The Biorefiner

Annual Magazine

2016

What does it mean to be a biorefiner?

Editorial letter

One year of the IBEST

An account of activities

Knowledge, knowers and biorefining! ♦ New bio-based technology for levulinic acid production from waste ♦ Organisation members' profiles ♦ Research showcases ♦ Book Showcase

IBEST *Advancing cross-disciplinary knowledge and education in Biorefinery Engineering*

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One year of the IBEST

by Dr Jhuma Sadhukhan

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The **Biorefiner** is the annual magazine of The IBEST.

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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Editorial letter

What does it mean to be a “biorefiner”?

Editorial Letter

By the Editors

Welcome to this very first issue of The Biorefiner! Turning biomass and waste streams - from industry, agriculture and from almost every activity, into valuable products is always in the mind of the *biorefiner*. In a world of cycles of cheap and expensive crude oil barrel (the direct competitor of biomass determining the pace of biorefinery deployments), climate change and resource scarcity, the biorefiner thinking is essential. In brief, the biorefiner can be defined as someone always up to the challenge and seeks to turn resource constraints and changing conditions into economic growth opportunities and social welfare thus contributing towards a sustainable bio-economy development. This is the spirit and driving force for this annual magazine.

In this first issue we feature an account of activities by the IBEST in its first year of age, including our two very successful research workshops, one in Mexico and one in Malaysia. The issue also features organisation profiles and research showcases from our members and we are extremely grateful to all of them who actively contributed to this issue. The IBEST is privileged by having their interesting, excellent and forward-looking research articles. New Biorefiner is a section for those new to the field who want to tell their story on how they embarked into the biorefinery arena and their ongoing work.

Through this first publication of The Biorefiner, the IBEST aims to create some stimulus for knowledge and research exchange in order to advance the field of biorefineries, and biomass and waste processing in general. As Prof Grant Campbell says in his Special Note, knowledge requires knowers and believers, we all have some of these and thus this magazine is dedicated to our current and future members for believing in what we pursue: to fully realise the biorefinery potential for providing sustainable energy, food ingredients, chemicals and materials for the sustainable future of our society.

Sincerely yours,

The Editors

Knowledge, knowers and biorefining!

Special Note

by Prof Grant Campbell

"Knowledge is power!" We believe that biorefineries have the power to make a positive difference to the world, and are committed to creating the knowledge and equipping the people to bring about the transition to a world where biorefineries take their place.

To those of us in the business of creating and transmitting knowledge in the context of universities, it's mildly interesting to note that, philosophically, a really robust definition of "knowledge" is elusive. A working definition, albeit inadequate, is that knowledge is "justified true belief" (inadequate in part because philosophers also cannot agree on definitions of the notions of truth, belief and justifying!). Alternatively, knowledge can be viewed as a sort of a link between a truth and a belief – a truth that is in some sense "out there" and a belief that is "in here". Whatever its other conditions, knowledge is only knowledge if it is true and if someone, somewhere believes it to be true. Engineers, being somewhat pragmatic, might be inclined to start from the perspective, a la George Box, that "All models [and knowledge, and design methods, etc.] are wrong; some are useful", thus evaluating our concepts of "knowledge" and "truth" against their empirical utility and accuracy. Even so, this useful knowledge is the kind that we value and that we try to create and disseminate; it is only knowledge if it is true to an adequate approximation and if someone out there is sufficiently aware of it and confident ("believing") of it to put it to use.

"We believe that biorefineries have the power to make a positive difference to the world"

All of which makes us philosophise about all that knowledge that is in old books that nobody reads any more. If a piece of knowledge, won at some point by the human race, and recorded in memory or in a book (or a modern digital equivalent) is no longer known by anyone, is it still knowledge? Apparently not, because knowledge requires a knower. When the last knower died, until and unless that knowledge is rediscovered, the knowledge borne by our little blue planet on behalf of the universe decreased as that piece died. More positively, how is the knowledge content of the planet increased? Apparently, by increasing the quanta of truths to be known, and by increasing the number of knowers. (And, if knowledge is viewed more than two-dimensionally to include justification as well, by strengthening the evidence base of the truth to be known.) In two dimensions, the sum total of knowledge is then the integral of the things known over the number of knowers.

Which is the more powerful mathematical operator: addition or multiplication? A basic principle of mathematics is that "more powerful operations have precedence over less powerful ones". Raising to an exponent is considered in general more "powerful" than multiplying (hence the expression "raising to a power") and is evaluated first in a mathematical expression, with addition and subtraction the weakest and undertaken last. So multiplication is in a general sense more powerful than addition. When it comes to the knowledge business as undertaken by universities, the business of creating and disseminating knowledge, which is more powerful – the addition of new knowledge (new truths to be known), or the multiplication of existing knowledge (via the creation of new knowers)? These two aspects of knowledge might naturally be identified with the research and teaching duties of universities. Whilst valuing the mutually edifying connections between research and teaching, from this perspective it might be considered that the teaching role of universities has the greater power to leverage knowledge for the benefit of the world.

Knowers and believers in biorefineries at an industrial visit in Malaysia.

"Knowledge is power!" In the context of this magazine's interest in biorefining, what, then, is our most powerful strategy for directing knowledge, via biorefineries, to address the problems and challenges we face in the post-oil age? Is our limitation insufficient truths to tackle the problems, or insufficient knowers competent to deploy those truths? It is well known that very little university research in science and engineering makes it to industrial application. Perhaps this is because there are too many creators of new knowledge, but too few knowers of both existing and new knowledge. Perhaps our greatest gift to the emerging biorefining community is people equipped to access and deploy knowledge to that end. In which case, what knowledge ought a biorefining curriculum contain? No doubt this will be a theme of this magazine.

To engineers, conservation of mass and energy are second nature. To information scientists, conservation of information is proposed as an equivalent law. But knowledge is not conserved – knowledge requires knowers, and the two are created and destroyed together. (Harvard president AL Lowell quipped "Universities are full of knowledge. The freshmen bring a little in, and the seniors take none away, and knowledge accumulates!") There is a well-known hierarchy in information science, the DIKW system – Data, Information, Knowledge and Wisdom. If Knowledge can be created, how much more so Wisdom – and how much more is this commodity required to deploy biorefineries, and other solutions, to the pressing problems of the coming century and beyond? How, then, do we also insert Wisdom into the curriculum of the biorefiner?

About the author

Professor Grant Campbell is an award-winning teacher of chemical engineering and researcher in cereal process engineering for food and non-food uses. Grant's research and teaching aim to create the knowledge and equip the people to allow cereals to meet, in integrated and synergistic ways, our food, fuel and chemical needs. Grant has a first class degree in Food Technology from Massey University, New Zealand, followed by a PhD from University of Cambridge. In 1995 Grant joined UMIST, now University of Manchester. Grant helped set up the Satake Centre for Grain Process Engineering, where he established world-class research on cereal biorefineries, wheat milling and aerated foods such as bread. Grant also contributed to undergraduate chemical engineering teaching at Manchester, winning several awards including the Institution of Chemical Engineers (IChemE) Morton Medal for Excellence in Chemical Engineering Education, and the IChemE Hanson Medal for an article on cereal biorefineries. In 2014 Grant was recruited to the University of Huddersfield as Professor of Chemical Engineering, to lead the introduction of the new chemical engineering programmes that build on Huddersfield's long strength in teaching chemical engineering within the chemistry context. Grant's ambition has long been to make chemical engineering "the best education ever devised", and his intentions for Huddersfield are to produce some of the most valued chemical engineering graduates in the country. Contact: g.campbell@hud.ac.uk

IBEST Advancing cross-disciplinary knowledge and education in Biorefinery Engineering

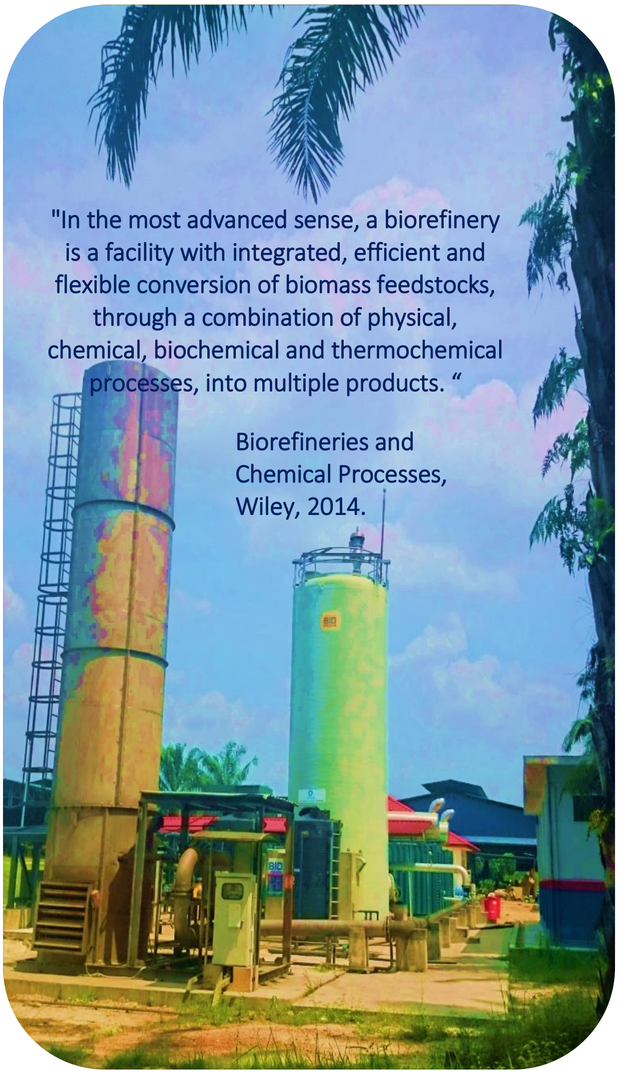
One year of the IBEST

Feature

by Dr Jhuma Sadhukhan

The birth of an Institution

In brief, we are a network of professionals committed to research and development of biorefinery, foster cross-disciplinary research excellence and esteem, communicate the best practices and sustainability trilemma objectively, demonstrate benefits to society, provide education, training and support in biorefinery R&D, promote and develop biorefinery for sustainable bioeconomy, poverty alleviation and climate change mitigation.



The **IBEST** was inaugurated at the British Council / CONACyT funded Researcher Links Workshop in Mexico: ***Biorefinery research - promoting international collaboration for innovative and sustainable solutions***, 18-22 May, 2015. In one year, the **IBEST** has been active in addressing numerous societal challenges and innovative solutions to industrial problems of making drugs & pharmaceuticals, food ingredient, agrochemicals, functional materials, platform chemicals, fuel additive, transportation fuel, and energy in a nexus whole system context and in the context of circular economy. The network is rapidly growing with engineers, with specialisms in resource efficiency, systems optimisation and analysis, local supply-demand network resilience analysis, process integration, and techno-economic, life cycle and life cycle sustainability assessments, chemists, material scientists, physicists, biologists and social scientists are coming together in developing sustainable bioenergy, biorefinery and bioeconomy systems. We address nexus challenges, such as energy-water-food-health-ecosystem-environment, in close concert with premier national institutions, industries and the Governments. We facilitate bilateral and multi-lateral R&D projects at the frontiers of science and engineering of significant mutual interest, foster inter-national activities, share innovation expertise and enhance undertaking of highly important international agenda of climate change mitigation, poverty alleviation, economic value and social welfare generation and the development of circular economies.

Our **Mission** is to promote and develop Biorefinery Engineering as a discipline with contributions from professionals from diverse range of science and engineering backgrounds with a research focus on bio / renewable systems.

