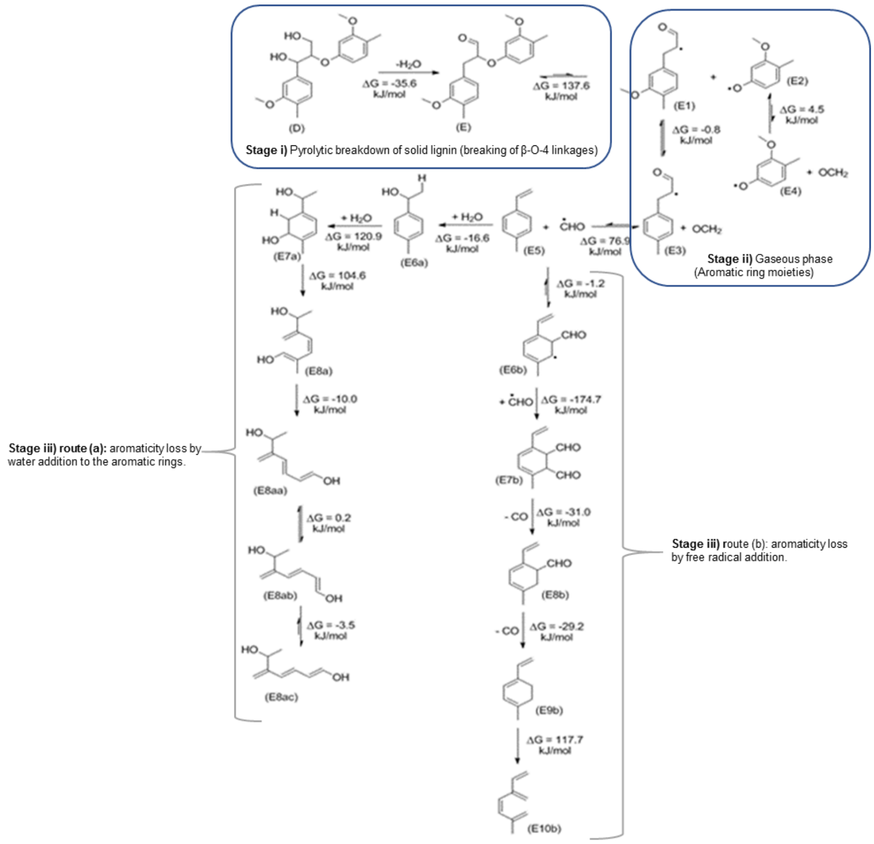
Thermochemical approach

The main goal of this study was to understand the influence of experimental conditions on loss of aromaticity among the most likely products during solid lignin pyrolytic breakdown. Consequently, this work focused on the analysis of three of the most important stages during the pyrolysis process i) initial solid lignin degradation, ii) chemical recombination of the pyrolysis products, and iii) the loss of aromaticity in likely products.

The experimental results (obtained by using thermo-analytical combined techniques, TGA-DSC/FTIR), revealed that the initial pyrolytic breakdown of solid lignin occur by cracking of aliphatic hydroxyl groups, followed by a massive breaking of β-O-4 linkages, which is its most important intrinsic feature. This last stage has unique characteristics, (energetically-equivalent bond breaking), so that the heating rate and temperature do not affect the ratio of the individual reaction rates of the involved processes.



Scheme 2. The most likely chemical routes for the thermal decomposition of β-O-4 linkages in solid lignin (stage i), and aromaticity loss by chemical recombination in gas phase (stage iii) (route a: reactions involving water addition as an example of neutral molecules), and for CO elimination (route b, reactions involving •CHO as an example of reacting free radical species).

The thermochemical analysis (using Gaussian 09 package) indicates that at the first and third stages, the rate determining steps are the β-O-4 homolysis, and species addition to the aromatic rings, respectively. Scheme 2 describes the thermochemical reaction routes during the pyrolytic degradation of solid lignin, including the most likely chemical recombination reactions in the gaseous phase, which promote the aromaticity loss during the pyrolysis process. In both cases, the relative high barrier of the rate-limiting step indicates a slow kinetic process.

Research Impact

The study indicates that the yields of aromatic vs. aliphatic compounds can be modified through experimental conditions, in particular by controlling heat transfer rates and residence times. The yields toward aromatic fragments are favored by a synergistic relationship between high heating rates and short residence times of the gaseous products. Such coupling would help avoid or control secondary gas phase reactions (e.g., water and/or free radical species with aromatic moiety), which seems to be required for the aromaticity to be lost.

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Instituto Mexicano del Petróleo (IMP)

IMP is the National Public Research Center dedicated to basic and applied scientific research, to develop technologies applicable to the petroleum industry and the formation of specialized human resources: IMP provides support to Petróleos Mexicanos (PEMEX) and other new oil, gas and energy companies starting operations in Mexico to explore, produce, transport and refine hydrocarbons at global environmental specifications. IMP worked on the UK-Mexico RAEng Newton Collaborative Grant "Economic Value Generation and Social Welfare in Mexico by Waste Biorefining".

"Biologically Based Chemicals Technology Plan"

A technology plan is a set of principles and guidelines that indicate the actions for the development, acquisition, transfer and assimilation of a technology by the organization.

The Biomass Conversion Division of IMP is looking for having a technology plan.

A technology plan is a specific type of strategic plan that lets an organization know where they are now and where they want to be some time in the future with regard to the technology and infrastructure in their organization.

"How Mexican Petroleum Institute faces energy transition"

The first-generation, or 1G, technology converts edible biomass basically into fuels. The promise of the second-generation (2G) bioconversion industry is that it will transform cellulose based, non-edible biomass and agricultural waste into clean and affordable high-value fuels or chemicals. In this way, 2G could offer an alternative source both of energy and of chemical-industry inputs, which other renewable technologies cannot provide. That is 2G's potential, but the industry failed to deliver on this promise for almost a decade.

However, there has been progress in recent years to produce products from biomass. What is the most promising building blocks from biomass? The answer is not easy to respond. A state of the art as well as the Technological Route Map on value-added bioproducts is necessary to have a series of projects to carry out.

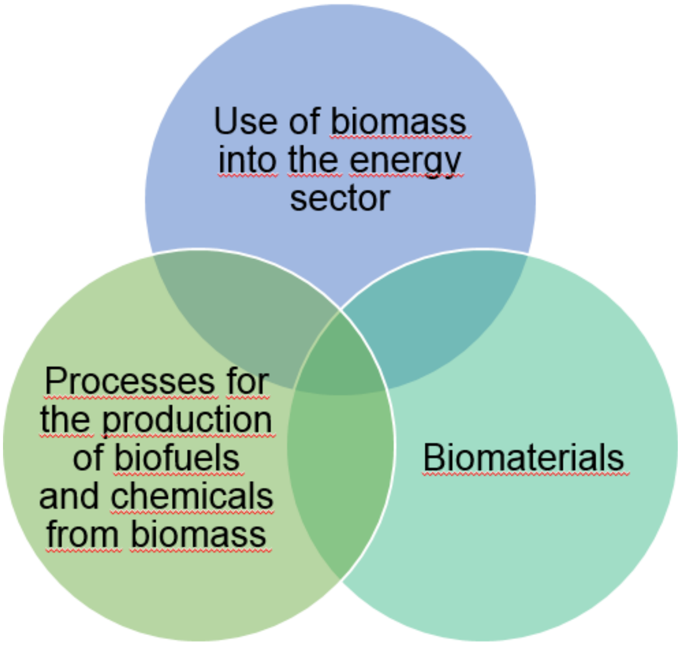
Researchers

Jorge Arturo Aburto Anell, Ph D., Head of Biomass Conversion Division.

Myriam Adela Amezcua Allieri, Ph D., Technological Leader of Biomass Conversion Division.

Biologically Based Chemicals Technology Plan

The objective of this work is to elaborate a technological plan for the Biomass Transformation Management of the Mexican Petroleum Institute, in order to ensure that research lines, projects and technology are aligned with the Institute's strategic objectives under a niche strategic market for Mexico.



The Biomass Conversion Division of IMP is looking for a portfolio of projects based on high added value bio-products.

Results

The main findings of the state of the art were taken as input, as well as the Technological Route Map on value-added bioproducts 1) to make a proposal for a series of project prospects that Biomass Management can carry out alone or together with other areas within IMP and/or national or international organizations, and 2) to carry out a plan for the execution of these project prospects in the short, medium and long term. The main results were the selection of 22 building blocks. Based on the experience of the working group, market, competitors, development expectations, as well as barriers and technical and scientific challenges, the list was limited to only 10 biologically based chemists, among which are glycerol, bioethanol and biomethanol . These chemicals were grouped into three lines of research: bioalcohols, bioplastics and organic acids, which gave rise to a total of 25 projects.

Research Impact

Offering technological basis for the development of a market for biologically based chemicals. Strengthens the environmental management policy and promotes sustainable bioproducts, low environmental impact, and high social impact and integrates the biomass valorization in a biorefinery scheme.

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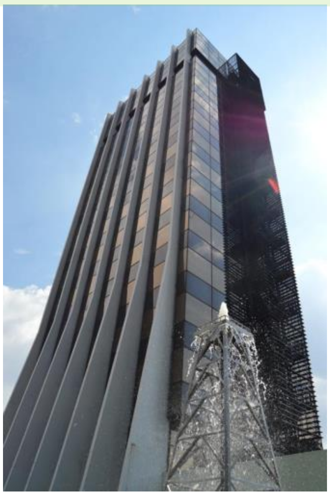
Mexican Petroleum Institute

The Mexican Petroleum Institute (IMP) is a national centre dedicated to basic and applied scientific research and is intended to develop technological solutions to the petroleum and energy industry challenges, form specialized human resources, and provide scientific, engineering and technical support to Petróleos Mexicanos (PEMEX) and new energy companies operating in Mexico. The IMP covers not only all value chains from exploration, production, logistics, refining, and petrochemicals, but also environmental issues and bioenergy. IMP worked on the UK-Mexico RAEng Newton Collaborative Grant “Economic Value Generation and Social Welfare in Mexico by Waste Biorefining”.



Biomass Conversion Division at IMP

It is responsible for the scientific and technological development in biomass conversion to fuels, bio-based chemicals and materials. Develop technologies for the use of lignocellulosic materials, processes for the production of biofuels and chemical products by biomass valorization.

“Bioenergy, Bio-based chemicals and materials into a biorefinery scheme”

The actual and global energy transition is already changing the face of the world, from an oil and gas industry which is non-renewable, with a high carbon footprint and dominates by subsidies into a renewable energy industry with carbon neutral or negative footprint and competitive without subsidies. In this context, bioenergy may contribute to the production of clean, zero or negative carbon footprint energy as well as biobased chemicals and materials into a biorefinery scheme. The latter is defined as a processing plant where biomass is converted in a holistic way to thermal or electric power but also to advanced biofuels and specialized or commodity chemicals, materials and goods. This approach is the main one that assures a competitive and efficient strategy that might contribute to the energy transition.

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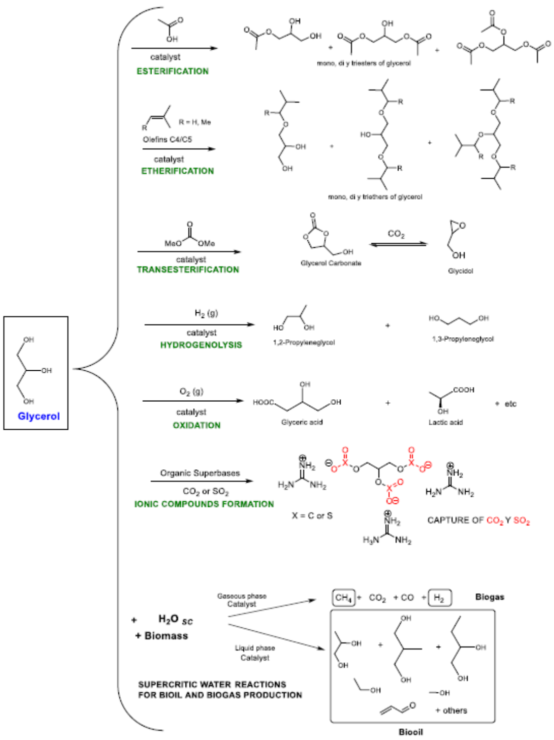
Dr. Jorge Arturo Aburto Anell

Technological route for the production of high value chemicals from waste bio-based alternatives

In this project, we propose several routes for the transformation of crude glycerol, obtained in biodiesel production, to sustainable chemicals with high added value, sustainable and competitive manner for the chemical and petrochemical industry such as carbonates, alcohols, esters, ethers, epoxides among others. Today, glycerol of low purity and low cost (ca. 0.2 USD/Kg) and increasing production allows its valorization into chemicals or energy by establishing routes for processing and enhancement and thus also contribute to reducing the environmental impact by replacing non-renewable chemicals derived from fossil resources. The derivative of glycerol might be also a new alternative for fuel and biofuel additives, i.e. antiknock agents as well as improve cetane number enhancers. Glycerol ethers and esters, propylene glycol, epoxides such as glycidol and propylene oxides are precursors to a variety of polymers. Glycerol based solvents are of big interest for biomass dissolution such as cellulose, lignin and chitosan. Finally, our group works on eutectic liquids from glycerol that are low toxic products and that can be used for CO_2 and SO_2 capture.