Our **Vision** is to create generations of creative and competent engineers with a strong social consciousness and awareness, with ability to shape future integrated production and consumption systems that can help divesting from fossil fuels.

Fostering biorefinery engineering through workshop activities

Mexico-UK Researchers Links Workshop on Biorefinery Identified Important Developments and Research Needs for Sustainable Bioeconomy

"The Mexico Biorefinery Workshop in May 2015 was a unique experience, one of few allowing such an in-depth viewpoint into the development of the biorefinery concept in a country very different from the UK." "I have a clearer picture of the situation and initiatives on biorefining which are taking place in Mexico (and also in UK). I am now more aware of the complexity of a biorefining plant, and how the tools for process integration and life cycle analysis can assist the design of biorefining process and individual processing units." "The Workshop brought together established experts and young researchers working within the biorefinery field from the participating countries." "I found the Workshop to be of tremendous interest which greatly added to my knowledge and broadened my thinking regarding biorefineries. The ideas exchanged and contacts made will absolutely yield a fruitful result" – these have just been a few of the feedbacks collected after a very successful Mexico-UK Researchers Links Workshop: "Biorefinery research - promoting international collaboration for innovative and sustainable solutions". About 60 researchers and practitioners in the field from the two nations gathered at the Instituto Mexicano del Petróleo (IMP), in Mexico City, Mexico, for a week-long Workshop, 18-22 May, 2015. The Workshop covered the following topics:

1. Recent advances in biorefinery technologies.
2. Biomass including waste stocks in the two nations and also important ones world-wide.
3. Industrial biorefinery activities.
4. Process Integration and Sustainability Analysis.
5. Discussions on "Biomass availability, characterization and processing" and "Waste processing, circular economy and sustainability".

"Biorefinery Engineering is a discipline providing a methodological framework to address the challenges posed by the planning and design of sustainable biorefineries, from a systematically integrated perspective that accounts for inter- and intra-process integration opportunities together with external interactions and their complexities, ranging from agronomic, physical, chemical, biological, process systems, economic, environmental and policy issues, with emphasis on integration across the life cycle and within and across the system levels or scales".

Thoughtful biorefinery engineers, scientists and technologists (true Biorefiners!)

The group of researchers at the Biorefinery Workshop in Mexico City in May 2015.

The event coincided with the inauguration of the **IBEST**, a network of biorefinery researchers and practitioners, for *"Advancing cross-disciplinary knowledge and education in Biorefinery Engineering"*. A participant said, "Initiatives emerged from group discussions held during the Workshop, such as the creation of Institution of Professionals in Biorefining related topics, show the important role that Biorefinery is foreseen to play in the future, but also the wide scope and variety of disciplines it will require from." To celebrate the Mexico-UK Bilateral year, 2015, research and networking outcomes have been disseminated through journals, webinars and news on the **IBEST** website. A Special Issue (SI) on Biorefinery Value Chain Creation in Elsevier: Chemical Engineering Research & Design has been dedicated for dissemination of selected papers from the workshop: Sadhukhan J., Martinez-Hernandez E. and Ng K.S. 2016. (Eds) Biorefinery Value Chain Creation. Chemical Engineering Research and Design. Elsevier, 107, 1-280. About half the papers in the SI have been from the Workshop.

Organizing Committee (from left): Drs Elias Martinez-Hernandez (University of Bath), Myriam A. Amezcua Allieri (IMP), Kok Siew Ng and Jhuma Sadhukhan (University of Surrey) and Jorge Arturo Aburto-Anell (IMP).

Bioenergy, Biorefinery and Bioeconomy: Promoting Innovation, Multidisciplinary Collaboration and Sustainability - British Council Researcher Links Workshop in Malaysia supported by the British Council and the Akademi Sains Malaysia

The workshop provided an outstanding platform for exchange of latest research and developments in two nations, building future collaborations and creating sustainable researcher links between UK and Malaysia. Our quest for integrative thinking and approach in sustainable bioenergy, biorefinery and bioeconomy development was substantially complemented by the **IBEST** activities. The workshop helped in further connecting to researchers from Malaysia. "For attendees from the UK it was interesting to learn about Malaysian biomass and wastes such as rubber seed oil, sago and the waste streams from palm oil plantations and milling operations. Attendees heard about the work that is going on to convert these streams into unique products such as particle board or fuel. For the Malaysian attendees it was interesting for them to hear about the latest technology developments within the UK for converting biomass and waste into valuable products and the tools that have been developed to aid researchers and policymakers. The presentations and posters sparked lively discussions and interesting ideas between the attendees about how to move forward with biorefinery development." – commented by Dr Katie Chong of Aston University. The workshop generated interests and research potentials in the following main strands:

1. Biorefinery: from the state-of-the-art to blue sky concepts.
2. Industrial biorefinery activities and perspectives.
3. Health and safety and life cycle sustainability assessment for biorefinery and bioeconomy development.
4. Process design, operation and value chain creation.
5. Future prospects, policies and incentives and challenges of bio-based economy.

A full technical report has emerged from the exchange of ideas and research outcomes reported at the workshop. A publication out of the technical report is under consideration in a top tier journal, Renewable and Sustainable Energy Reviews, Elsevier:

Sadhukhan J., Ng K.S. Murphy R.J., Ng D.K.S., Hassim M.H., Martinez-Hernandez E., Wan Y.K., Leung M.Y.P.H., Andiappan V. and Jaye I.F.M. 2016. Role of Bioenergy, Biorefinery and Bioeconomy in Sustainable Development: Strategic Pathways for Malaysia. *Renewable & Sustainable Energy Reviews*, under review.

We have got the right spirit, synergy and a highly enthusiastic and an incredibly friendly team to pursue internationally important projects on climate change mitigation, poverty alleviation, economic value and social welfare generation in developing countries. The following gaps identified set a strong case for sustainable UK-Malaysia cooperation.

Indigenous industries tend to target products of low-risk and high demand (low hanging fruit), such as bioenergy and biofuel, which primarily rely on policy and 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. Better functional or quality product and faster marketability, greener and sustainable production and consumption, and least production cost are the main targets to tap into the chemical market. Co-production of bio-based products, food and pharmaceutical ingredients, fine, specialty and platform chemicals, polymers, alongside biofuel and bioenergy can achieve overall sustainability by the replacement of fossil resources.

However, clear policies are not in place for mitigation of emissions. Majority of biomasses are disposed to local streams, which cause severe pollution to the environment. As a result, majority of biomasses remained unutilized in reality. In order to develop a bioeconomy and a circular economy, environmental emissions must be mitigated by recovering apparently pollutants as resources from biomass, thereby remedying environmental impact and closing the loop. Of particular interest is the (Sustainable Development Goals

(SDGs)) SDG 12: "sustainable consumption and production", that recognizes the important role of resource efficient technologies and there is a clear policy gap to turn SDG 12 into practices.

The group of researchers at the Biorefinery Workshop in Kuala Lumpur in May-June 2016.

What's on at the biorefinery research front?

As a result of the workshop activities, some fruitful research collaborations are ongoing right now between various participants from the workshop. Projects developed under the IBEST umbrella are:

Research projects
1. British Council Researcher Links Workshop in Malaysia supported by the British Council and the Akademi Sains Malaysia: Bioenergy, Biorefinery and Bioeconomy: Promoting innovation, multidisciplinary collaboration and sustainability, 01/16–08/16.
2. Newton Collaborative Research Programme between UK-Mexico of the Royal Academy of Engineering (RAEng): Economic value generation and social welfare in Mexico by waste biorefining. 01/16–02/17.
3. EPSRC EP/N009746/1: Liquid Fuel and bioEnergy Supply from CO2 Reduction (LifesCO2R). 03/16–03/20.
4. Natural Environment Research Council (NERC): NE/L014246/1: Resource Recovery from Wastewater with Bioelectrochemical Systems. 08/14 – 08/17.
5. British Council / CONACyT funded Researcher Links Workshop in Mexico: Biorefinery research - promoting international collaboration for innovative and sustainable solutions, 09/14–08/15.

Sustainable Use of Residues in Mexico in Biorefinery Setting

J Sadhukhan[1], E Martinez H[2], K S Ng[1], J A Honorato S[3]
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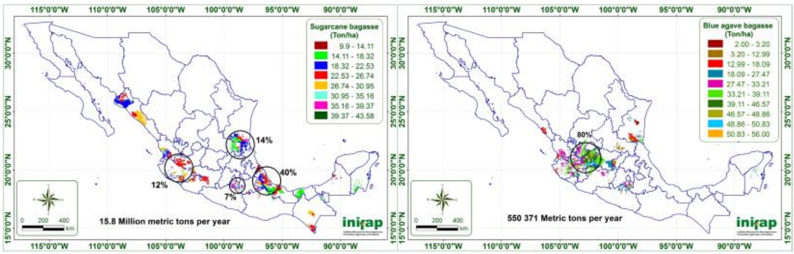
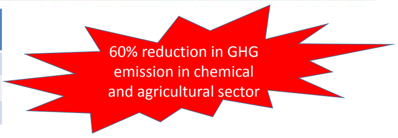
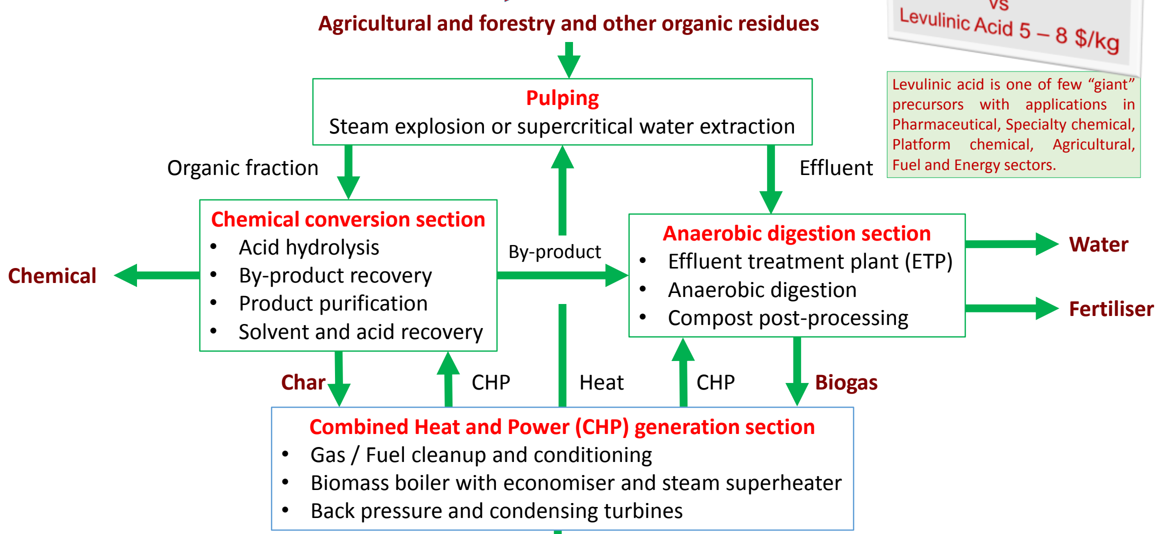


	Sugarcane bagasse	Blue agave bagasse
Payback time, years	5-5.7	3.7-4.1
Cash flow, $/t	115-180	295-360
GWP saving, t/t	0.7	0.74



Ethanol 0.3 – 0.5 $/kg
vs
Levulinic Acid 5 – 8 $/kg

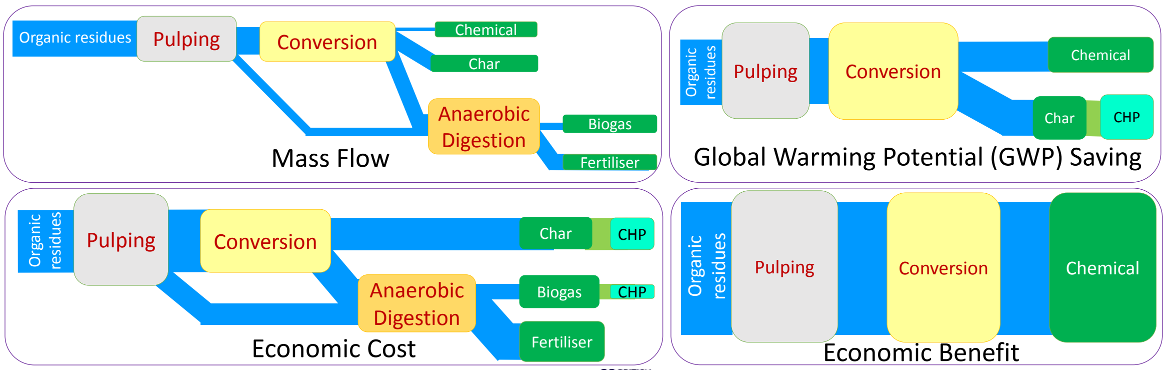
Levulinic acid is one of few "giant" precursors with applications in Pharmaceutical, Specialty chemical, Platform chemical, Agricultural, Fuel and Energy sectors.



Based on the **BEST PAPER** in Special Issue of *Bioresource Technology*, Elsevier, "*Waste Biorefinery – Advocating Circular Economy*", Vol 215:pp1-396. **FIGURE 1 IN THE PAPER** showing the simulation flowsheet of levulinic acid production features on the book's **COVER PAGE**.

Electricity

J Sadhukhan, K S Ng, E M Hernandez. 2016. Novel integrated mechanical biological chemical treatment (MBCT) systems for the production of levulinic acid from fraction of municipal solid waste: A comprehensive techno-economic analysis. *Bioresource Technology*, Vol 215:pp131-143.

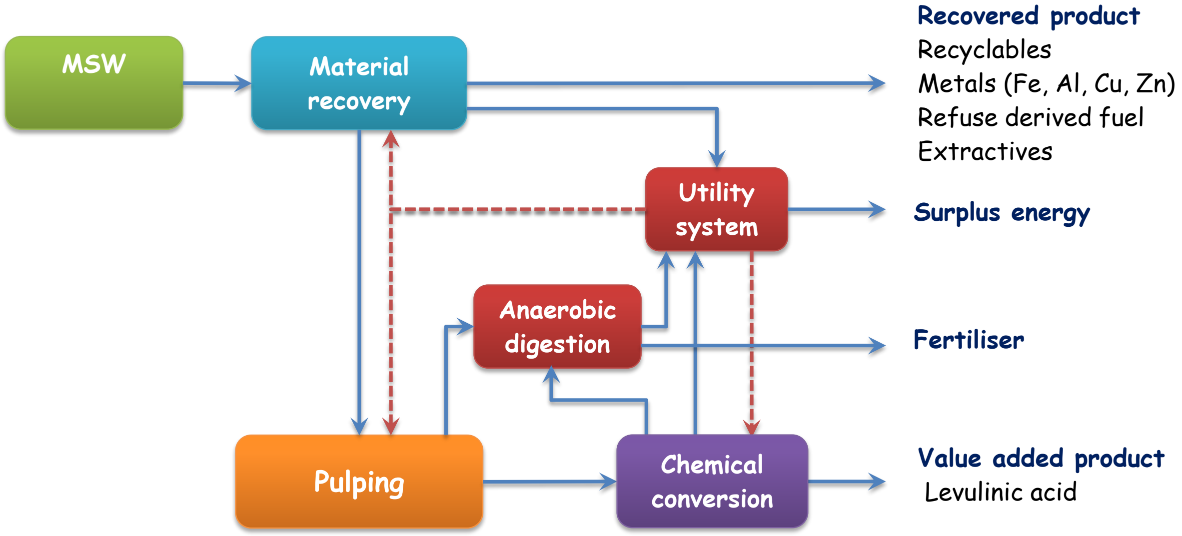


www.theibest.org

Researchers develop new bio-based sustainable technology to add value and increase sustainability of waste resources

A team of researchers at the Universities of Surrey and Bath in the UK has discovered an effective way of adding value and increasing sustainability of waste resources, by the recovery of recyclables, extractives, metals, chemicals, fertiliser and energy. We for the first time reported an integrated conceptual *mechanical biological and chemical treatment* (MBCT) system for unlocking the value of organics in municipal solid waste (MSW) through the production of **Levulinic acid** (LA by 5 wt%) that increases the economic margin by 110-150%.

The findings are published in Bioresource Technology, 215, 131-143, 2016: "Novel integrated mechanical biological chemical treatment (MBCT) systems for the production of levulinic acid from fraction of municipal solid waste: A comprehensive techno-economic analysis" selected as the best article.



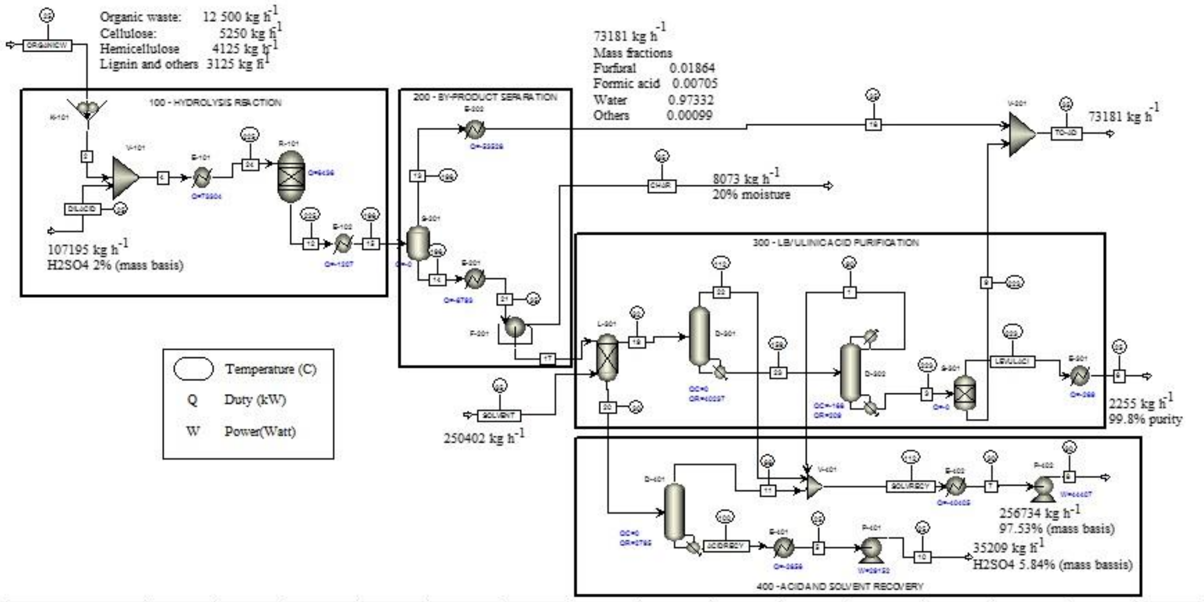
Overview of the Novel integrated mechanical biological chemical treatment (MBCT) systems for the production of levulinic acid from fraction of municipal solid waste.

The findings under the NERC programme: Resource Recovery from waste (RRfW) are published in: Bioresource Technology, 215, 131-143, 2016. The paper has been selected as the best article amongst all published in the Special Issue "Waste Biorefinery – Advocating Circular Economy" of Bioresource Technology, Volume 215, 1-396, Elsevier, 2016. Figure 1 in the article showing the simulation flowsheet of levulinic acid production features on the cover page of the Special Issue.

Increasing waste generation is the largest problem of the world today. Usually, source separated MSW in developed economies consists of paper and cardboard packaging; glass; dense plastic and plastic films (container, plastic packaging); wood, garden and food waste; textiles; WEEE (waste electrical and electronic equipment); metals and unidentified wastes. These streams are into various lines for recycling by a facility called material recovery facility (MRF) or mechanical biological treatment (MBT) plant. The latest DEFRA statistics show the recovery efficiencies on mass basis as follows WEEE: 86%; glass: 69%; paper and cardboard packaging: 54%; metals: 27%; textiles: 17%; dense plastic and plastic film: 17% and other materials: 8%, respectively. The rest goes to landfill. Landfilling must be eliminated by integrating resource efficient recovery technologies from waste that are built on the principles of sustainable consumption and production of Sustainable Development Goals (SDGs), SDG 12.

Paper, wood, garden, non-consumable food and other organic waste is the feedstock for chemical conversion into levulinic acid and char. Resulting effluents are treated for water recovery in effluent treatment plant

(ETP). Residues from ETP are subjected to anaerobic digestion (AD), which produces biogas as an energy vector and digested matter as fertiliser. To date, there is no chemical conversion plant of MSW for unlocking the value of organics before AD. The state-of-the-art cases of MSW treatment include incineration, composting and AD, all of them rely on subsidies and release various harmful emissions to the environment.

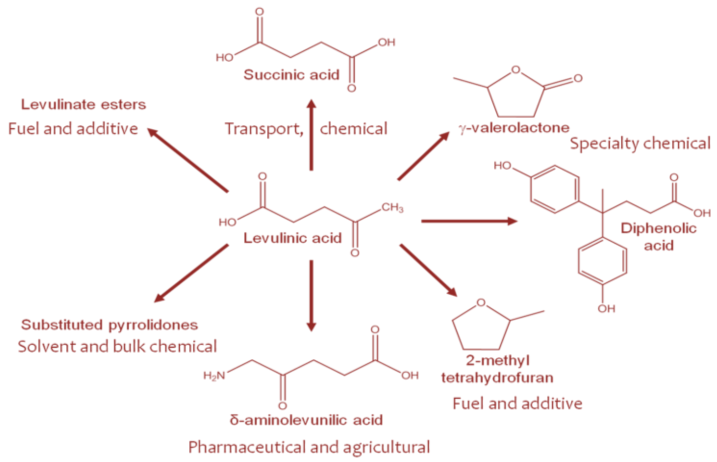


Stream name	ORGANICW	DILACID	15	18	21	17	19	23	3	LEVULACI	20	ACIDRECY	SOLVRECY	CHAR	SOLVENT
To unit	K-101	V-101	S-201		F-201	L-301	D-301	D-302	S-301	E-301	D-401	E-401	E-402		L-301
From unit			E-102	E-202	E-201	F-201	L-301	D-301	D-302	S-301	L-301	D-401	V-401	V-201	
Mass Flow kg/hr															
CELLULOS	5250.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HEMICELL	4125.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LIGNIN	3125.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H2SO4	0.0	2143.9	2143.9	12.2	2131.7	2055.9	0.0	0.0	0.0	0.0	2055.9	2055.9	0.0	75.8	0.0
LEVULINA	0.0	0.0	2415.0	60.8	2354.2	2270.5	2263.0	2257.5	2253.0	2253.0	7.5	7.5	10.0	83.7	0.0
FORMICAC	0.0	0.0	945.0	515.7	429.3	414.1	412.7	0.0	0.0	0.0	1.4	1.4	412.7	15.3	0.0
FURFURAL	0.0	0.0	1650.0	1364.0	286.0	275.8	275.8	202.9	2.4	2.4	0.0	0.0	273.4	10.2	0.0
CHAR	0.0	0.0	6458.7	0.0	6458.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6458.7	0.0
SOLVENT	0.0	0.0	0.0	0.0	0.0	0.0	249646.0	998.6	0.1	0.1	755.9	15.1	250387.0	0.0	250402.0
WATER	5357.1	105051.0	111439.0	71228.4	40210.7	38780.9	5603.9	0.0	0.0	0.0	33177.0	33124.9	5656.0	1429.8	0.0
Total Flow kmol/hr	297.4	5853.1	6266.2	3979.8	2286.3	2205.1	2834.8	31.5	19.4	19.4	1870.2	1859.9	2825.7	81.3	2500.0
Total Flow kg/hr	17857.1	107195.0	125052.0	73181.1	51870.6	43797.2	258201.0	3458.9	2255.5	2255.5	35997.7	35204.8	256739.0	8073.4	250402.0
Temperature C	25.0	25.0	196.0	35.0	35.0	35.0	31.7	159.3	223.5	223.5	30.4	99.6	112.1	35.1	35.0
Pressure bar	1.0	1.0	14.0	1.0	5.0	4.8	3.0	1.0	0.4	0.4	3.0	1.0	1.0	1.0	5.0

Flowsheet of levulinic acid production comprising controlled acid hydrolysis, levulinic acid purification, by-product, and solvent and acid recovery. This figure features in the cover of the Special Issue of Bioresource Technology journal, Volume 215, 1-396, Elsevier, 2016. Copyright © Elsevier 2016.