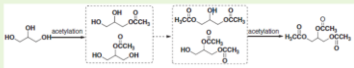
"Glycerol derivatives as a straightforward strategy to holistic biorefineries"

This project searches to find out new alternatives, into a biorefinery scheme, to crude glycerol, a byproduct of low cost from biodiesel production. By promoting this strategy, it is possible to obtain a higher cost-benefit of biodiesel production and high value added co-products. IMP's researchers are working to develop holistic alternatives to biorefineries thanks to our "sustainable chemistry concept" for the use of biomass.

Results

Glycerol esterification

The esterification reaction of glycerin is a widely used method for products with higher added value in the process of obtaining biodiesel. This reaction is conducted using acetic acid and the products known are: mono acetate glycerol (MAG), di acetate glycerol (DAG) and tri acetate glycerol (TAG). These products are widely used in various industries ranging from the manufacture of explosives, solvents and/or fuel additives, respectively.



The transformation of glycerol in their acetates is increased by the use of acidic heterogeneous catalysts. In this work, different catalytic starting materials were used and their acidity modified.

Till now, reaction selectivity increases toward di-substituted derivatives.

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Feasibility Study of a biodiesel plant in México

The main objective of this work was to define the techno-economic, and environmental viability of the construction of a biodiesel plant in México. To achieve this objective, conceptual Engineering was carried out following the FEL I methodology shown in Figure 1.

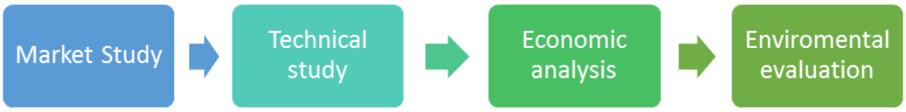

Figure 1. Methodology followed for feasibility study of a biodiesel plant.

The market study was done with the aim of defining the plant capacity and the target market. Using historical data, the demand was projected for 10 years from today. It was found that there will be an unsatisfied potential demand in the transport and agriculture sector. The biodiesel quantity required for B5, B10 and B20 blends was then calculated. After this results, it was decided to focus on the agriculture sector with a B5 mix as our target market and the capacity required is 148,000 tons per year.

The technical study was then carried out to establish the type of technology and the feedstock to be used, the material and energy balance, the equipment dimensions and the plant location. To obtain the material and energy balance and the equipment dimensions the plant was simulated using Aspen plus 8.8 software as shown in Figure 2; with the equipment dimensions, a V class cost estimate was calculated which corresponds to a conceptual engineering estimate, and the different indicators of the viability of the biodiesel plant construction in Mexico were determined.

Finally, the environmental evaluation was done to calculate the GHG emissions in the different stages of the production chain: the *Jatropha* cultivation, oil extraction and biodiesel production. This work was conducted under the supervision of Chem. Eng. Arturo Moreno Xochicale, at the Faculty of Chemistry, UNAM, with advice from Dr. Elias Martinez Hernandez.

Results

A heterogeneous process known as "Esterfip-h" was selected. This process uses a zinc aluminate commercialized by Axens, the *Jathropa curcas* was chosen as feedstock and Tuxpan, Veracruz was selected as the plant location due to the high potential for cultivating Jatropha in the region.

Table 1. Biodiesel plant results

Concept	Result
Catalyst	$ZnAl_2O_4$
Biodiesel production	148, 352 Tons/year
Glycerol production	13,039 Tons/year
Biodiesel selling price	0.42 USD/L
Investment in fixed capital	20.3 million USD
Total capital investment	26.8 million USD
10-year net present value	17.2 million USD
Internal return rate	23%
Total emissions	287, 833 tons of CO_2-eq/year

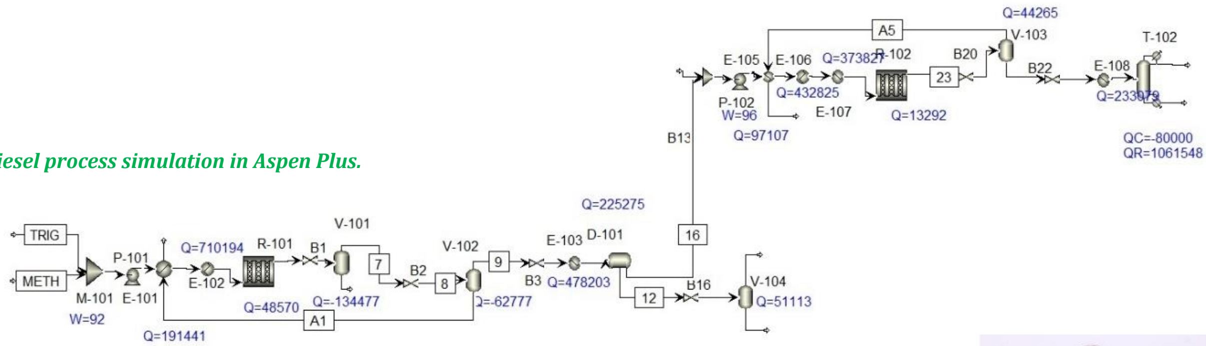

Figure 2. Biodiesel process simulation in Aspen Plus.

Research Impact

The main impact of this work is to demonstrate that biodiesel production is profitable and can help to reduce the GHG emissions in Mexico.

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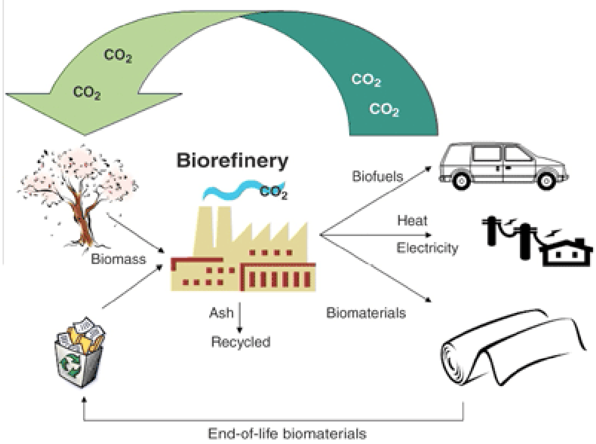
Shahid Beheshti University

The biorefinery group is one of the main biotechnology research centers at the Department New technologies at Shahid Beheshti University in Iran. We are interested in developing catalytic fast pyrolysis, biochemical, bio-polymers technologies to produce bio-oil, bio-ethanol, bio-composites, and bio-nano-products from biomass available from farms and forest industries nearby to our campus.

Catalytic fast pyrolysis

Industrial biorefineries have been identified as the most promising route to the creation of the bio-based industry. The objective of a biorefinery is to optimize the use of resources and minimize wastes, thereby maximizing benefits and profitability. In order to meet sustainable development, the industries need to shift from petrochemical sources to bio-based resources towards a future bio-economy. Biomass is the only source of renewable carbon which can be converted into biofuels and added value products through biorefineries combining biochemical and thermochemical routes. Amongst them, fast pyrolysis can play an important role for developing biorefinery concepts by producing different types of products such as biofuels, biochemical and syngas in both economically and environmentally beneficial manners.



Biorefinery concepts

"Sustainable Bio-planet from biomass"

There is a necessity to integrated and systematic approaches to optimize the bio-plastic production from benzene, toluene, xylenes (BTX) regarding type of biomass, catalyst characteristics, catalyst use (in-, or ex-situ), catalyst / biomass ratio, pyrolysis technology, pyrolysis operation conditions, etc. The effect of pyrolysis temperature, types of HZSM-5 catalysts (different Si/Al ratio), and catalyst to biomass ratio on the yield of BTX from low cost sugarcane bagasse via ex-situ catalytic pyrolysis has been investigated.

Researchers

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Dr. Paul de Wild (Project manager, Energy research Center of the Netherlands)

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Prof. Paul Stuart (Professor, Ecole Polytechnique de Montreal)

Prof. Erik Heeres (Professor, University of Groningen)

Ex-situ catalytic fast pyrolysis

Sugarcane bagasse is one of the most abundant biomass resources in Iran. Sugarcane bagasse has not been used as a source for BTX synthesis using catalytic pyrolysis. Process conditions were optimized via response surface methodology (RSM). This combination of an experimental screening study with variation of crucial pyrolysis parameters and RSM optimisation to elucidate the conditions for maximum BTX yield from sugarcane bagasse is unique and has not been reported before. The elemental composition (CNHOS), was used by applying an EXETER CE 490 elemental analyzer. Hot water pre-treatment was performed to remove inorganic materials from sugarcane bagasse. The thermal degradation characteristics were measured via TGA. Ex-situ catalytic fast pyrolysis was conducted in a tandem micro-pyrolyzer system (Rx-300 TR, Frontier Laboratories, Japan).

Micro and bench scales of ex-situ catalytic fast pyrolysis for Bio-BTX

Results

The ex-situ catalytic pyrolysis of sugarcane bagasse shows a considerable change in the yield of BTX, depending on the type of HZSM-5 catalyst used. Unlike the bio-oil process for which temperature has higher effect on the production, the type of catalysts and catalyst to biomass ratio showed the most significant parameters on bio-plastic yield. Results indicate that Brønsted acidity lead to increasing conversion of biomass to aromatic products at lower Si/Al ratios of the HZSM-5 catalysts used.

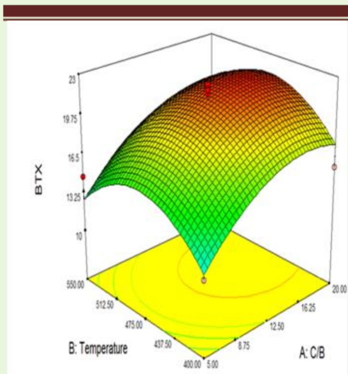

Figure. Optimization of yield of BTX

Research Impact

Increased biofuel and bio-chemical production and technologies can potentially generate a significant amount of economic development for forest industries in Iran. Replacement of fossil based BTX and plastic gives energy security and sustainability and can thus increase economic investments by forestry industries. If incentives are put in place to increase biofuel and bio-products from wood wastes, industries and farmers will shift their biomass residues to added value products. Pyrolysis can play an important role in future biorefineries to valorize side-streams. Finally, the potential benefits associated with this research cover: i) energy security ii) enabling industries to meet their responsibilities to mitigate climate change, iii) increased economic development / revenue / jobs, and iv) increased opportunities for biofuel and bio-products development in the Iranian industries by cooperating with other countries.

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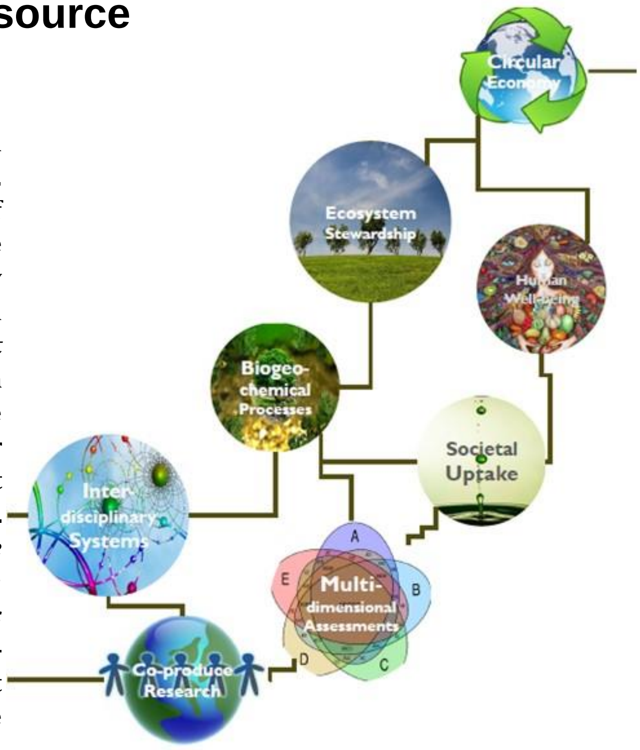
Resource Recovery from Waste

Resource Recovery from Waste (RRfW) is a UK-based collaborative environmental research programme engaging academia, industry, government and the general public to develop knowledge and tools to reduce pressure on natural resources and create values from wastes.

We envision a circular economy in which waste and resource management contributes to a resilient environment and human well-being.

Restoring the Balance between Resource Scarcity and Waste Overload

Current production and consumption patterns drive a dual environmental crisis of resource scarcity and waste overload. Positioning waste and resource management in the context of ecosystem stewardship, RRfW relates increasing resource demand and waste production to the violation of planetary boundaries and human rights, and argues that a transition towards a circular economy (CE) *that contributes to a resilient environment and human well-being* is necessary. The transition requires scientific and technological progress, including the development of low-energy biogeochemical technologies for resource recovery, and multi-dimensional value assessment tools integrating environmental, social, and economic factors. The programme aims '*...to gather the evidence to improve the way that waste is valued as a resource, based on a whole system approach, i.e., incorporating environmental and social benefits and not just economic*'. Through our transdisciplinary project- and programme activities, we develop interdependent technical and social solutions for waste and resource management as part of a CE, striving to maximise societal benefits.