The MBCT system, we designed, can achieve complete recycling of MSW or any other biomass and economic independence and competitiveness. The findings have been published in star articles. The price of levulinic acid is 5-8 Euro/kg compared to bioethanol, 0.3-0.5 Euro/kg. Highly integrated process scheme eliminates the need for any subsidies including gate fees. Based on source segregated MSW, oil palm biomass in Malaysia, sugarcane and agave residues in Mexico, if priced at 50 Euro/t, a net income of 43-300 Euro/t can be generated. It is important for bio-businesses to be at the leading edge by investing in breakthrough technologies such as these published in star papers.

To date, organic wastes are used to produce, bioenergy via incineration, biogas and fertiliser via AD and compost like output. A chemical conversion section can be retrofitted before bulk conversion of organic waste into bioenergy. The chemical conversion section consists of hydrolysis reaction in 2 wt% dilute H_2SO_4 catalyst producing levulinic acid (LA), furfural, formic acid, in plug flow (210−230°C, 25 bar, 12 s) and continuous stirred tank (195−215°C, 14 bar, 20 mins) reactors; char separation and LA extraction/purification by methyl isobutyl ketone solvent; acid/solvent and by-product recovery. Engineering, procurement and construction (EPC) companies have the ability to apply the concept to the real world problem.



Levulinic acid, a *sleeping giant* building block chemical.

Bio-based products from waste can offset fossil fuels by displacing equivalent products. Bio-based products can contribute to greater than 40% of the total greenhouse gas emission cut by the biorefinery system, which is over 90% compared to equivalent petroleum based system. Levulinic acid offers many functionalities of petrochemicals and is a precursor to numerous added value pharmaceutical, specialty chemical, agricultural, solvent, platform chemical and fuel additive products. Levulinic acid is one of few molecules referred as 'sleeping giants' owing to their vast potentials in the emerging bio-based economy due to their key positions in the production of biomass-derived intermediates and transition from fossil based economy to bio- renewable- based circular economy. Levulinic acid has emerged as a niche platform chemical in production of pharmaceutical: δ-aminolevulinic acid, specialty chemical: γ-valerolactone, agricultural: diphenolic acid, platform chemical: pyrrolidones, succinic acid and fuel additive: levulinate esters, 2-methyltetrahydrofuran with addressable petrochemical replacement potential of over 25 million tonne by 2020. The most substantial challenges to overcome were the development of the new process that integrates RRfW and biorefinery configurations, to sustainably replace petroleum with biomass. This integration is needed to mitigate i) negative effects of impurities in heterogeneous waste feedstock on reaction-separation process yields and thereby to give flexibility in feedstock processing, and ii) environmental and health impacts by transforming pollutants into valuable resources, as well as to achieve total site energy optimisation such that the integrated system is a net energy source. The highly integrated and effective process is not selective in the choice of feedstocks because RRfW removes and recovers impurities as resources prior to chemical valorisation of organic fraction. Hence, choice of biomass is not a constraint for chemical valorisation. Flexibility in processing a whole range of biomass allows uninterrupted production lines. The process can be fully automated with online analytical, monitoring and control systems for optimal trouble-free reliable operations throughout the year.

What's on at the biorefinery training front?

This year, the IBEST has taken a great leap forward in achieving its goal in providing professional training courses in biorefinery subject. The dedicated team was constituted by the founders of the IBEST, Dr. Jhuma Sadhukhan (University of Surrey), Dr. Elias Martinez Hernandez (University of Bath) and Dr. Kok Siew Ng (University of Surrey) who are also authors of the advanced biorefinery textbook "Biorefineries and Chemical Processes: Design, Integration and Sustainability Analysis". the IBEST has offered insightful hands-on problem solving sessions on conceptual design, simulation and integration of biorefinery process systems via the following workshops:

• **Application of Chemical Engineering to Sustainable Biorefineries**, University of Surrey, supported by IChemE, 29th April 2016.

Website: http://www.icheme.org/sustainablebiorefineries#.V6mzHVQrLNM

•**Advanced Biorefineries: Simulation, Process Integration, Value Analysis and Life Cycle Assessment**, 24th European Biomass Conference and Exhibition (EUBCE), Amsterdam, The Netherlands, 8th June 2016.

Website: http://www.eubce.com/parallel-events/workshops/advanced-biorefineries.html

The workshops have attracted researchers and engineers from the academia and industry, from junior to senior levels. Furthermore, the workshops have helped the attendees in identifying niche research areas, sharing and creating innovative ideas for new projects and courses. More importantly, the workshops have also brought together people with similar interest in biorefinery to foster new collaboration opportunities. Overall, it was a wonderful experience to be interacted with the biorefiners and the workshops have received excellent feedbacks from the attendees.

The speakers at the EUBCE workshop: Dr. Jhuma Sadhukhan, Dr. Elias Martinez Hernandez and Dr. Kok Siew Ng

"*Biorefineries and Chemical Processes: Design, Integration and Sustainability Analysis*" was officially launched at the EUBCE! The authors were honoured to share the book with Dr. Keng-Tung Wu (Associate Professor at the National Chung Hsing University, Taiwan), Dr. David Baxter (Senior Scientist at the Cleaner Energies Unit in the Institute for Energy & Transport of the Joint Research Centre, European Commission) and Prof. Andre Faaij (The Chairman of the EUBCE).

Organisation members' profiles

This section is dedicated to organisation members showing their profiles on 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 40 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 have also contributed to an increase in the number of organisations that have become members.

The IBEST website (www.theibest.org) has been the main communication channel with our members, other researchers and the world in the general. After the Malaysia workshop, the number of visitors increased from 2000+ to up to 5000+ visits from all over the world and keeps increasing steadily. This means your organisation profile and research showcase in the next sections will surely have wide reach and thus more potential to make an impact and also to connect with new organisations and facilitate knowledge exchange and, why not, future international collaborations. So, the IBEST invites you to join this growing, successful community of Biorefiners. In fact, new biorefiners have been dedicated another section where you can showcase your very own profile.

Enthusiastic members, committed to transform waste biomass resources (such as oil palm empty fruit bunch or EFB) into valuable products that contribute to improve our quality of life.

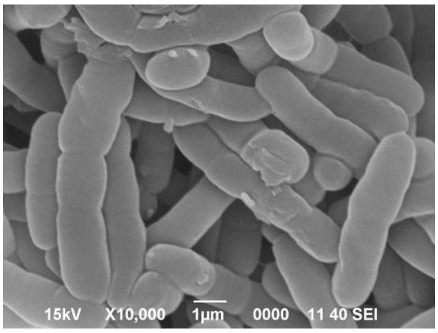
Environmental Biotechnology Research Group, Universiti Teknologi Malaysia

"Turning waste into wealth through biosciences and biotechnology"

Environmental Biotechnology Research Group (EnVBiotech), Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia (UTM) focuses on two themes of research: Biomass-Biorefinery and Bioenergy–Biobased Chemicals. EnVBiotech undertakes research in core areas of solid waste utilisation and liquid wastes treatment specifically in the production of renewable and valuable green bioproducts (including chemicals and energy). The group aims to be a high performance research group conducting research on various liquid and solid wastes, as well as other renewable resources in Malaysia and turn them into valuable green products. There are four main sub-groups under EnVBiotech: *Environmental Bioengineering, Biofuel and Renewable Energy, Biocatalysis and Fermentation,* and *Biosensor Technology*.

Research Focus

Environmental Bioengineering sub-group focuses on microbial degradation of recalcitrant xenobiotics, transformation of xenobiotic pollutants and real time monitoring of biological treatment process using molecular tools. In addition, research under this sub-group also involves Petroleum Biotechnology, particularly on developing an understanding of microbial behaviour to enhance oil recovery via bacterial plugging and biodesulfurisation of high sulfur content crude oil.



Electron micrograph of bacterial cells used for biohydrogen generation

Biofuel and Renewable Energy sub-group works on developing renewable, economically sustainable systems by converting lignobiomass to liquid fuels (e.g. bioethanol, biobutanol and biodiesel) using yeasts, bacteria (*Clostridium* sp.) and microalgae. This includes research on biogas production (methane, hydrogen) using single and mixed culture. Researchers in this sub-group also work on developing microbial fuel cell utilizing catalytic reactions of microorganisms. Research on *Biocatalysis and Fermentation* includes application of enzyme and fermentation technology in biodegradation of recalcitrant substances, and biotransformation of agricultural wastes into beneficial products through microbial bioprocessing and enzymatic degradation. *Biosensor Technology* sub-group focuses on development of biosensors for rapid detection of Biochemical Oxygen Demand, toxic inorganic and organic pollutants and clinically important analytes. The researchers also work on molecular engineering of proteins for site-directed immobilization onto solid supports for biosensing application, and also development of nano-biosensors and microarray-based bisosensors.

Researchers

Dr. Adibah Yahya (Head, EnVBiotech)
Group members: Prof. Dr. Zaharah Ibrahim, Assoc. Prof. Dr Madihah Md Salleh, Assoc. Prof. Dr. Shafinaz Shahir, Dr. Mohd Firdaus Abdul Wahab, Dr. Shaza Eva Mohamad, Dr. Maryam Firdaus Mad Nordin, Dr. Norahim Ibrahim, Dr. Haryati Jamaludin, Dr. Chong Chun Shiong, Dr. Fazilah Abdul Manan, Huszalina Husin, Zarita Zakaria, Nurliyana Ahmad Zawawi

Cranfield University

We are an exclusively postgraduate university located at the heart of the UK. We transform people and organisations through research, postgraduate education, and professional development. Research and innovation is the basis of all our activities. Cranfield's key areas of expertise are grouped under eight multidisciplinary themes: Energy, Water, Environment and Agrifood, Aerospace, Manufacturing, Transport Systems, Defence and Security, and Leadership and Management.

Bioenergy and Resource Management Centre

The centre is part of the Energy division. The Energy division at Cranfield University has been leading the development of innovative technological solutions within the energy sector for over 20 years; working with global strategic partners in industry and government such as E-On, BP, SSE, EDF Energy, Rolls-Royce, Bill & Melinda Gates Foundation, EPSRC, BBSRC, or NERC, among many others.

Cranfield's AD Pilot Plant

"Cranfield generates and transforms knowledge, translating it to the benefit of society"

Apart from the Bioenergy and Resource Management Centre, the Energy division consists of other four research centres which work with us in close collaboration: Combustion, carbon capture and storage; Oil and gas exploration and production; Power systems; and, Renewable energy technologies centres.