RRfW works according to eight core values.

"Academia must play a key role in the transition towards a circular economy, engaging multiple actors from across society in participatory research that creates windows of opportunity for radical change in waste and resource management."

RRfW Projects

AVAnD: Adding Value to Ash and Digestate: Developing a suite of novel land conditioners and plant fertilizers from the waste streams of biomass energy generation
B3: Beyond Biorecovery: Environmental win-win by biorefining of metallic wastes into new functional materials
MeteoRR: Microbial Electrochemical Technology for Resource Recovery
INSPIRE: In Situ Recovery of Resources from Waste Repositories
R3AW: Resource Recovery and Remediation of Alkaline Wastes
CVORR: Complex Value Optimisation for Resource Recovery

Participatory Research on Resource Recovery

RRfW believes that collaboration between academia, industry and government from research initiation up to delivery and dissemination of results is crucial. This ensures our work is relevant to solve real societal problems and creates commitment outside academia to use research outcomes in the uptake of more sustainable patterns of consumption and production. We engage industry and government actors in academic research at increasing levels of participation; from informing them via social media, professional publications and networking events, to consultation with the help of surveys and workshops, up to co-production through placements, co-publications and contribution to government policy and industrial standards. Ultimately we strive for changes in mentality, industry practices, and policies and regulations in the waste and resource management landscape in the UK.

To engage partners from academia, government and industry in RRfW, we need reasons to speak with them. For this we have a number of 'vehicles'. Our first vehicle was a project to co-create a vision and approach for waste and resource management. Starting from the initial RRfW vision (recently published, see impacts below), we spoke with government and industry partners to answer the following questions:

1. What would the resource and waste management landscape ideally look like by 2020, 2030 and 2050?
2. If we would like waste management to be driven by environmental and social values as well as economic benefits, what would be the key policy and regulatory approaches?
3. How could RRfW best engage governmental organisations to translate knowledge into practice?

The academic, government and industry perspectives will be combined into an integrated vision and approach to realise the envisioned changes in waste- and resource management as we transition towards a CE.

Key themes identified through government engagement

Research Impact

RRfW's participatory research resulted in numerous outcomes and impacts, including:

- *Velenturf, Anne P.M. and Purnell, Phil (2017) Resource Recovery from Waste: Restoring the Balance between Resource Scarcity and Waste Overload. Sustainability 9 (9): 1-17. DOI 10.3390/su9091603.*
- *Invited presentations at industry-led events e.g. by International Synergies Ltd (leading the National Industrial Symbiosis Programme) and the Resource and Waste Management exhibition.*
- *Contributions to government consultations and reports, such as on the UK industrial strategy, GO Science report "From waste to resource productivity", case study for the European Network of Environmental Protection Agencies, and an extensive waste infrastructure review used by the National Infrastructure Committee.*
- *Emerging transdisciplinary community on resource recovery reflected in e.g. follow-on research applying and commercialising research outcomes and co-authored publications including the forthcoming RSC book "Resource Recovery from Wastes: Towards a Circular Economy".*

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Website: www.rrfw.org.uk ¦ Resource Recovery from Waste ¦ @RRfW6

Coventry University

Coventry University (CU) is a forward-looking, modern university with a proud tradition as a provider of high quality education and a focus on applied research. It is an ambitious and innovative university, delivering research that makes a significant contribution to a number of global challenges. It has twelve research centres focusing on a range of real world issues including sustainability, disease prevention and innovative engineering.

The Use of Waste Cardboard, Polymeric Fibres and Agricultural by-product in Manufacturing of Fibre-Cement Composite Board

The applications of Agricultural-Waste Fibres, waste cardboard and polymeric fibres are considered in producing the fibre-cement composite boards (FCB). A broad range fibres including; bagasse fibre, wheat fibre, eucalyptus fibre, waste cardboard and some polymeric fibres are applied to produce FCB. Moreover, the effects of silica fume and lime stone powder are studied on mechanical and physical properties of FCB made of these novel materials.

The use of cement board for external/internal wall, cladding and roofing

- Cement Composite (application of natural, mineral and polymeric fibres in cement composite)
- Concrete Technology (corrosion, repairing, additives and admixtures, shrinkage control and High strength concrete)
- Application of waste materials in production of construction materials and products
- Develop & improve in Construction techniques, Materials and structural systems in construction industry
- Development and properties of low-calcium fly ash-based Geopolymer concrete
- Retrofitting of steel and concrete structure.

Researchers

Dr Morteza Khorami,
Lecturer in Civil Engineering

Prof Eshmaiel Ganjian
Professor of Civil Engineering Materials

Fibre-Cement Board

Proposition of several mixes to produce non -asbestos fiber cement board using Hatcheck process in the factory

Since recognizing the impact asbestos has on human health, thorough research have been carried out all over the world, particularly in developed countries, to find alternatives for asbestos base products. The most common alternatives have been obtained from cellulose fibres solely or blending with synthetic fibres. After this achievement, since late 1990's and early 2000, most countries, including the developed countries and even some developing countries banned or cease the use of asbestos in their products. At present, there are many composite cement- fibres factories in developing countries that use asbestos fibres as the main fibre to produce cement boards.

This comprehensive research started by authors in 2008 at Building and Housing Research Centre (BHRC) in Iran and then continued by collaboration of Coventry University in the UK. The outcomes of several research projects carried out by the Dr Khorami and Prof Ganjian in the UK and Iran lead to this research which offers several mixes that could be used by asbestos cement factories to replace asbestos with non-asbestos fibres. In this research asbestos fibres are replaced by different types of cellulose and synthetic fibres.

Results

The results of this research showed that Kraft cellulose fibres that could be extracted from waste cardboard in combination with acrylic fibres and some additives could be replaced for asbestos in production of fibre cement board.

Successful replacement of asbestos fibers in a Cement Board Factory

Research Impact

The results of this research led to find some appropriate mix designs for manufacturing non asbestos fibre cement board in the Hatcheck machine. With providing required equipment or modified existing equipment to the factory setup, it can be applied to existing asbestos-cement board factories to produce the Fibre Cement Board without asbestos fibres. The results of this research has been published by Ministry of Housing, Urban and Development in Iran. Over the past two years many of Asbestos- Cement actories have replaced asbestos fibres in their products.

Contact Us

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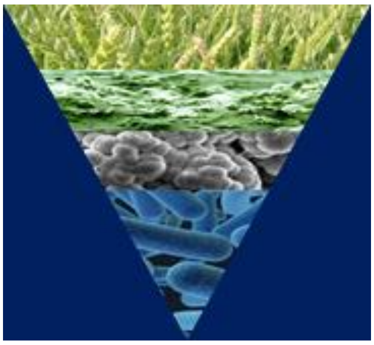


Anaero Technology Ltd

Anaero Technology is a Cambridge-UK developer of state of the art research digesters for batch and continuous operation. Our products include patented automatic feeding systems for true semi-continuous and batch reactors for AD research BMP sets. Our aim is to contribute to more representative and cost-efficient AD research. Our advanced research equipment will help you address the new challenges and opportunities of AD and fermentation.

EVALUATION OF ANAEROBIC DIGESTIBILITY OF AGRICULTURAL BY-PRODUCTS, INDUSTRIAL WASTE AND ENERGY CROPS

Utilising anaerobic digestion (AD) to produce biogas from various waste streams and crops is a favourable source of renewable energy. There are abundant wastes and by-products produced through the food and drink supply chain, both pre- and post-consumer, that are valuable and infrequently used as substrates for AD. This study aims to quantify the biomethane potential of these wastes to contribute to solid waste reduction and energy production.

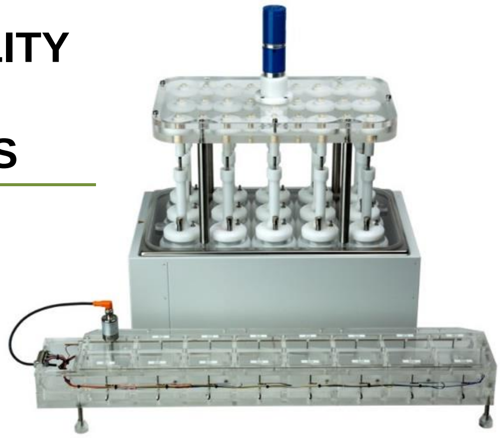


Figure 1 Biomethane Potential test kit

Sugar beet tops | Potato peels | Wheat | Triticale | Banana peels | Straw | Cow Manure

In this study, batch reactors were used under mesophilic conditions to evaluate the biomethane potential of six different organic materials: livestock slurries, energy crops, pre-treated agricultural by-products, arable crops, agro-industrial wastes, fruit and vegetable wastes and co-digestion of chicken litter and fruit wastes. The co-digested feedstocks were tested in 6 automatically fed, continuously stirred digesters at mesophilic temperatures with a maximum organic loading rate of 3.8 kg/VS day. The CSTR tests were conducted using automatically-fed CSTR digesters with 5.3 litre working capacity and each reactor was connected to a feeder syringe that contained the feed. Feed was delivered to the digesters in hourly intervals. The continuous digestion tests aimed to optimise methane production from chicken litter.

Researchers

Alexa Spence, MSc Student, Cranfield University, United Kingdom

Edgar Blanco, Managing Director, Anaero Technology, United Kingdom

Rashmi Patil, Research Scientist, Anaero Technology, United Kingdom

Dr. Yadira Bajón Fernández, Academic fellow in Chemical Engineering, Cranfield University, United Kingdom

Evaluation of anaerobic digestibility of agricultural by-products, industrial waste and energy crops

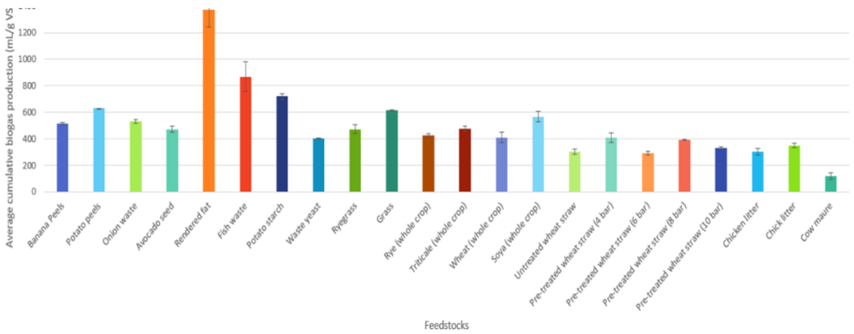
The objectives of this research were to:

1. Determine potential biogas yield and methane content for livestock slurries, energy crops, pre-treated agricultural by-products, agro-industrial wastes, fruit and vegetable wastes and co-digestion of chicken litter with fruit wastes in batch tests.

2. Investigate the feasibility of co-digesting chicken litter with fruit wastes to maximise methane production in auto-fed semi-continuous digesters.

Methodology

Batch digestion experiments: Biomethane Potential (BMP) tests were conducted in 1 litre reactor bottles submerged in a water bath and maintained at 38°C (Figure 1). All reactors were continuously stirred at 45 rpm by a paddle mixer to ensure homogenous conditions.



Research Impact

Figure 2 Biogas yields of different feedstocks using BMP test kit

This study highlights the use of anaerobic digestion (AD) to produce biogas and recycle nutrients from various agro-industrial by-product streams which until now were considered to be waste. These materials have the potential to displace energy crops as feedstock for AD, avoiding the utilisation of agricultural land to grow energy. There is a need for efficient use of by-products in society, enabling the recovery and enhancement of value on the grounds of sustainability and "decarbonation".

Results

Figure 3 Auto-fed CST

Figure 4 Daily biogas yield and OLR of all substrates for semi-continuous digestion tests day 1 to 40

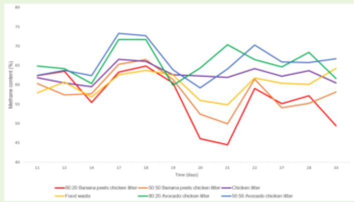


Figure 5 Methane content of all substrates for semi-continuous digestion tests day 11 to 33

Contact Us

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Birmingham Centre for Energy Storage

Established in 2013, the Birmingham Centre for Energy Storage brings together research expertise from across the University to drive innovation from the laboratory to market. The Centre consists of two components: the Birmingham Centre for Thermal Energy Storage and the Birmingham Centre for Cryogenic Energy Storage; both of which draw on the capability in materials, thermodynamic processes, application development, smart grid and policy economics.