The Bioenergy and Resource Management Centre has a dynamic team that works alongside industrial and academic bioenergy and waste management partners to deliver high quality research, design and consultancy. The team strives to overcome the challenges in managing waste and biomass as valuable resources and producing affordable and sustainable bioenergy and biofuels. To achieve this, our research focuses on a range of strategic inter-related activities, from waste and biomass characterization, thermochemical and biochemical conversion, downstream product upgrading and recovery processes, simulation and optimization, to environmental protection and management, and energy markets and policy. We combine a wealth of industrial and research expertise with resources from other complimentary departments within the University and external industrial partners. As a leading UK bioenergy research group, we are a core member of the £1.5m EPSRC SUPERGEN Bioenergy project focused on developing advanced biofuel technologies. We have pilot scale thermochemical conversion facilities with fluidised bed reactors for combustion, gasification and pyrolysis. Our recently commissioned Anaerobic Digestion pilot plant facility at industrial demonstration scale offers an excellent research capability for clients and students. We have also algae pilot scale facilities for growing and processing algae for biofuel production including an oscillating wave tank, photobioreactors and a good range of biological and analytical facilities.

Researchers

Prof Gary Leeke – Professor in Chemical Engineering & Head of Bioenergy and Resource Management

Gary has extensive expertise in high pressure and temperature processes (including pyrolysis and steam and supercritical gasification), polymer processing, reaction engineering, separation, rapid crystallization, phase behaviour, and processing of waste materials into valuable products gained through RCUK, European and industrial funding. Of particular interest are the use of catalysts to upgrade fuels, controlled lignocellulosic degradation and supercritical biocatalysis.

Dr Philip Longhurst – Reader in Environmental Technology

Phil's research investigates the way that materials can be recovered or diverted from landfill to improve resource use and reduce environmental pollution. He is involved in wide portfolio of projects including creating wealth from recovering trace metals in contaminated land, nutrient recovery from waste, developing benchmarking methods for better environmental regulation, establishing opportunities for SMEs to develop AD infrastructure capacity, and systems modelling for waste minimisation and policy appraisal.

Dr Beatriz Fidalgo – Lecturer in Clean Energy Technology

Beatriz has solid background in thermochemical and thermocatalytic conversion of conventional and renewable carbon-based fuels. She has broad experience in microwave-induced process involving carbon materials, pyrolysis and gasification of solid fuels, upgrading of heavy oil and coal-derived hydrocarbons, and characterization of fuels and carbonaceous materials. She is currently involved in research activities related to integrated biorefinery for biofuels, energy and chemicals.

Dr Gill Drew - Lecturer in Environmental Management

Gill's background is on waste management and resource efficiency, monitoring and environmental informatics, climate adaptation and environmental risk, and environmental policy and regulation. Her recent research has focused on improving our understanding of bioaerosols emitted from composting.

Dr Stuart Wagland – Lecturer in Renewable Energy from Waste

Stuart has solid background in waste management and conversion. His research interests are in the properties of solid waste materials, such as the composition, recovery of resources and the energy potential of UK waste streams. His recent projects include the identification of the next generation of energy from waste technologies, and the determination of the renewable energy potential and energy yield from the bio-based fraction of waste materials.

Dr Ying Jiang – Research Fellow in Energy and Biomass

Ying's research interests are in the area of renewable energy production through biological as well as thermochemical processes. He has extensive knowledge of renewable energy production using anaerobic digestion technology. He is currently working on an EPSRC funded project: 'Cleaning Land for Wealth' (CL4W), developing research to integrate renewable energy production with plant based land remediation (phytoremediation) method to achieve low carbon and low cost remediation.

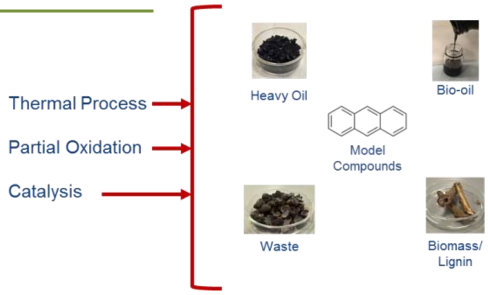
Imperial College London

Imperial College London

The Department of Chemical Engineering in Imperial College London is one of the world's leading institutions in both teaching and research in chemical engineering. Research in the Department cover a wide range of disciplines from the design of reactors and processes to the development of new materials. Our research group belong to the Reaction and Catalysis Laboratory Division that focuses on catalyst technology as well as reaction and reactor process design.

Fuel Production through Catalytic and Thermochemical Processes

Our research is focused on the study of thermochemical and catalytic processes for the production of fuel from renewable and fossil sources. The group has a strong background in the design, synthesis and application of catalysts as well as in the design of batch and continuous reaction systems operating at high temperature and pressure.



Some of the main research interests include the development of catalysts and catalytic processes for the upgrading of coal and heavy oil fractions, characterization of fuels and carbonaceous materials in terms of molecular weight and chemical structure and the thermochemical processing of solid feedstocks such as biomass, coal and waste. Some of the current research areas explored in the group are the following:

- Pyrolysis and Gasification – In these processes we study the conversion of biomass and coal samples in different reaction media varying reaction conditions. Some specific projects involve coal gasification in CO_2 and steam, fast pyrolysis in inert media and co-gasification of biomass and coal.
- Hydrotreating – Research on the catalytic hydrotreating of petroleum and bio-oil samples. Some selected projects involve the development and testing of catalysts with model compounds and real feedstock and the hydro-deoxygenation of bio-oil with Ni/Al_2O_3 catalysts.
- Hydrothermal – Research on hydrothermal processes in sub-critical and supercritical water conditions for the upgrading of bio-oil, biomass, waste and heavy oil feedstocks. Some relevant projects are the study of the partial oxidation of polycyclic aromatic compounds in hydrothermal conditions, the development of catalyst resistant to hydrothermal and supercritical water as reaction media, catalytic upgrading of lignin in hydrothermal conditions and biomass liquefaction and co-processing with glycerol in hydrothermal conditions.

Researchers

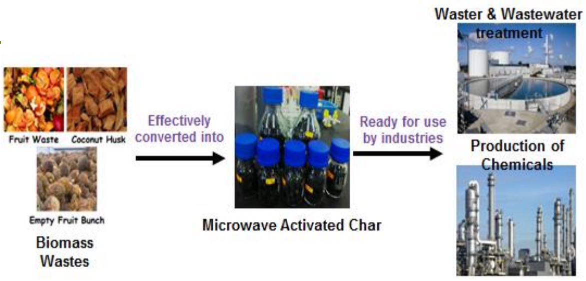
Dr Marcos Millan Agorio, Principal Investigator
Dr Pedro Arcelus Arrillaga, Research Associate
Dr Jose Bermudez, Research Associate
Dr Jie Yu, Research Associate
Mr Aderlanio Da Silva Cardoso, PhD Student
Ms Xyangyi Long, PhD Student
Mr Ziyin Chen, PhD Student
Mr Javier Remon, Visiting PhD Student

East Coast Biorefinery Group (ECBG)

ECBG is a research group from the Universiti Malaysia Terengganu that is newly formed to pursue R&D in the field of Environmental Technology and with emphasis on bringing advancement in Biorefinery and Bioenergy applications. The group is formed by researchers with expertise in Pyrolysis, Microwave Processing, Catalytic Reforming, Sustainable Materials and Composites, Membrane Technology and Adsorption, Anaerobic Digestion, and Bio-Separation.

Biorefinery and Bioenergy

We currently have several research projects working on converting biomass and waste materials (e.g. food wastes, agricultural residues, municipal solid wastes, jatropha seeds) into useful products (e.g. biofuels, transportation fuels, petrochemicals).



Pyrolysis processing of biomass wastes to produce activated carbon for use in environmental applications

The works involve:

- Thermal processing of agricultural wastes into useful products (e.g. fuel, petrochemcals, activated carbon, solid fuel, soil additive, catalyst)
- Development and integration of pyrolysis and microwave heating in thermochemical and biochemical processing applications.
- Process development for bioethanol production from Jatropha curcas Seed Cake

Researchers

Dr. Su Shiung Lam, Senior Lecturer

Dr. Shahrul Ismail, Senior Lecturer

Assoc. Prof. Dr. Mohamad Awang, Associate Professor/ Reader

Dr. Asmadi Ali, Senior Lecturer

Mr. Mohammad Shahrir Mohamed Zahari, Lecturer

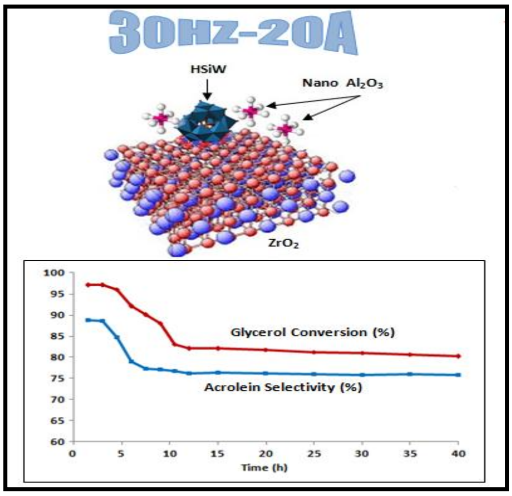
Chemical Reaction Engineering Group

Malaysia is endowed with abundant natural resources such as natural gas, palm oil and rubber. It is the interest of the nation for these resources to be converted to higher value-added products via environmental friendly and energy efficient processes. Conversion of the resources from laboratory to industrial scales requires creative, innovative and systematic approaches from the reaction engineering field. Chemical Reaction Engineering Group (CREG) is formed to conduct research and development (R & D) in applying the theories and principles of chemical reaction engineering to industrial processes. Our concerns are in the areas of reactor modeling, pollution prevention and applied catalysis.

Biomass conversion to value-added Chemicals

Different types of biomass can be transformed into value-added chemicals in homogeneous and heterogeneous catalytic processes. Our main focuses are production of acrolein, levulinic acid, and hydrogen. Also, we have done the kinetic and mass transfer studies for each process to provide highly valuable information for further investigations particularly commercialization and industrialization purposes.

Catalytic conversion of biomass (glycerol, glucose, and oil palm) to value-added chemicals (acrolein, levulinic acid, and hydrogen), photo-catalytic CO_2 reduction, and production of bio-diesel from various feedstocks' are our main research areas.



Schematic diagram of catalyst and catalyst long-term stability

"Innovative. Entrepreneurial. Global"

Researchers

Pro. Ir. Dr. Nor Aishah Saidina Amin, Head

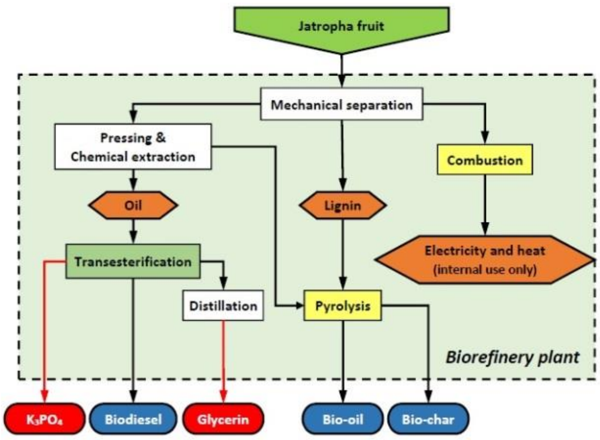
Dr. Amin Talebian-Kiakalaieh, Postdoctoral Fellow

Universidad Autónoma de Yucatán (UADY)

Located at Merida, in the centre of the Yucatan Peninsula and home of the Maya culture, UADY is the main university in southern Mexico. The Faculty of Chemical Engineering (FIQ-UADY) has a tradition of graduating engineers with the highest standards according to national certifications for the last 20 years. FIQ-UADY is committed to prepare highly capable, internationally competitive professionals who contribute to Mexico's sustainable development with an entrepreneur spirit.