Thermal energy storage – research from materials to system integration

Thermal energy storage (TES) has the potential to facilitate the deployment of renewable energy through addressing the demand-supply mismatch, ultimately leading to the decarbonisation of heat supply. However, TES still rely on solutions developed decades or even century ago, largely based on sensible thermal energy storage which is intrinsically limited by low energy density, poor performance of the storage materials, few suitable materials and excessive thermal losses.

"New storage technologies could transform how energy is supplied and used, helping to make future energy systems efficient and reliable, lower carbon and more affordable"

Competitive TES technology requires to address a number of scientific and technological challenges including TES materials, TES components and devices, and integration of TES devices into energy networks. Our research provide a perspective of TES technology with a focus on latent heat thermal energy storage and cryogenic energy storage, with a particular emphasis on composite thermal storage material (PCMs) and modular devices currently under development at the Birmingham Centre for Energy Storage. Composite PCMs have the potential to meet the thermal energy storage challenges through hierarchical structures capable to meet thermal, mechanical and chemical requirements for future TES technology. However, understanding the structure-property-performance of PCMs is crucial; our latest research advancements bring exceptional innovation in formulation, manufacturing and scale up validation, elucidating the multiscale thermal energy storage challenge, bridging scales across ten order of magnitudes

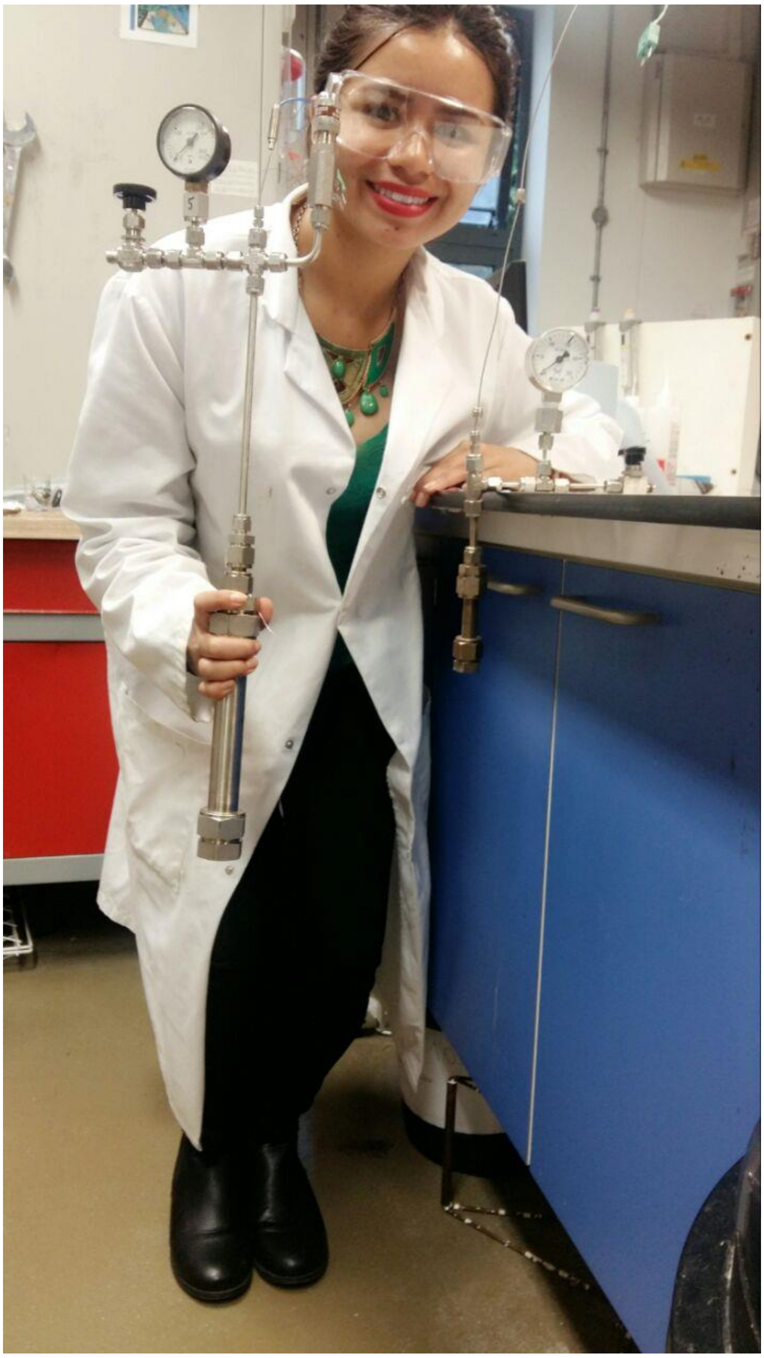
For more info visit: *http://www.birmingham.ac.uk/energystorage*

Researchers

Prof Yulong Ding, Director
Dr Jonathan Radcliffe, Senior Research Fellow
Dr Yongliang Li, Senior Lecturer
Dr Adriano Sciacovelli, Lecturer
Dr Hui Cao, Research Fellow
Dr Helena Navarro, Research Fellow

New Biorefiner

This section is dedicated to members presenting their profile as a New Biorefiner by either doing research, as process engineer, chemist, biologist, and any background. Like all the IBEST members, a New Biorefiner is committed to advance the field and translate knowledge into real impact to help biorefineries deliver their full potential as an enabler of better economic opportunities and social welfare.



Waste Fed Biorefinery: Re-engineering Remediation for Sustainable Bioeconomy

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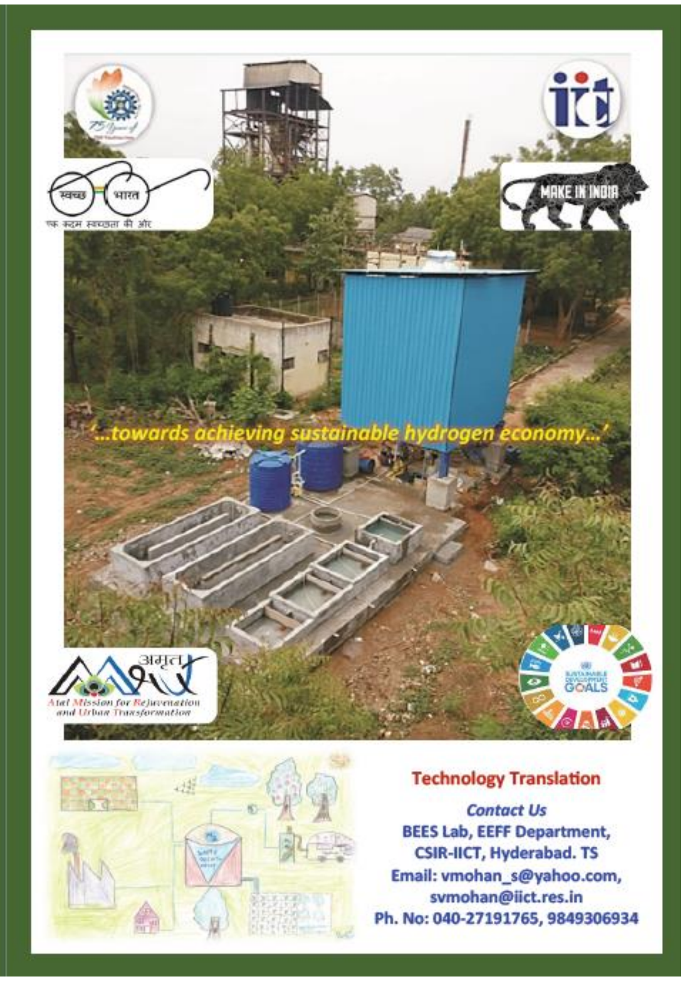
Realizing the necessity, the world is gradually shifting from fossil-based linear economy to bio-based circular economy. Bringing waste as the core element in this framework is fundamentally essential and therefore, allows sustainable development. Valorizing of waste is our broad interest in the modern bio-economies. The potential use of waste as alternative feedstock towards valorization of energy, chemicals and materials is our core research domain in the context of developing enabling technologies that can be commercially deployed. To envisage environmental sustainability and economic viability, integrated approach is necessary and development of waste biorefinery models in this domain is important. CSIR-IICT recently commissioned a state of art pilot plant facility (10,000 liters) for the production of biohydrogen from waste/wastewater. The pilot plant has acidogenic reactor inter-connected with seven unit operations each with a defined function i.e. inoculum preparation, redox control, buffering/pre-treatment, biogas holding, anaerobic digestion, auto biogas-flare and water storage/waste feeding. We are attempting to holistically address the production of biobased products from waste by designing a biorefinery models with a closed loop approach. The pilot scale operation in integrated with dedictaed waste-biorefinery platform structuring acidogenic process for biohydrogen production at focal point and sequentially integrating multiple processes towards the production of diverse biobased products viz., bioplastics, biodiesel, biomass, bioelectricity, etc. Waste biomining would pave a way towards sustainable transition to circular bioeconomy. Though the concept of waste biorefinery mimics environmental sustainability, it needs optimization through cross-cluster mix of different disciplines in science, engineering and management (policy design and technology management) to compete with the current/conventional fossil based economy.

Plant Capacity (m^3)	Organic load (g COD/L-day)	Biohydrogen (Kg/day)	Energy (MWh)	Unit Cost of Hydrogen (Rs/Kg)	Operation cost** (Rs/day)	Plant Cost (Rs in Lakhs)	ROI (Years)	Fatty Acids (C2-C4) (Kg/day)
10	100	11	0.3	240	2500	-	-	300
100	100	11 0	3.4	150	8500	200	6.6	3,500
500	100	560	15.0	60 (100)	16000	650	4.5	16,000
1000	100	1100	30.0	50 (100)	20000	900	2.7	32,000


Waste Biorefinery Platform
Integrated Facility for Biofuels and Biochemicals from Waste
Any Biodegradable Waste
(Municipal Solid Waste/ Industrial Effluents)
Salient features
- Abundantly produced waste is the feedstock
- Simple and low cost pretreatment
- Not influenced by seasons and regions
- Doesn't compete with land for food based agriculture
- Zero carbon emission
- Sustainable technology with commercial viability
- Advocates circular bioeconomy
- Aligns with national flagship programs
- Addresses united nations sustainable developmental goals
Biogas (Biohydrogen, Biomethane and Biohythane)
Platform Chemicals
(Carboxylic Acids and Alcohols)
Biofertilizers and Secondary Process Feedstock
Bioelectricity and Waste Remediation


MAKE IN INDIA
'...towards achieving sustainable hydrogen economy...'
Atal Mission for Rejuvenation and Urban Transformation
Technology Translation
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Social, Economic and Environmental Sustainability of Energy systems

Alejandro Gallego-Schmid, Carlos

Gaete-Morales, Jhud Aberilla, Joan Manuel F. Mendoza,

Ximena Schmidt-Rivera, Laurence Stamford, Adisa Azapagic

Sustainable Industrial Systems (The University of Manchester, UK)

Email: alejandro.gallegoschmid@manchester.ac.uk

The Sustainable Industrial Systems (SIS) Group is a research group from the School of Chemical Engineering and Analytical Science at The University of Manchester (UK). The main aim of our research is to help identify sustainable solutions for industrial systems on a life cycle basis, taking into account economic, environmental and social aspects.

Dr Gallego-Schmid research work on sustainable energy (electricity and heat) is focused on developing countries. Dr Gallego-Schmid, Dr Stamford and Professor Azapagic supervise the research of Mr Aberilla and Mr Gaete-Morales and on the sustainability of the polygeneration energy systems for remote and off-grid communities in the Philippines and of actual and future electricity scenarios in Chile.

In the case of the Philippines, Life Cycle Assessments (LCAs) on potential technologies (namely diesel, solar PV, micro wind, biomass combustion, gasification and anaerobic digestion) for small-scale autonomous electricity production have been done. The results show that compared to diesel generators, the renewable technologies have lower life cycle impacts in many categories such as climate change, air pollution, acidification and eutrophication. However, some impacts are higher as well (e.g. metal depletion for solar and wind, terrestrial ecotoxicity for biomass). Among the technologies investigated, anaerobic digestion of animal manure provides the lowest impacts across almost all categories. This is primarily due to the co-services of manure management and digestate use as a fertiliser. Future work will extend the study to heating and cooling technologies, as well as economic and social life cycle assessment.

The electricity mix of Chile in 2014 was shaped by 41% coal, 34% hydro, 14% natural gas, 4% oil, 4% biomass, 2% wind and 1% solar with a total generation of 70 TWh and 20 GW of installed capacity. If compared per kWh of electricity produced, wind power and hydropower are the most environmentally sustainable options. Solar power is the option with the highest impact in abiotic depletion of elements and the second largest contributor for freshwater and marine aquatic ecotoxities. Biomass has the highest impact for photochemical oxidants creation and oil for ozone layer depletion. Natural gas has the third largest contribution to global warming and abiotic depletion of fossil resources. Finally, coal is the option with the highest impacts for eight categories: global warming, human toxicity, acidification, eutrophication, abiotic depletion of fossil resources, and marine, freshwater and terrestrial ecotoxicities. Future work will focus on social and economic aspect and analyse future scenarios for year 2050.

Dr Gallego-Schmid, Dr F. Mendoza, Dr Schmidt-Rivera and Professor Azapagic are studying the sustainability implications of the use of solar cookers instead of microwave for heating food in Spanish urban areas. Preliminary results show the use of home-solar cookers could avoid a significant emission of greenhouse gases, reduce household waste generation and electricity requirements.

Finally, Dr Gallego-Schmid, in collaboration with Dr F. Mendoza, and Professor Azapagic, has studied the environmental effects of European Union regulations in energy-related products like vacuum cleaners, microwaves or kettles. For example, for vacuum cleaners, the implementation of European policies in 2020 are expected to reduce by 20%-57% twelve different environmental impacts compared to the current situation, with the global warming potential being 44% lower than today.

Bio-based research for industry

Julian Steer

Centre for Research in Energy,

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Centre for Research in Energy, Waste and the Environment (CREWE)

Cardiff University in the UK is at the centre of the capital city of Wales, it is a research intensive university, ranked 5th in the 2014 UK Research Excellence Framework (REF). Based in the School of Engineering, the CREWE centre's research focus is to provide efficient, reliable heat and power generation, whilst moving towards a lower carbon economy.

Biomass Research in Ironmaking and Steelmaking

The steelmaking industry is a significant emitter of carbon dioxide and is keen to explore opportunities to reduce the industry's contribution of this greenhouse gas into the atmosphere. Biomass has been investigated as a potential source of renewable feedstock and in the following list are examples of work carried out on this and related areas:

- The **utilisation of different forms of biomass**, or bio-based materials such as paper waste, for injection into the blast furnace as an alternative reductant to the coke predominately used for ironmaking.
- The incorporation of **biomass as a catalyst/additive** to improve the combustion and gasification of injected coals.
- The **role of surface chemistry** on the reactivity and physical properties of reductants in this context.
- Biomass as a reductant in the **carbothermal processing and recovery** of steelmaking process dusts.
- **Utilisation of unconventional gas mixtures** such as syngas derived from biomass.
- Potential **utilisation opportunities for carbon dioxide** by the Boudouard reaction.
- **Differentiation of the types of carbon** in dust emissions, using analysis by X-ray Photoelectron Spectroscopy, Thermogravimetric analysis and microwave techniques.

Researcher Profile

An Industrial Research Fellow supported by **TATA Steel UK** through the **Ser Cyrmu** funding scheme in Wales, I conduct collaborative research with the Steel industry in Europe in the fields of energy and materials recovery, with the aim of improving their process efficiency, reducing the environmental impact and investigating alternative technologies for the future of the industry. Particular areas of interest and expertise include:

- Thermal conversion & processing of solids, liquids and gases for energy (combustion, gasification, pyrolysis).
- Analysis and characterisation of surface chemistry and material properties of solid fuels, polymers and plastics.
- Catalysis, surface treatment and hydrometallurgical extraction.
- Carbon dioxide utilisation.

Development of advanced bio-energy technologies

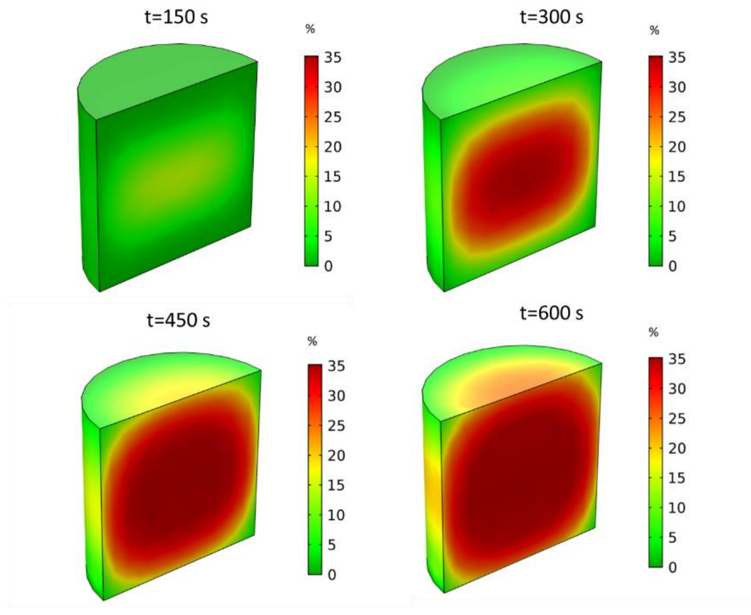
Dr. Siddharth Gadkari and Prof. Sai Gu

Department of Chemical and Process Engineering

Email:s.gadkari@surrey.ac.uk

Surrey is a world-class, research-led University, committed to research excellence. Department of Chemical and Process Engineering (CPE) at Surrey is the oldest continuing chemical engineering programme in England and has long-standing collaborations with the chemical industry. Clean energy production and Bioenergy are among the priority research interests of CPE with specific focus on fast pyrolysis and other advanced technologies for biofuel production. CPE is also UK's leading department in research of biorefineries, hybrid refineries and biomass life-cycle analysis. Overall, CPE's research in bioenergy plays a vital role to achieving the energy transition from fossil to renewable suorces pursuing a sustainable energy model based on bioeconomy.

My work is mainly focussed on CFD modeling of new biomass treatment processes such as those based on microwave or plasma technologies which have the potential to enhance productivity and reduce the emissions compared to the current processes. The microwave assisted biomass pyrolysis process is aimed at improving the efficiency of the system using targeted microwaves for heating instead of conventional heating sources. From a modeling perspective, the presence of a large number of coupled phenomena make this process highly complicated to model. I have developed the first 3D coupled mathematical model accounting all the important physics for microwave assisted biomass pyrolysis process. This model helps to predict and dynamically visualize the multiphysical behavior of the whole integrated system.



Volume plot of increasing tar concentration when a biomass sample is subjected to microwave pyrolysis

I am also working on an EPSRC funded project focussed on developing a novel gas cleaning process based on low temperature plasma/catalytic technology to produce a clean, high quality syngas from the gasification of waste biomass (EP/M013162/1). I am developing plasma-catalysis models for partial and fully packed dielectric barrier discharge (DBD) plasma reactors to understand the influence of catalyst packing on the discharge performance and the overall contaminant conversion. These models will help in identifying the optimum catalyst packing configuration in the DBD reactor for maximum conversion.

In addition, I am working on development of dynamic models for bioelectrochemical systems (BESs). BES such as microbial fuel cell or microbial electrosynthesis system use microorganisms to facilitate oxidation/reduction processes through the release/capture of electrons from an electrode. These systems have drawn great attention in recent years as an emerging technology for energy-efficient wastewater treatment, desalination, electricity generation, and chemical production. The dynamic models will help to determine the influence of operational and biological parameters on the overall system performance.

Production/techniques of high value products using biomass processing, to produce energy that can be used for further biotechnology applications

Dr. Mayri Alejandra Diaz De Rienzo
Lecturer in Biotechnology
Liverpool John Moores University
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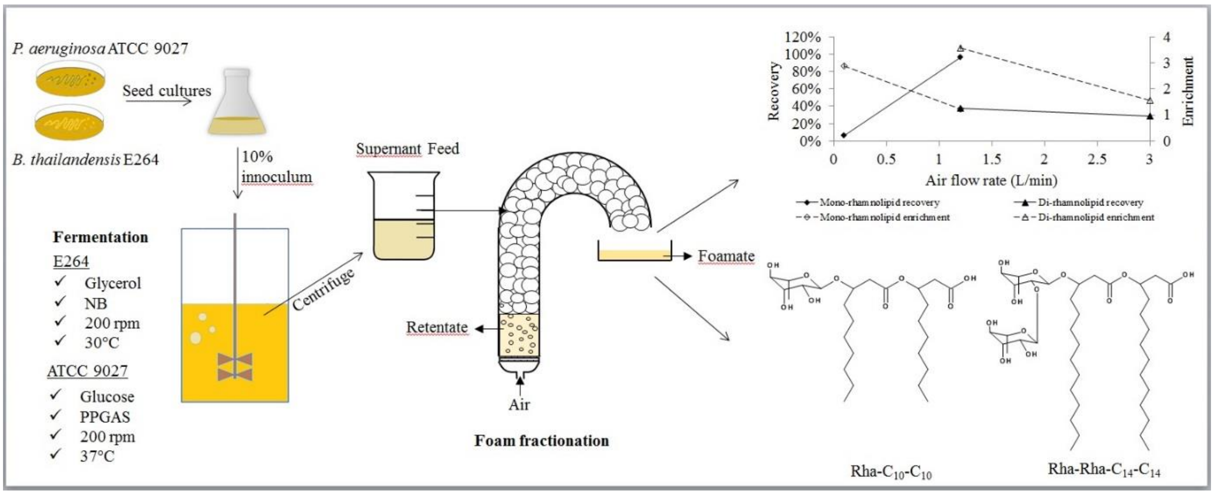
Surfactants or surface active agents are substances capable of reducing energy hydrogen bounds between water molecules, i.e., reduce the force of surface tension of water. These have been used in a wide range of applications, among which are: agriculture and food industry, in industrial processes involving mineral flotation and leaching of minerals as well as in the textile industry and the ***oil industry***. Due to the inconvenience caused by synthetic surfactants recent studies have been conducted, aimed at finding alternative products compatible with the environment, having demonstrated the feasibility of production of these compounds from microorganisms. The biosurfactants produced by some microorganisms, are biodegradable, biocompatible and stable activity in extreme environments. Many of these biosurfactants produced by *Pseudomonas aeruginosa*, have been characterized and studied as agents capable of removing hydrophobic compounds from soil. Our research aims to study the production of biosurfactants from different species of microorganisms in aerobic and anaerobic conditions, using PAH's as carbon sources in order to obtain the better performance in terms of biomass and production of biosurfactants, since these have been used in a wide range of applications, especially in the oil industry, where they are used in the solution of problems caused by interfacial phenomena from drilling operations to the packaging of finished products. I have over twelve years of experience in Fermentation and downstream processing of biosurfactants, with a global experience in initiative design and development of techniques for the use of biosurfactants in the petroleum/cosmetic/health care industry. Currently I'm focus in the use of foam fractionation in continuous stripping mode as a downstream process for the recovery and enrichment of rhamnolipids produced by *Pseudomonas aeruginosa* and *Burkholderia thailandensis*. The effects of air flow rate on the foam properties and foam fractionation separation efficiency of rhamnolipid from both microorganisms it's been investigated as well in my group. As part of the purification process there is the potential use of rhamnolipids as antimicrobial agents and disruptors of biofilms pre-formed by different microorganisms. I hope to expand the bases on my knowledge about the production/techniques of high value products using biomass processing, to produce energy that can be used for further biotechnology applications.



The use of waste cardboard, polymeric fibres and agricultural by-product in manufacturing of fibre- ement composite board

Name(s): **Dr Morteza Khorami**

Organization or Institution: **Coventry University**

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Coventry University (CU) is an ambitious and innovative university, delivering research that makes a significant contribution to a number of global challenges. It has 12 research centres focusing on a range of real world issues including sustainability, disease prevention and innovative engineering.

Abstract:

After banning asbestos fibres due to its hazardous effects on human health, finding alternatives fibres to produce Fibre Cement Board has drawn the researcher's attention. The investigations for a replacement of asbestos fibres resulted in many synthetic and natural fibres being examined in numerous laboratories around the globe.

In this research, the applications of Agricultural-Waste Fibres (AWF), waste cardboard and polymeric fibres are considered in producing the fibre-cement composite boards (FCB). A broad range fibres including; baggase fibre, wheat fibre, eucalyptus fibre, waste cardboard and some polymeric fibres are applied to produce FCB. Moreover, the effects of silica fume and lime stone powder are studied on mechanical and physical properties of FCB made of these novel materials.

The results showed some of aforementioned fibres and materials has potential to produce FCB. The results of the carried out research has been published in many journals and conferences such as;

1. Ganjian. E; Khorami, Morteza ,''Application of Kraft and Acrylic Fibres to Replace Asbestos in Composite Cement Board" IIBCC , the 11th International Inorganic Bonded Composite Conference, Madrid, Spain. , Nov 2008.
2. Gnjian. E, Khorami, Morteza; Parhizkar. T "Production of Cement Composite Board Using Cellulose Fibre" Second International Conference on Sustainable Construction Materials and Technologies June 28, 2010 - June 30, 2010, **Ancona, Italy**.
3. M. Khorami, E. Ganjian, "Comparing flexural behaviour of fibre–cement composites reinforced bagasse: Wheat and eucalyptus", **Construction and Building Materials.** 25 (2011) 3661-3667.
4. M. Khorami, E. Ganjian, "The effect of limestone powder, silica fume and fibre content on flexural behaviour of cement composite reinforced by waste Kraft pulp", **Construction and Building Materials.** 46 (2013) 142–149.
5. Ganjian, E, and Khorami, M, "Flexural strength behaviour of fibre cement board reinforced by blast furnace Slag fibres", 14th International Inorganic Bonded Fibre Composites Conference, **Da-Nang, Vietnam**, pp 123-134, 15th -19th September 2014.
6. Khorami, Morteza, Ganjian, E. & Srivastav, A. 2016, "Feasibility Study on Production of Fiber Cement Board Using Waste Kraft Pulp in Corporation with Polypropylene and Acrylic Fibers", **Materials Today**: Proceedings, vol. 3, no. 2, pp. 376-380.
7. Khorami, Morteza; Gnjian. E. 2016 ; "Improvement of flexural performance of fibre cements composite board through fibre impregnation." 4th International Conference on Sustainability Construction Materials and Technologies (SCMT4), **Las Vegas, USA,** August 7-11.
8. Khorami, Morteza., Ganjian, E., Mortazavi, A., Saidani, M., Olubanwo, A. and Gand, A., 2017. Utilisation of waste cardboard and Nano silica fume in the production of fibre cement board reinforced by glass fibres. **Construction and Building Materials**, 152, pp.746-755.