Process Engineering for Sustainability

The Process Systems Engineering research group focuses on the design and evaluation of chemical- and bio-processes with the aim to improve their technical, socio-economical, and environmental performance. Research projects span from technological development through sustainability evaluation of processes related to: biofuels and biorefinery, transport phenomena in bioreactors, separation processes, calorimetry, and process control. All these areas converge in the Process Engineering for Sustainability research line, with projects developing the conceptual design and sustainability evaluation of biorefinery concept systems. We apply Techno-Economical Analysis, Life-Cycle Assessment, and sustainability indicators to make an integrated sustainability analysis of biorefinery conceptual designs.



Process pathway of the biorefinery configuration with the best sustainability performance among the studies cases

"Advancing in the fulfilment of our social responsibility by securing our social, environmental, and economic sustainability"

Research on biorefinery development at UADY has focused on assessing opportunities for Yucatan to: increase jobs both in agriculture and specialised in technology and at the same time diversifying the fuel and specialty-chemicals industries in the region. The biorefinery systems currently being explored are based on biomass from *Jatropha curcas* and microalgae, both of which can be grown under the local climate at good productivities. The major challenge is matching the social, economic, and environmental benefits of biorefinery systems with the demands of existing markets and business models, using both traditional and state of the art technologies.

Researchers

Dr. Julio C. Sacramento-Rivero, Faculty member. Life-Cycle Assessment, Techno-Economic Analysis, Sustainability Evaluation.

Dr. Antonio Rocha-Uribe, Faculty member. Supercritical extraction, Separation processes.

Dr. Sergio Baz-Rodriguez, Faculty member. Transport Phenomena in chemical- and bio-reactors.

Dr. Luis Vilchiz-Bravo. Faculty member and Head of the Process Systems Engineering Research Group

C I D E T E Q

Centro de Investigación y Desarrollo Tecnológico en Electroquímica S.C. (CIDETEQ)
CIDETEQ is an institution for Research and Technological Development in Electrochemistry, which aims to contribute to social welfare through generation and transfer of knowledge, focused on the environment and energy at national and international level.

Valorization and reuse of agro-industrial wastes as biosorbents for the removal of organic compounds and heavy metals in aqueous solution

In our research group, we are studying the preparation of biosorbents materials from fruit peels, as an alternative for the reuse and valorization of agro-industrial wastes from the food industry. These biosorbents are cheap and effective in removing organic compounds and heavy metal ions present in the water, so they have a special interest for his study as an alternative to solve environmental problems. We have prepared biosorbents with higher adsorption capacities from orange, grapefruit and pineapple peels using a new method of preparation, which consists of a pre-treatment employing Instant Controlled Pressure Drop (DIC), to modify the morphology of the materials giving them adsorptive properties.

Fig. 1. *Biosorbents preparation from fruit peels for its use in wastewater treatment.*

"Waste management for valuable organic materials"

After this treatment, a chemical modification is performed to make the biosorbent selective to the contaminant of interest azo dyes and phenol and metal ions (Cu^{2+}) obtaining excellent adsorption capacities (Romero-Cano *et al*, 2016). For the case of Cu^{2+}, adsorption capacities up to 7 times greater than those obtained by commercial activated carbons were obtained. We characterized and tested the biosorbents in batch and continuous flow to study the mechanism of adsorption of contaminants. The results show the feasibility of using this new method of preparing biosorbents from fruit peels. So that it is possible to present alternative solutions to two environmental problems: the reduction and valorization of agro-industrial wastes from the food industry and obtaining alternative adsorbents of low-cost with high adsorption capacities for use in water treatment processes.

Researchers

Luis A. Romero-Cano
CIDETEQ –
Universidad de Granada

Linda V. González-Gutierrez
CIDETEQ

Leonardo A. Baldenegro-Perez
CIDESI

Francisco Carrasco-Marin
Universidad de Granada

Shahid Beheshti University

Behehsti University is one of the 5 top Iranian universities with almost 10000 graduate students. Our center has been involved in several projects related to bio-based products including bio-polymers, bio-composites and bio-fuels. The majority of the biomass available in the nearby locations to our campus includes wheat and rice straw as well as the agricultural residues like waste stalks. Also, many papermaking and wood-based panels manufacturing plants produce considerable amount of wastes with the potential to be utilized in the pilot plant. It should be noted that our campus is located in northern part of Iran known as farms and forests core center.

Research Focus

The researches focus generally on biochemical and thermochemical biomass conversion to biofuel and added value products. For example, one of the colleagues research on biomass fast pyrolysis. The project, addresses the question how to efficiently convert the available wood residues from Mazandaran pulp and paper industries (MWPI) and bagasse in Iran into biofuel. The solid wastes including sugarcane bagasse and chips preparation residues from mixed hardwood logs may be considered as main resources in this research. Bio-oil can be produced from these residues via fast pyrolysis and can be used as transportation fuel. But its properties need to be improved, particularly in terms of temperature sensitivity, oxygen content, chemical instability, solid content, and heating values. To achieve these properties, activities across the feedstock analysis, biomass pretreatment with or without catalyst such as calcium format, bio-oil production by fast pyrolysis process must be integrated. Also, the piloting work has to be strongly supported by GC-MC analysis, simulation of bio-oil production systems and techno-economic and life cycle assessment analyses. A successful experimentation and modelling of integrated bio-oil production system is imperative for up-scaling of fast pyrolysis technologies for energy security as well as environmental improvement.

Researchers

Mr. Payam Ghorbannezhad (PhD Student)
Prof. Hossein Resalati (Professor)
Dr. Hossein Kermanian (Associate Professor and Head of New Technologies College)
Dr. Omid Ramezani (Assistant Professor)
Dr. Sepideh Hamedi (Assistant Professor)
Dr. Jhuma Sadhukhan (Associate Professor at the University of Surrey as advisor professor in Payam's research work)
Prof. Paul Stuart (Professor at the Ecole-Polytechnique de Montreal as advisor professor in Payam's research work)


Payam


Prof. Resalati


Dr. Kermanian


Dr. Ramezani

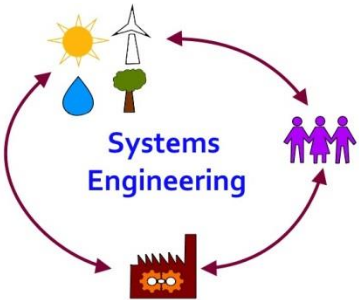
University of Oxford

Our group is part of the Systems Engineering research at the Department of Engineering Science at Oxford. We are interested in developing systems engineering tools to support decisions in engineering and the wider world. With concepts and approaches rooted in process systems engineering, computer science, industrial ecology and complexity science, we have been working on computer-based decision support, multiscale modelling, rational utilisation of renewable resources, and design of sustainable energy and production systems.

Developing systems engineering tools

Rational utilisation of biomass resources

Biomass is an important renewable resource for the sustainable provision of energy, chemicals and materials. We are interested in applying systems engineering tools such as multi-criteria decision making, mathematical modelling and optimisation to assess, improve, and integrate processes and supply chains that utilise biomass for various products or services. Research in this area is closely linked to the treatment of municipal and industrial waste streams, including application of micro-algae based systems. A recent publication has demonstrated the potential for integrated waste processing in an urban biorefinery (Satchatippavarn, S; Martinez-Hernandez, E; Leung Pah Hang, MY; Leach, M; Yang, A. Urban biorefinery for waste processing. ChERD 2016, 107: 81-90).



Systems engineering tools for sustainable production processes

"Looking at the whole picture for designing sustainable production processes and systems"

Design of sustainable energy and production systems

Sustainable provision of energy, water, food, and other goods and services poses significant challenges to our society, calling for innovations at both the technology and the systems level. Our work is aimed to further develop concepts and approaches in process systems engineering and industrial ecology, to enhance our understanding of the challenges from a systems perspective and to devise methods and tools for improving engineering systems in a holistic manner. In particular, we are exploring ways to design decentralised and multifunctional systems with improved sustainability. Current projects include LocalPURE and The Local Nexus Network, in collaboration with the University of Surrey and other partners. Our work on co-designing food, energy and water systems based on the nexus concept is presented in the research showcase section.

Researchers

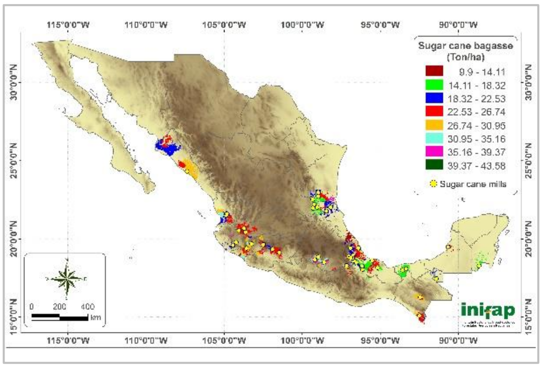
Dr Aidong Yang, Associate Professor
Dr Rene Bañares Alcantara, Associate Professor
Dr Elias Martinez Hernandez, Researcher
Dr Hans Veldhuis, Researcher
Ms Melissa Y. Leung Pah Hang, PhD student
Mr Bo Zhang, PhD student
Mr Di Sihao, PhD student
Research group website: http://www.eng.ox.ac.uk/systemseng

National Research Institute of Forestry, Agriculture and Livestock (INIFAP) of Mexico

INIFAP generates scientific knowledge and technological innovation in agricultural and forestry as a response to the demands and needs of the agroindustry, contributing to sustainable rural development and maintaining the natural resource base. INIFAP's mission is to generate scientific knowledge and technologies that contribute to sustainable development of forestry, agriculture and livestock sub-sectors in Mexico, with a vision of being a leader institution in science and technology, with responsive capacity in dealing with the demands and needs of forestry, agriculture and livestock subsectors, which emphasizes teamwork, overcoming personal and user satisfaction. One of the main research areas of INIFAP is bioenergy, focusing mainly in biofuel crops and use of lignocellulosic materials for biofuel production.

Lignocellulosic Materials

Research on lignocellulosic materials is mainly focused on physicochemical characterization of biomass from fast-growing tree, grass, agave and cacti species that can be used for energy production, as well as forestry and crop residues generated from primary and secondary processing. Mapping and assessment of biomass is also carry out to locate the major amounts of biomass that can be processed to obtain bioenergy or biofuels. Main chemical composition, gross heat values, proximal analysis, bulk density, and particle size distribution are among the main determinations that are performed to each kind of biomass.



Temporary and spatial distribution of sugar cane bagasse in Mexico.

"INIFAP is a Mexican institution of scientific and technological excellence with leadership and national and international recognition. INIFAP has 5 National Disciplinary Research Centres, 8 Regional Research Centres and 38 experimental campuses where a team of 884 researchers work in various disciplines of the forestry, agriculture and livestock sector."

Studies on techno-economic feasibility and life cycle assessment have also been incorporated to lignocellulosic materials for thermal and chemical processes. This will allow to scope several options for making investment decisions in processing biomass residues and biofuel crops around Mexican regions, where the amount of biomass supply would be suitable for a sustainable industry.