Software development for bioelectrochemical systems

Mobolaji Shemfe, Kok Siew Ng and Jhuma Sadhukhan

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As the search for sustainable alternatives to fossil fuels has intensified, bioelectrochemical systems (BESs) have been generating significant research interest. A BES is fundamentally an electrochemical device, aided by pure cultures or bacteria communities, or isolated enzymes to catalyse redox reactions of biodegradable substrates to generate electricity, fuels, and chemicals, depending on the mode of operation. The main modes of operation of BES, currently being trialled at various research laboratories around the globe, include microbial fuel cells, microbial electrolysis cells and microbial electrosynthesis systems. The primary driver for the upsurge in interest in BESs is their suitability for the production of sustainable energy, along with other synergetic benefits, including wastewater treatment and resource recovery. A process illustration of a BES for CO_2 reuse is shown in figure 1.

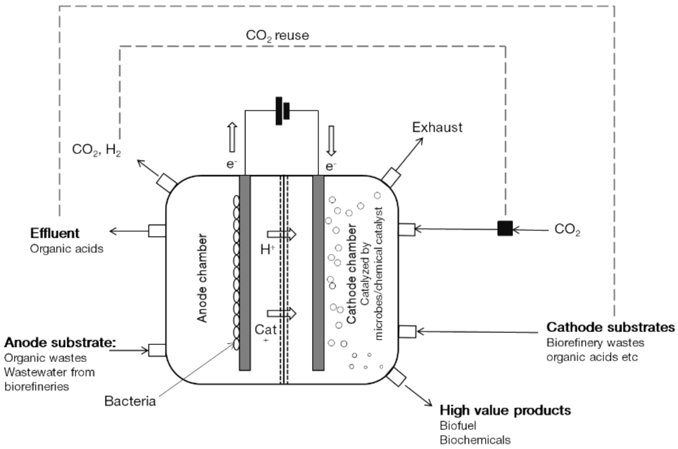

Figure 1 A process diagram of BES for CO_2 reuse

Despite the apparent benefits of BESs to tackling various global issues, such as climate change, waste management and pollution, there is no modelling software/tool for assessing their sustainability. This is partly because BESs are riddled with intrinsic complexity: non-ideality and underlying physical-chemical, biological and electrochemical phenomena. Nevertheless, a robust tool for assessing the sustainability of BESs is of critical importance, as it can not only help to dictate the direction of research and development, but it can also help with the sustainable acquisition of inventory among alternatives for the system. The development of such tool necessitates four major components: thermodynamic/kinetic evaluation module, an economic evaluation module, an environmental evaluation module and a social evaluation module.

For this purpose, “Global Sustainability and Engineering analysis of Resource recovery Technologies” (GSERT™) coined by Jhuma Sadhukhan under trademark processing, is currently being developed. GSERT™ is a first of its kind tool for assessing the life cycle sustainability of various configurations of BESs. Based on input data, e.g. substrate COD, the material of construction of electrodes, catalyst type and operating conditions, GSERT™ can predict operational performance, life cycle cost, economic performance and environmental and social life cycle benefits or impacts. The tool has been developed to aid effective decision making for researchers and policy formulators interested in the technology. The philosophical framework of the software is depicted below in Figure 2.

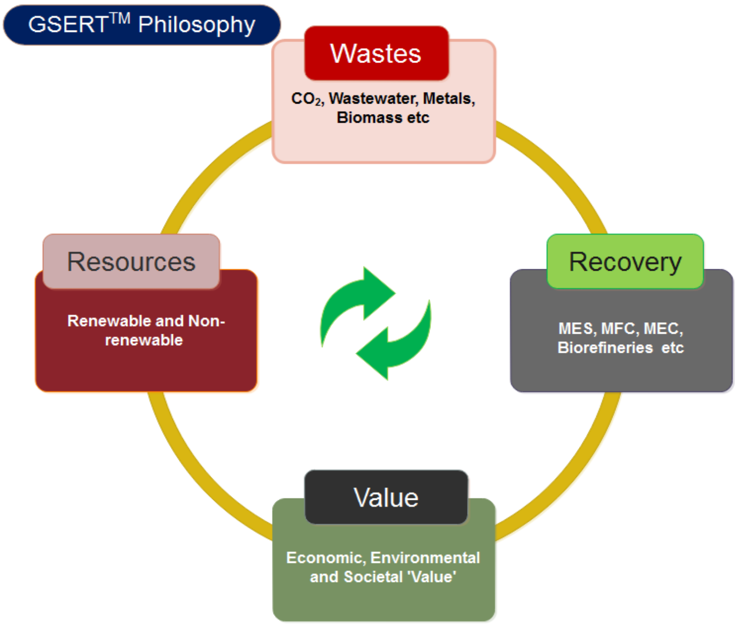

Figure 1 GSERT philosophical framework

The software has application across various industries, including biorefineries, mining and metal manufacturing and plating sectors, where it can be used for quick evaluation of the generatable value from industrial wastewater and effluents. For example, in biorefineries, the value of converting low-value waste streams and CO_2 into high-value products can be quickly assessed, thereby suggesting possible ways of enhancing the polygeneration potential and energy and conversion efficiencies of the system. Similarly, the value of wastewater from mining and metal industries, typically containing metal ions that are recovered by low efficiency methods, such as chemical precipitation, filtration, conventional electrochemical methods and solvent extraction, can be adequately assessed by GSERT™, giving industrial decision makers an array of options for either integration of BESs with traditional methods or its sole application.

While the software is still at the prototyping stage, considerable progress has been made towards it commercialisation. Work in the pipeline includes improvement to software functionality: dynamic simulation mode, the capture of microbial growth and activity in BESs, the inclusion of policy analysis in particular country context, and the addition of carbon tax in the economic analysis module etc. The robust modular nature of the software makes it applicable to biorefinery systems, and possibly other chemical industries.

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Energy Harvest: Bio-Energy from waste

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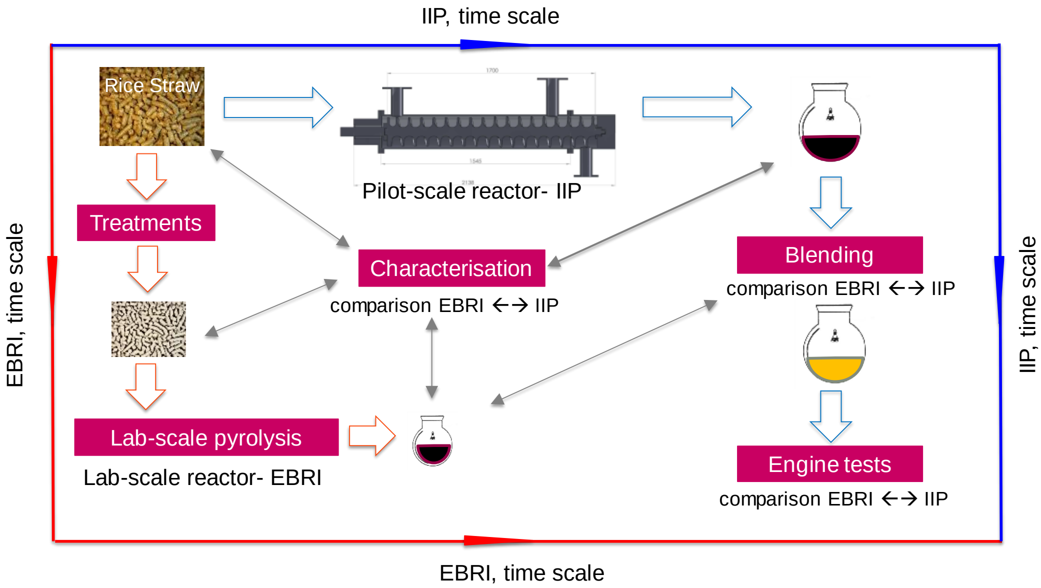
The **European Bioenergy Research Institute (EBRI)** is focused on research activities on scientific and technological aspects of biomass conversion and utilization of products for renewable power, heat, transport fuels, hydrogen and chemicals. The main research objectives of EBRI are to develop world class research into all aspects of Bioenergy, developing innovative thermal biomass conversion technology, creating energy from waste and residues, delivery local bioenergy schemes through North-West Europe.

The Bio Oil Energy Harvest Project is addressed to stop crop burning in the Punjab region, India, by the valorisation of their agricultural residues, mainly rice straw. The objective of the project is to obtain a liquid pyrolysis product that has an industrial or domestic use (*i.e.* transport fuel, or feedstock in bio-refineries). Pyrolysis is the thermal decomposition of biomass in absence of oxygen, producing pyrolysis liquid, also called "bio-oil", char and py-gas. Temperature, particle size and residence time mainly affect the quality and products yield.[1] The biomass studied in this project is rice straw. As a lignocellulosic feedstock, it has three main components: cellulose, hemicellulose and lignin. Lignin is the component that bond cellulose and hemicellulose, forming the biomass structure. Studies on thermal decomposition of lignocellulosic biomass showed that lignin decomposes at higher temperatures than cellulose and hemicellulose[2]. Therefore, a pre-degradation of lignin will make more easily available the cellulose/hemicellulose thermal deconstruction.



The project is a collaboration between EBRI (UK) and Indian Institute of Petroleum IIP (India). The Scheme above gives an overview of the collaboration activities and interactions between the partners. A pilot scale auger-screw reactor is installed and being tested at the IIP and a lab-scale smaller replicate reactor is placed in EBRI to perform optimisation and comparative studies. Experimental results at both reactor length scales will be compared, in terms of biomass quality/properties, pyrolysis liquids, blends and engine tests.

Acknowledgments. Authors thanks the Oglesby Charitable Trust for the financial support of the project.

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Catalytic reforming of biomass-derived liquids for the sustainable production of hydrogen

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Among the main thermochemical biomass conversion technologies, pyrolysis, producing high energy density liquids, is especially attractive for the production of chemicals and fuels, while gasification is highly efficient as a power generation technology. Bio-oil, the liquid product of pyrolysis, can be steam reformed to produce hydrogen, the latter either utilised as an energy carrier in the framework of fuel cells or used to further upgrade bio-oils to fuels and chemicals via hydrodeoxygenation. Similarly, tars, the volatile products of gasification, can be steam reformed, in situ or downstream of the gasifier, to enhance the efficiency of the process. The fundamental understanding of the reforming of the, chemically similar, bio-oil and tar is, thus, of critical importance to the development of efficient biomass upgrading processes.

The work focuses specifically on the experimental and computational investigation of the reforming of selected bio-oil and tar model compounds, aiming at the development of an elaborate mechanistic understanding. The fundamental knowledge gained will, ultimately, allow the optimal design of catalytic materials, enabling the faster implementation of these biomass upgrading processes. Currently, ethanol, a model compound of the aqueous phase of bio-oil, is investigated over Ni catalysts, while the use of noble metal catalysts and the study of phenol and cresol representative of tars are planned.

Experimentally, a kinetic study of ethanol steam reforming over Ni supported on Sepiolite and Silica has revealed a striking difference on the order of the reaction in terms of the two main reactants (Figure 1). Results on Ni/SiO_2 suggest a metal-dominated reaction pathway, where the decomposition of ethanol on Ni sites is the rate determining step, with steam derived intermediates contributing only to the equilibrated water-gas shift reaction. On the other hand, on Ni/Sepiolite a water activation-limited is observed, indicating the occurrence of ethanol activation on the acid sites of the support.