Researchers

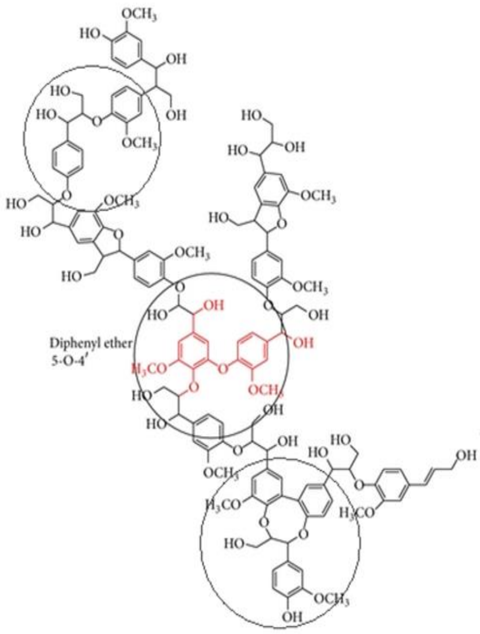
Dr J. Amador Honorato S., Senior Research Scientist
Dr. Jorge Martinez Herrera, Senior Research Scientist
Miss Flora Apolinar Hidalgo, Research assistant
Mrs Gertrudis Colotl Hernández, Research assistant
Miss Patricia Aguilar Sánchez, Research assistant

Instituto Mexicano del Petróleo

The Mexican Petroleum Institute (IMP) is a national laboratory dedicated to basic and applied scientific research and intended, to develop technological solutions to the petroleum and energy industry, the formation of specialized human resources, to provide scientific, engineering and technical support to the national oil company, Petróleos Mexicanos (PEMEX). IMP covers all value chain from exploration, production, logistics, refining, and petrochemicals; but also environmental issues and bioenergy.

Lignin pyrolysis for value added products

This study is focused on lignin transformation into high value products using pyrolytic processes. Despite the wide interest in this topic few studies have focused on establishment of a theoretical-experimental approach of the relationship between structural requirements, their energetic demand and the most probable products during the pyrolysis of lignin, with the purpose of more detailed understanding of the structure and composition of lignin in order to devise pathways to break down a controlled manner and selective the polyphenolic structure into useful compounds. It is well-known that the lignocellulosic biomass consists of three basic main components; cellulose, hemicellulose and lignin, and that the use and harnessing of the lignin currently represent the biggest challenge.



Scheme 1. Representative structure of lignin with some highlighted common linkages.

"IMP is a leading national laboratory with more than 2500 engineers, technical and scientific and is considered the largest engineering firm in Mexico dedicated to petroleum industry"

Lignin is an amorphous highly branched polyphenolic polymer of phenylpropane units (**scheme 1**), which may be present in varying amounts into the biomass, comprising around 15-30% of all biomass weight. In this context, the integration of lignin at the biorefinery concept is widely recognized as an important contributor to the economy and rentability of the transformations processes of renewable sources into fuels and chemicals. Hence the relevance of develop new methods and processes to convert biomass and organic residues into diverse chemicals and oils products.

Researchers

Dr. E. Torres-Garcia (Scientific researcher)

Dr. A. Galano (Professor)

Dr. J. Aburto (Head of the Biomass Conversion Department)

University of Bath

Algae photo-bioreactor (PBR) in operation

Innovative research, prestigious degree programmes and strong relationship with the commercial sector makes the University of Bath's Chemical Engineering department one of the most successful in the UK. Our Department's research has been ranked top ten in the 2014 Research Excellence Framework (REF). The Department has also been ranked Top 3 in the UK for Chemical Engineering (2017 Complete University Guide and The Times Good University Guide 2016).

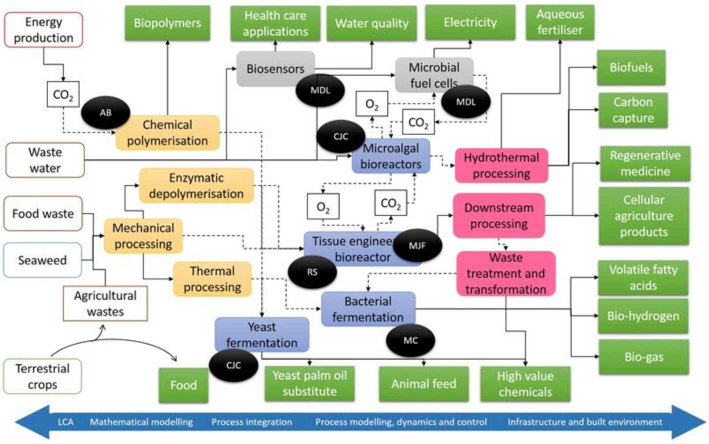
Bioprocessing Research Unit (BRU)

The bioeconomy is now estimated to make a £36.1bn contribution to the UK economy, with UK Industrial Biotechnology generating up to £3bn in sales revenue. However, to deliver a sustainable bioeconomy then the concept of the circular economy, where all by-products and wastes from a process are used as the feedstocks in another, must also be embraced. We aim to bring these two concepts together to create the Bioprocessing Research Unit, which we aim to grow into the Centre for the Circular Bioeconomy. The main areas of expertise at BRU include:

- Waste and biomass conversion in integrated biorefineries
- Process development using life cycle thinking and holistic approaches
- Bioprocessing for tissue engineering, specifically designing and fabricating bioreactors for large-scale cell culture
- Polymers and Biomaterials
- Bioenergy
- Aerobic and anaerobic fermentation of waste
- Process Systems: components and integration
- Waste management
- Biosensors

"BRU carries out interdisciplinary research at the interface between biology, chemistry and chemical engineering."

Our vision is to become a world-leading Centre of Excellence in industrial bioprocessing, addressing the technical challenges inherent in building a global circular bioeconomy. For more info visit: http://www.bath.ac.uk/chem-eng/research/bioprocessing-research-unit/index.html



Overview of breadth and interconnectivity of biorefinery research at Bath

Researchers

Researcher	Position	Field / expertise
Dr. Chris Chuck	Reader in Sustainable Technology	Bioenergy, yeast fermentation
Dr Marianne Ellis	Senior Lecturer in Biochemical Engineering	Cellular agriculture; Regenerative Medicine
Dr Elias Martinez Hernandez	Lecturer in Chemical Engineering	Biorefineries, process integration and optimisation, Life cycle assessment (LCA)
Dr. Mirella di Lorenzo	Lecturer in Biochemical Engineering	Microbial and enzymatic fuel cells, biosensors
Dr. Ram Sharma	Lecturer in Biochemical Engineering	Regenerative Medicine
Dr. Antoine Buchard	Whorrod Research Fellow	Biochemicals
Dr. Marta Coma	Whorrod Research Fellow	Bacterial fermentation, biogas

Centre for Sustainable Chemical Technologies (CSCT)

Established in 2008, the Centre for Sustainable Chemical Technologies (CSCT) brings together academic expertise from the University of Bath with international industrial, academic and stakeholder partners to carry out research, training and outreach in sustainable chemical technologies. The centre has rapidly become an important hub for sustainable chemistry in the UK. Our Centre for Doctoral Training (CDT) in Sustainable Chemical Technologies offers 4-year integrated PhD studenships.

Research at CSCT

The Centre for Sustainable Chemical Technologies is a multidisciplinary research centre, including the Departments of Biology & Biochemistry, Chemistry, Chemical Engineering, Electrical Engineering, Mathematics, Mechanical Engineering, Pharmacy & Pharmacology and Physics, and the School of Management. We develop new molecules, materials and processes for sustainability in the broadest possible sense, structured around four main themes:

- **Energy and Water**: solar cells, fuel cells and batteries, sustainable water supply, water cycle & human health
- **Renewable Feedstocks and Biotechnology**: biofuels, biopolymers, biorefineries, platform chemicals
- **Processes and Manufacturing**: reaction engineering, sustainable integrated processes, process intensification, flow chemistry
- **Healthcare Technologies**: synthetic methodology for pharmaceuticals, rapid sensing in hospital environments, infection detection, diagnostic nanomedicines

"Our multidisciplinary research aims to deliver new and sustainable chemical technologies for the future."

Renewable Feedstocks and Biotechnology

Environmental, economic and political pressures demand the development of novel routes to fuels and chemicals from renewable feedstocks to replace current fossil fuel based processes. Economic viability often depends on process integration into the existing manufacturing infrastructure, requiring a significant level of interdisciplinary understanding. Current research at CSCT on this area include:

- Application of enzymes for the recycling of polymers and composites
- Synthesis of chemicals from sugar beet pulp (SBP)
- Fractionation and exploitation of the component value of DDGS
- Nano-scale-integration of CO2 uptake and utilisation processes
- Terpene-based Manufacturing for Sustainable Chemical Feedstocks

Researchers

For more info visit: http://www.bath.ac.uk/csct/

Professor Matthew Davidson, Director of the CSCT, Professor Tim Mays, Co-Director

Metabolic engineering for conversion of renewable feedstocks into bulk chemicals

Professor Michael Danson, Professor David Leak, Professor Rod Scott, Dr Chris Chuck

Chemical conversion of bio-derived molecules into chemicals

Professor David Leak, Professor Rod Scott, Dr Chris Chuck, Dr Davide Mattia, Dr Pawel Plucinski, Dr Steve Bull, Professor Matthew Davidson, Professor Chris Frost, Dr Matthew Jones, Professor Frank Marken

Materials from renewable sources

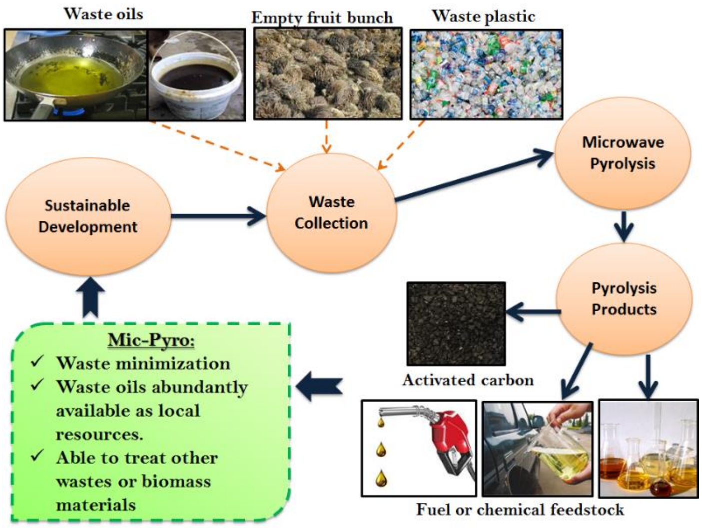
Dr Davide Mattia, Dr Laura Torrente, Dr Antoine Buchard, Dr Dave Carbery, Professor Matthew Davidson, Dr Matthew Jones, Dr Janet Scott

Research showcase

This section is dedicated to members showcasing their latest research in the biorefinery arena.

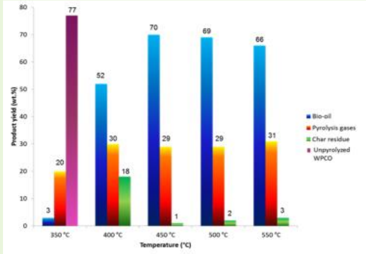
"Microwave Pyrolysis - A Promising Technique for Bio-refinery and Waste Recovery"

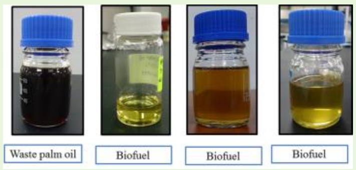
Microwave pyrolysis is proposed as a potentially viable technique to recover useful oil and char products from biomass and waste material (e.g. used cooking oil, forestry and agricultural residues). It is an innovative pyrolysis technique that combines the use of microwave magnetron and a continuous stirred bed reactor. It shows advantages in providing fast heating, extensive cracking, and a reducing reaction environment. The pyrolysis produces biofuel that can be utilized as a fuel or petrochemical, and the char produced can also be used to produce activated carbon or as a precursor to synthesize catalyst. The biofuel is diesel-like, low in oxygen, free of sulphur, carboxylic acid and triglycerides. This pyrolysis approach offers an attractive alternative to transesterification that avoids the use of solvents and catalysts, and the need to remove free fatty acids and glycerol from the hydrocarbon product. The char obtained has high carbon content, showing durability in terms of high resistance to chemical reactions. It also shows a highly uniform porous structure with a high surface area, the majority of which is comprised of both micropores and mesopores, indicating a characteristic of good adsorption capacity and high internal porosity, thus it can be used as an adsorbent to remove pollutants from air or water streams in environmental applications.