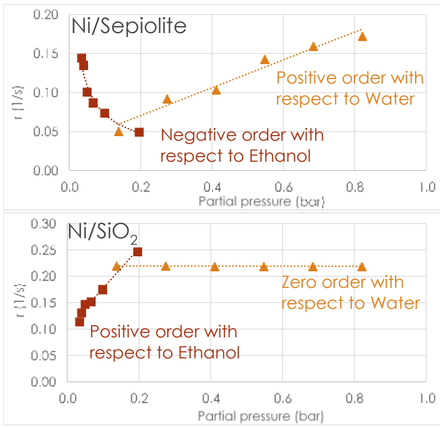

Figure 1. Experimentally determined reaction orders of ethanol steam reforming at 400°C

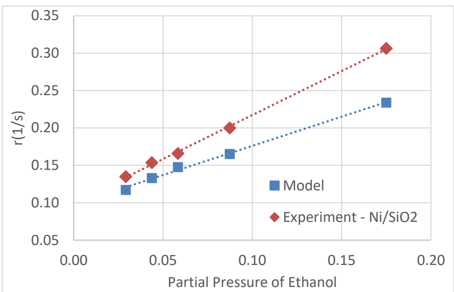

Figure 2. Comparison of model predicted and experimental reaction orders in respect to ethanol

The modelling work focuses on the development of a thermodynamically consistent microkinetic model, aiming at the further elucidation of mechanistic details. The prevailing reaction chemistry is currently described via a reaction network of 66 elementary steps among 8 gas-phase molecules and 22 surface intermediates. Kinetic parameters are calculated *a priori* via various methodologies (e.g. collision and transition state theories and UBI-QEP calculations). Results agree well with a metal-dominated reaction mechanism, as observed on Ni/SiO_2 (Figure 2). Extensions are currently being implemented in the model to explicitly account for support effects and elucidate the differences among the two catalysts, while *in situ* IR spectroscopic investigations are underway to provide further mechanistic insight.

Collaborating researchers: Marinela Zhurka (PhD student on experimentation), Teejay Afolabi (PhD student on modelling), Prof James Anderson (Professor in Chemical Engineering), Prof Chun-Zhu Li (Director of Fuels and Energy Technology Institute, Curtin University, Perth, WA)

Advancing Innovation in Energy and Resource Recovery from Fecal Sludge: A case-study of the Nano-membrane Toilet

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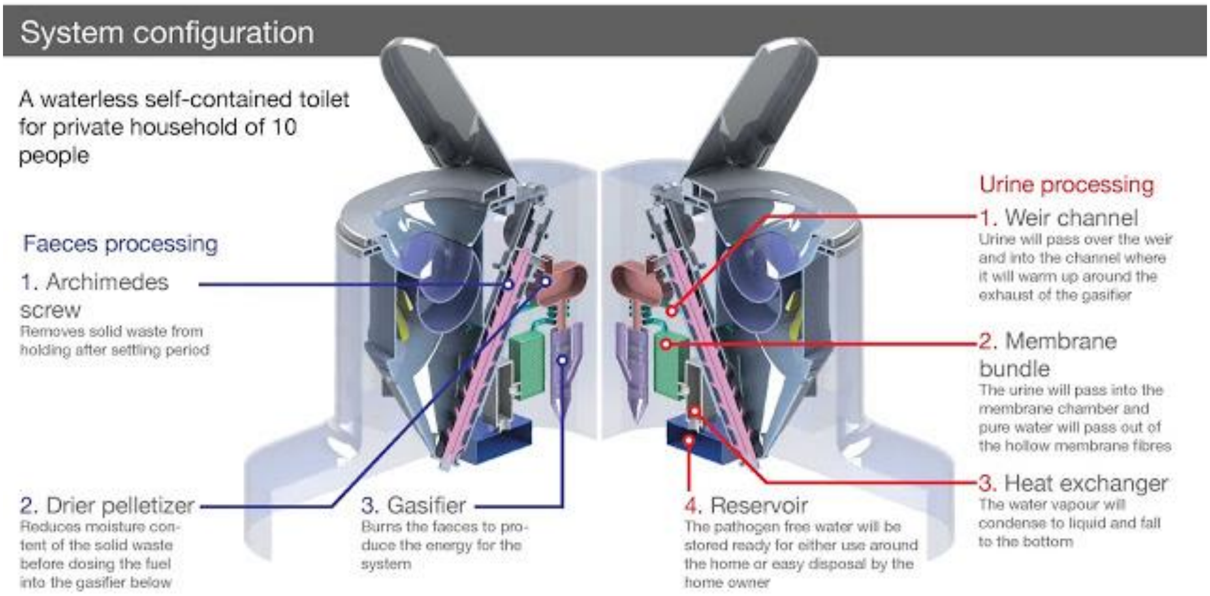
As the UK's only exclusively postgraduate university and one of the UK's top five commercial research-intensive universities, Cranfield University specialises in science, engineering, technology and management. The University is focussed on creating leaders in technology and management, unlocking the potential of people and organisations by partnering with business and governments to deliver transformational research, postgraduate education and professional development.

As part of the Nano Membrane Toilet, a project funded by the Bill & Melinda Gates Foundation 'Reinvent the Toilet Challenge', my research is focussed on recovering energy from faeces. The Nano Membrane Toilet is being developed to enable those without modern sanitation to have access to safe, clean and hygienic facilities. The toilet employs processes such as thermochemical conversion and water purification via membranes to thermally treat faeces and urine. As a result, useful by-products such as clean water, fertiliser and electricity are recovered without external energy, water or sewer connections.



This research is of significant economic importance and can enhance health, well-being and welfare, considering the amount of environmental pollution, land degradation and spread of parasitic worms and infectious diseases that are associated to poor sanitation. The use of faeces and urine for energy generation can cause a shift in the use of resources and energy paradigm of the conventional flush toilet.

No WasteR Cities project – Novel approaches for Waste management to Reduce environmental impact of Cities

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The Unit of Research Projects and Environmental Engineering (UPIIA), Faculty of Chemistry, National Autonomous University of Mexico (UNAM), is a multidisciplinary research group, using a wide range of chemical engineering tools to understand and optimize biomass conversion to renewable energy, including: wet and dry Anaerobic Digestion, kinetic modelling, heterogeneous catalysis, analytical chemistry, and conceptual process design. These tools have been combined to develop a number of technologies for the production of clean energy.

Currently, the list of the environmental problems is quite long and further actions are needed to catalyze sustainable activities across many areas. The fact that oil reserves are depleting, looking for renewable sources is essential. Biomass resources such as the Organic Fraction of Municipal Solid Waste (OFMSW) is one of the largest issues in Mexico City but also offers an opportunity to exploit this resource to generate energy and other useful products while reducing pollution. I am currently in the 4th year of my PhD research and my project focuses on improving the performance of anaerobic digestion, from waste streams that currently have no widespread use and can be utilized for bioenergy production. Due to heterogeneous composition, OFMSW has a high potential of biogas production, however the unbalance of carbohydrates, lipids and proteins can make the process prone to failure; codigestion with co-substrates rich in proteins i.e., cheese whey and meat waste, seems to be an option to enhance biogas production.

Seeking for more integrated ways to waste management and processing for resource recovery, a joint project was formulated with the University of Bath. From this idea, the collaborative project "No WasteR cities" emerged between Dr. Elias Martinez Hernandez (at Bath) and my supervisor Dr. Alfonso Duran Moreno (at UNAM). This gave me the opportunity to travel to Bath for a one-month research visit. The aim of the project is to develop waste processing systems for energy and resource recovery in Mexico City, combining anaerobic digestion (AD) and hydrothermal liquefaction (HTL) in a biorefinery concept.

During my visit I performed hydrothermal liquefaction reactions in a batch reactor as shown in Figure 1, focussing on three substrates: food waste, digestate and synthetic food waste separately and in combination with plastic waste. This research has provided insights by identifying some configurations for feedstock, technology, and energy vectors.

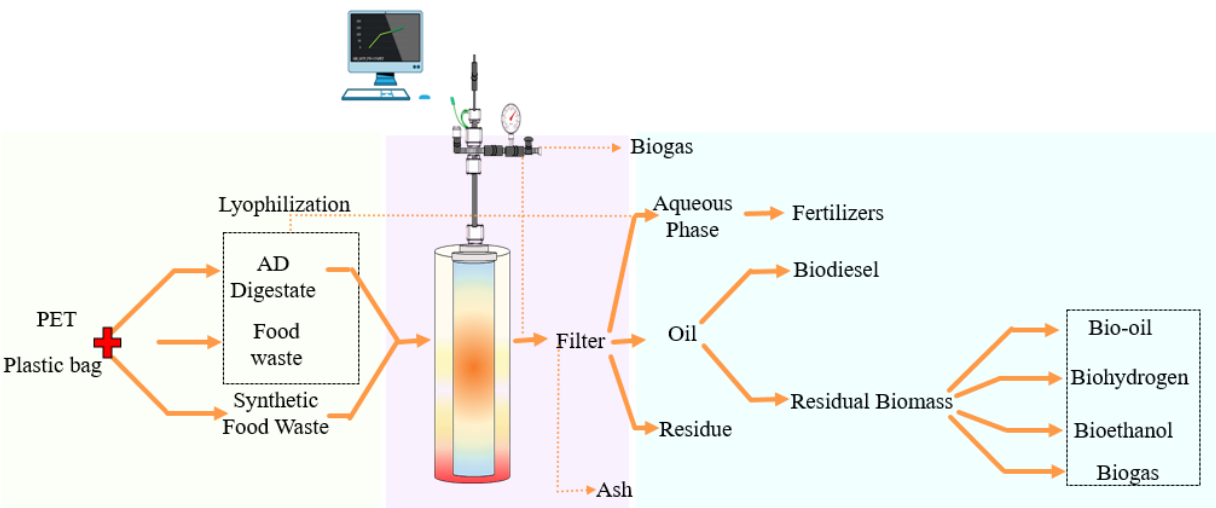

Figure 1. Integrated AD and HTL for a waste biorefinery concept

Solar Hydrothermal Liquefaction of Waste for Biofuels & Aquafeeds

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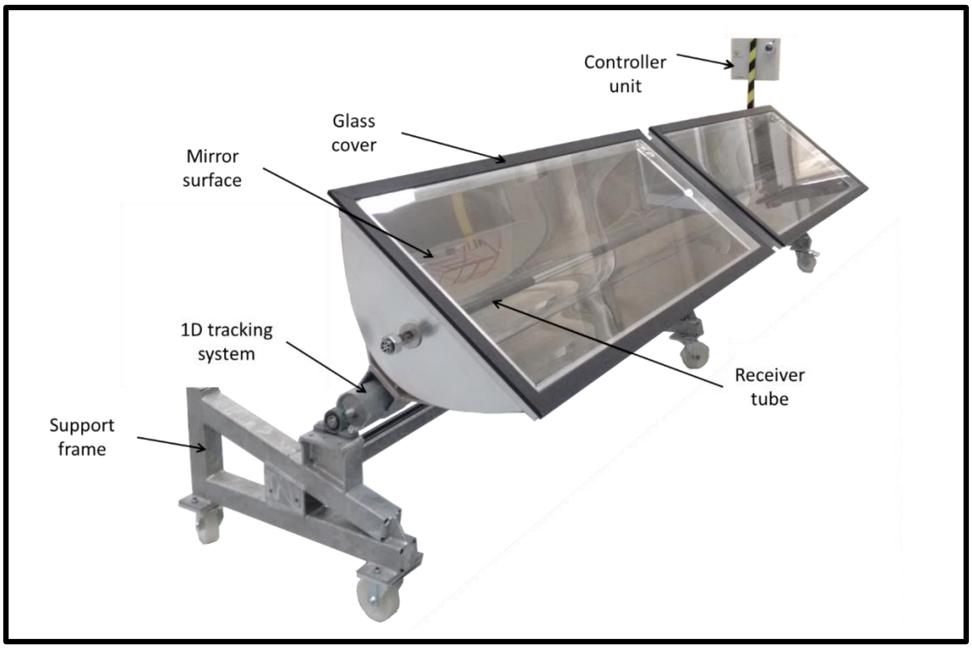
Phycofeeds integrates the engineering of solar thermal energy for Hydrothermal Liquefaction (HTL) to produce bio-oil rather than electricity generation. This area of research has not been widely reported by other authors'. Phycofeeds investigates the experimental scale-up and development which influence factors uniting HTL and Concentrated Solar Power (CSP) parabolic troughs for waste feedstock processing into bio-oil. Beneficial operational temperature requirements for HTL occur within the range of 250-350°C. A thermodynamic and practical analysis with experimental field trials of waste feedstocks justifies the potential viability of this technology integration.



Solar collectors are designed and manufactured by Global CSP Ltd (UK). New receiver tubes have had to be designed to handle the high pressure and temperatures required for bio-oil production. Solar receiver tubes are made of stainless steel and pressure valves with innovative internal arrangements, the pressure vessel tolerance of which is presently being evaluated. During early phase business development and production volumes, a key focus is to demonstrate the scaling up of the process from a lab to field scale. The integral design of the solar receiver as part of the solar captor should correlate with cost-efficiency savings of the overall HTL conversion process. Four feedstocks are being tested: microalgae. animal manures, PET plastic and sugar cane bagasse, Primary target markets are countries close to the equator (i.e. Asia, Southern Europe and Latin America) with high levels of solar energy. Bio-oil production for use as a feedstock and microalgae for aquaculture feeds will provide benefits for local rural communities.

Farm-based Biorefining Concept

Name(s): **Dr. Namdar Baghaei-Yazdi**

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Biotech Consultants Limited (BTCL) is a technology development SME specialising in optimising the performance of the microorganisms for the scale up, enhancing microbial production of high value added chemicals through selected evolution and pathway enhancement techniques. The company's in-house R&D programme, using their proprietary thermophilic microorganisms, focusses on valorization of waste biomass and residues into bio-products, which can be used as platform chemicals and renewable raw materials in chemical, food, cosmetic and pharmaceutical industries. BTCL brings expertise in the development of thermophilic fermentation processes, coupled with the wide-ranging industrial biotechnology and management skills. The BTCL team has over 25 years experience in the molecular engineering of *Geobacillus* together with considerable fermentation and analytical capabilities. BTCL has been involved in biorefinery projects and intends to continue operating in this exciting field. One past EU FP7 project that they were involved was titled: "Sustainable Liquid Biofuels from Biomass Biorefining" (SUNLIBB).

<u>**Key members:**</u> **Dr. Namdar Baghaei-Yazdi** is the Managing Director of BTCL with 30 years of experience in Microbiology and Biotechnology research and commecialisation, especially in the fields of biofuels, oil and gas microbiology and biodesalination. Namdar has his name on a number of publications and patents. He has a BSc degree in Microbiology from King's College London and a PhD in Biotechnology from Imperial College. **Dr. Muhammad Javed** is BTCL's Chief Science Officer with over 30 years of experience in Microbiology research and he has filed a number of patents. He has significant experience in engineering the metabolism of bacteria and archaea. He has an excellent understanding of primary metabolic flux analysis and has gained invaluable experience of the fermentation process development for metabolic products especially those of thermophilic ethanol production.

BTCL is currently involved in developing a farm-based biorfining project at a farm in East Anglia, UK in collaboration with the company that owns the farm. The picture above shows the biomass hydrolysis and fermentation pilot plat that they will use in this project.

Catalytic conversion of Biomass into Biofuels and Fuel additives

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The dwindling of fossil reserves and CO_2 emission problems encouraged many researchers to develop new technologies for the transformation of renewable resources to bio fuels and useful chemicals. Biomass derived carbohydrates are the most accessible renewable resources and possess great prospective as raw materials to produce fuels and bulk chemicals. These carbohydrates can be transformed to platform chemicals like 5-hydroxymethyl furfural (HMF), furfuryl alcohol (FAL), levulinic acid (LA) and its esters. Production of different bulk chemicals like HMF is considered as potential substitute for petroleum derived building blocks. It is considered as a useful platform molecule to produce fine chemicals and fuel/fuel additives. HMF can be transformed to fine chemicals by hydrogenation, oxidation, esterification and etherification.

We have been working on the development of catalysts for the selective conversion of carbohydrates to chemicals and fuel additives (Fig 1). The preparation of 5-HMF from carbohydrates (glucose/fructose) was studied using different modified hereropoly acid catalysts [1,2]. Simultaneous conversion of carbohydrates to fuel additives like alkyl levulinates also studied by using Lewis induced heteropoly acid catalysts. The possible reaction pathways and the role of catalysts actives sites were studied in detailed in conversion of carbohydrates or HMF in to fuel additives. Synthesis of fuel additives from furfural and levulinic acid were also explored and optimised at lab scale [3]. The waste biomass was also utilized to convert it in to biochar and used as catalysts or support in conversion of biomass in to chemicals or fuel additives (Fig 2) [4].

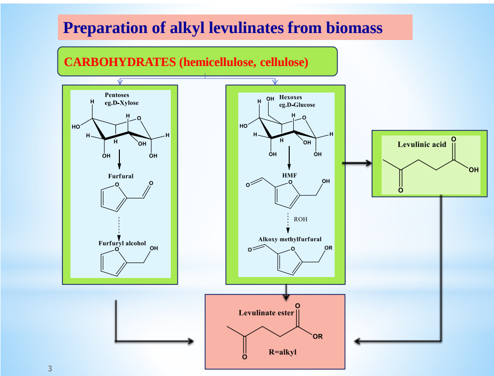

Fig 1. Biomass derived chemicals to alkyl levulinates

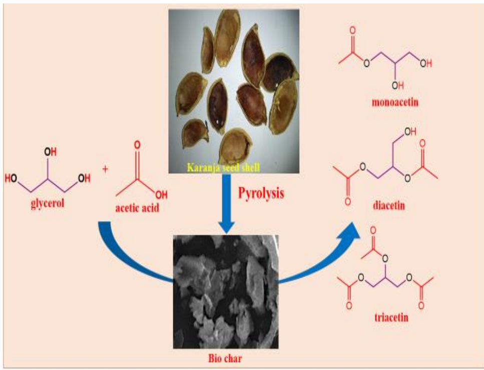

Fig 2. Waste biomass to bichar and its catalytic applications

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Catalytic route to renewable transportation fuels

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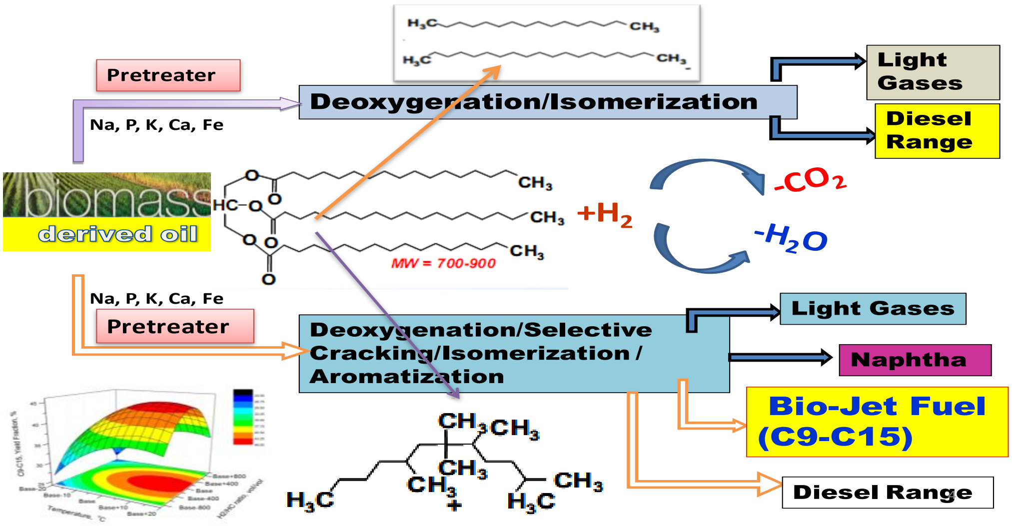
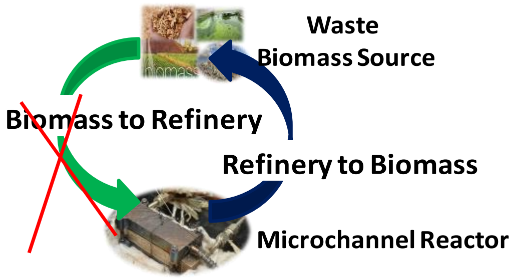
Technology development for the conversion of vegetable oils into biofuels is the major research area. Drop-in type aviation biofuels and renewable diesel can be utilized in the aircrafts and vehicles, respectively, without any need for modifications to engines. Bio-jet fuel is better than conventional Jet A-1 fuel in terms of high energy density and required Aromatics content. Drop-in renewable diesel, unlike bio-diesel, has no storage stability issues, is pure hydrocarbon, is not oxygenated and has high cetane.



Other research activity in the biofuels area is development of process know-how for conversion of renewable feeds into bio-fuels in microchannel reactors. Process intensification using microchannel reactors based modular units has advantage of higher throughput. Due to size reduction of the unit it could be established at the source of the feedstock.



Recent Publications:

1. Mesoporous γ-alumina with isolated silica sites for direct liquid hydrocarbon production during Fischer-Tropsch reactions in microchannel reactor. August 2017, ACS Sustainable Chemistry & Engineering.
2. Hydrotreatment of jatropha oil over NiMoS catalyst supported on thermostable mesoporous silica doped titania for the production of renewable drop-in diesel. April 2017, Catalysis Communications.
3. Improved hydrogenation function of Pt@SOD incorporated inside sulfided NiMo hydrocracking catalyst. March 2016, Catalysis Science and Technology,
2. Kinetics, thermodynamics and mechanisms for hydroprocessing of renewable oils. April 2016, Applied Catalysis A.

Waste nutrients based algal biorefinery and its sustainability aspect

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Indian Institute of Technology - Roorkee is among the foremost of institutes of national importance in higher technological education and in engineering, basic and applied research. Since its establishment, the Institute has played a vital role in providing the technical manpower and know-how to the country and in pursuit of research. There are twenty-one departments and several centres and these units are engaged in research in various aspect of engineering and sciences.

Several departments and centres including Dept. of Civil Engineering are engaged in research on biomass based biorefinery. Currently, our group is working on waste nutrients based biorefinery, in which, algae has been used to remediate municipal wastewater, and produced biomass is being used to produce several value-added products including lipid, protein and carbohydrate. Besides, value added products recovery, produced algal biomass has also been used to recover nutrients and sugar through chemical hydrolysis route. For treatment of wastewater, algal species are being isolated from various water bodies, and from strain banks. These algal strains are further being used to estimate their efficacy to treat municipal wastewater and production of value added products.

Besides, experimental investigation on waste biorefinery, the sustainability aspect of the biorefinery has also been investigated through life cycle approach. In this study, various algal biorefinery scenarios were investigated in which waste nutrients are being used as the sole nutrients source. Four scenarios of algal biorefinery were investigated and energy demand, GHG emissions from 1 GJ of produced energy was estimated. Besides, energy demand and GHG emissions, variability of energy demand, biomass produced and carbon sequestration were estimated from using one unit of nutrient (i.e 1 ton of nitrogen, as nitrogen was limited in this case). The dynamics of nutrients and carbon sequestration were investigated through DNDC model and later an inhouse model was developed to estimate the carbon sequestration from land applied nutrients and residual biomass. The model estimates the carbon sequestration due to residual carbon remained in the biomass as well as from production of biomass on the field due to application of waste nutrients.

Book Review

Use for Biorefinery Engineering projects

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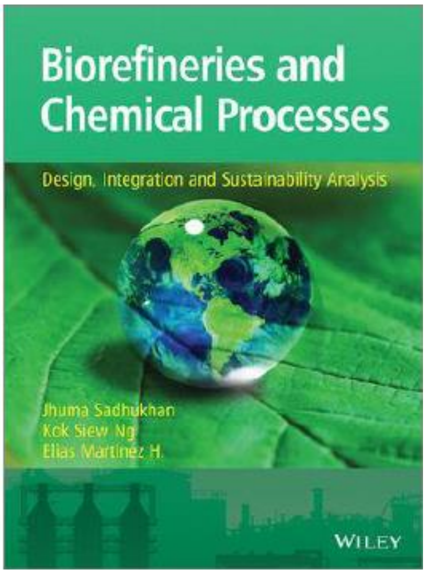
Biorefinery design case studies

In the development of engineering projects of the BSc. degree for chemical engineers, in the Faculty of Chemistry, UNAM, I proposed the use of the book "Biorefineries and Chemical Processes: Design, Integration and Sustainability Analysis". by Jhuma Sadhukhan, Kok Siew Ng & Elias Martinez H. published by Wiley. 2014. I find the book comprehensive and practical for final year students doing their final year dissertation and also in my class on Design Project. It is being used by me and my students to learn Material & Energy balances and to obtain the dimensioning of all equipment (by simulation models). The example I present here is about one project on biodiesel production from jatropha curcas oil as case study, including a preliminary analysis with waste oil & Higuerilla. We also made assessments between Heterogeneous Catalyst transesterification versus homogeneous catalyst.



The textbook used in the design and dissertation projects.

The species triglyceride, diglyceride and monoglyceride can be used to calculate the kinetics rates of reactions of oils with alcohols to produce fatty acid methyl esters (FAME) and then estimate the reactor's industrial size and validate the balance of matter and energy for different capacities. A way to introduce an industrial size plant is that students should learn that experimental research on design parameters is of great importance, but so is the conversion on an industrial and commercial scale, and comply with the elaboration of a business plan to confirm that the construction of a biorefinery is technically and economically feasible. They should also take care of the life cycle impacts on the environment and the value chain to achieve a sustainable project, while complying with the legal and regulatory framework in force in Mexico. In this case study ASPEN PLUS 8.8, NRTL and UNIQUAC methods were used for the simulation of an industrial size biodiesel plant.

The example demonstrated the importance for the decision-making on the acceptance of the project to install a biodiesel biorefinery that allows reducing to the maximum the risks of investment, in time, cost and scope properly defined to achieve success in the development of biorefinery engineering projects. This allows achieving the maximum use of biomass produced in México for sustainable projects.

Students

Ana K Brito performed the studies as the topic of her dissertation to obtain her Bachelor degree in Chemical Engineering.
Marcos Enrique Carpio Pineda from Ecuador studied in Mexico as external mobility student in the Bachelor degree in Chemical Engineering.

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University of Bath

University of Huddersfield

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inifap Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

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