Potential of Microwave Pyrolysis

Results





Bio-Oil from pyrolysis of waste cooking oil

Hydrocarbon components (%)	350 °C	450 °C	550 °C	
C_5-C_{10}	-	-	-	(Petrol range)
C_{11}-C_{15}	54	62	72	(Diesel range)
> C_{15}	28	25	18	(Heavy oil range)
Calorific value (MJ/kg)	41	46	46	(Petrol & Diesel) (38-46 MJ/kg)

INNOVATION in MAC

	MAC	AC by Other Method
Product Yield	50 wt%	37 wt%
Carbon	72 wt%	55 wt%
Fixed Carbon	70 wt%	57 wt%
Sulphur	0 wt%	8 wt%
Surface Area	1015 m²/g	880 m²/g
Adsorption Capacity	27 mg/g	14 mg/g

Research Impact

This pyrolysis technique provides new routes to recycle various types of organic wastes while simultaneously generating an additional fuel source for an energy-hungry world. It is beneficial and applicable to the Waste Treatment, Energy, Fuel, Oil and Gas industries. The work is funded by Malaysia government (MOSTI, MOHE) and has already received strong interest from industry where partnerships have been formed and investment received from both International and Malaysian companies. A pilot-scale prototype has been developed and is currently being tested by industry towards its commercialization.

Contact Us

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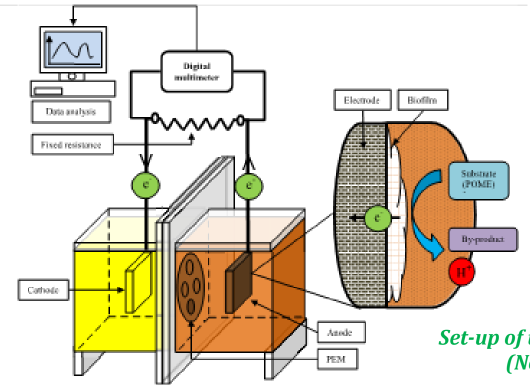
http://soe.umt.edu.my/wp-content/uploads/sites/12/2015/12/lam-su-shiung.jpg

"Harvesting the energy in the palm oil mill effluent (POME) using microorganisms"

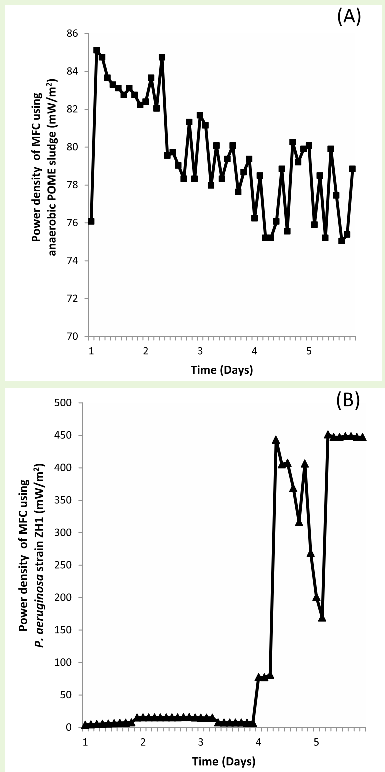
Researchers: Dr. Mohd Firdaus Abdul Wahab§, Prof. Dr. Zaharah Ibrahim, Dr. Norahim Ibrahim. §Contact: firdausw@utm.my.

The growth of the palm oil industry in Malaysia has been steadily on the rise, due to the versatility of this commodity. Despite greatly improved environmental friendliness compared to five decades ago, palm oil industries are still among the main producers of industrial solid wastes and wastewaters, mainly in the form of palm oil mill effluent (POME). The POME carries a high load of organic matter that can be converted into energy, which can eventually be used by the mill to reduce the cost of energy consumption. Researchers in EnVBiotech, UTM are investigating the potential of using bioelectrochemical system, namely microbial fuel cell (MFC) to harvest the energy content of POME in the form of electricity. In MFC, microorganisms are used as biocatalyst to convert chemical energy in organic compounds into electricity at the anode. The researchers use POME natural microflora (sludge) and single culture as the anodic biocatalysts in a dual-chambered MFC. MFC operation using natural microflora showed a maximum power density and current density of 85.11 mW/m^2 and 91.12 mA/m^2 respectively. Using single culture isolated from the anodic biofilm, a higher maximum power density and current density was achieved (451.26 mW/m^2 and 654.90 mA/m^2 respectively) (Nor et al., 2015). This demonstrates the potential of using single culture MFC for electricity generation from POME. Research are currently undergoing to optimise the electricity generation, and increase POME treatment efficiency, from various aspects.



Set-up of the microbial fuel cell (Nor et al., 2015)

Results



Power density in the MFC generated using sludge (A) and single culture (B) using POME as substrate.

Reference: Nor et al., 2015. Bioresource Technology. 190:458-465. DOI: 10.1016/j.biortech.2015.02.103

Research Impact

Research focusing on pure (single/consortium) culture bacteria for electricity generation in MFC especially using POME as substrate is very limited. Many reports in the literatures concentrate on POME sludge as inoculant in the anodic chamber. EnVBiotech researchers use defined cultures because they have the advantage of consistent efficiency and less inoculum batch-to-batch differences. The bacteria identified also have the potential to be genetically- and metabolically-engineered to increase carbohydrate conversion efficiency, and electron transfer efficiency through the biofilm formed on the anodic electrode.

Contact Us

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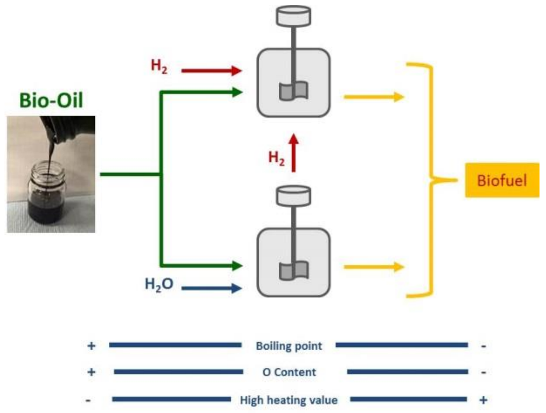
"Hydrothermal and/or Hydrotreating Processes for the Production of Transportation Fuel from Bio-oil"

P. Arcelus-Arrillaga (pma09@ic.ac.uk)

This work focuses in the study of hydrothermal (sub-critical and supercritical water conditions) and hydrotreating processes for the upgrading of bio-oil. Bio-oil is not suitable as a transportation fuel due to corrosive issues, high O content, low stability, and immiscibility with fossil fuels. As a result, research on upgrading processes to transform bio-oil into transportation fuel is necessary. In this work, two bio-oil upgrading routes: Catalytic hydrothermal upgrading in near-critical or supercritical water conditions and catalytic hydrotreating with hydrogen were studied.

Experiments were performed in two different microbomb batch reaction set-ups, one designed to carry out hydrothermal reactions and the second to use high pressure H_2 as reactant. Products of reaction were separated and classified as bio-oil fraction, gas fraction, char and coke. The bio-oil produced was analyzed through simulated distillation, size exclusion chromatography, gas chromatography with mass spectrometry and elemental analysis. The gas fraction composition was analyzed through gas chromatography with thermal conductivity detector. Char and coke fractions were analyzed through elemental analysis.

Experimental results showed that an important reduction in O content was achieved when bio-oil was treated through both processes. Moreover a significant increase in heating value and a reduction in boiling point were obtained. It is thought that both processes can be integrated, as high yields to hydrogen were produced in the hydrothermal process.



Results

Hydrothermal:

- Oil product mainly composed of kerosene, gas-oil and naphtha fractions

-Increase in the percentage of C and H and an important decrease in O.

-Important increase in HHV compared to the original bio-oil.

-H_2 and CH_4 rich gas product.

Hydrotreating:

-Oil present high C and H content and a considerably lower O compared to the original.

-Higher HHV was obtained in the oil compared with the original feedstock.

-Selectivity to gas or liquid products can be controlled by finely tuning operating temperature, pressure, catalyst loading and residence time.

Research Impact

The aim of our research is to develop efficient processes to obtain fuel from either fossil or renewable sources. The implementation of processes like hydrotreating or hydrothermal processing to the upgrading of biomass and waste has shown promising results with high yields to liquid products. Processes like this will facilitate the effective introduction of renewable fuels into the world's energy market.

Contact Us

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"Preparation, characterization and use of fruit peels as biosorbents for removal of organic compounds and heavy metals in aqueous solution"

Objectives: Prepare biosorbents from agro-industrial wastes (fruit peels) with high adsorption capacities, and elucidate the adsorption mechanisms of the contaminants onto this materials.

Methodology: The raw peels of pineapple (PP), orange (OP) and grapefruit (GP) were prepared by Instant Controlled Pressure Drop (DIC) as a pretreatment. This process involves a thermal treatment using steam injection in a chamber ("DIC reactor"). The peels were introduced into the DIC reactor operating at the following conditions: vacuum pressure of approximately 30 mbar, followed by saturated steam injection at a pressure of 3 bars for a short time; afterwards, an abrupt decompression to vacuum; and finally injection of atmospheric air (samples labeled as –DIC). Mainly because this treatment, prior to a chemical modification, increases porosity and surface area in the material. After DIC treatment, the materials were treated with NaOH (samples labeled as –DIC-Na) and citric acid (Samples labeled as –DIC-AC) to complete the preparation of the biosorbents, such that the materials are functionalized with carboxylic groups to increase his adsorption capacities.

The biosorbents characterization is carried out before and after the adsorption studies and was conducted by SEM, EDS, FTIR, XPS, Mercury intrusion porosimetry, determination of active sites and zero point charge. Adsorption studies were carried to evaluate the removal of organic compounds (reactive red dye 272 and phenol) and heavy metals (Cu^{2+}) in aqueous solution; the analysis were performed in batch mode and continuous flow, in fixed bed columns, to evaluate its use as a treatment technology of wastewater on a larger scale.

Results

Table 1. Adsorption capacities of Cu(II) onto biosorbents prepared from fruit peels at pH 5, 25°C, 100 ml, 0.4 g.

Biosorbents	qmáx, mg g^{-1}
OP	32.23
PP	19.42
GP	62.02
OP-DIC	27.88
PP-DIC	23.32
GP-DIC	76.80
OP-AC	67.34
PP-AC	42.36
GP-AC	87.38
OP-DIC-AC	107.98
PP-DIC-AC	48.31
GP-DIC-AC	106.85

Table 2. Adsorption capacity for phenol and reactive red dye 272 onto biosorbents prepared from orange peels at 25°C, 100 ml, 0.4 gr

	qmax, mg g^{-1}	
Biosorbent	Phenol at pH7	RR272 at pH5
OP	2.08	4.63
OP-DIC	15.23	17.83
OP-DIC-Na	12.15	34.27
OP-DIC-AC	39.77	14.92

Biosorbents preparation by Instant Controlled Pressure Drop (DIC) and chemical treatment.

Research Impact

This work showed a novel technique for fruit peels preparation as a biosorbent material. The peels are prepared by a combination of a physical pre-treatment by "instant controlled pressure drop" (DIC), this process modifies the peels surface area, micro- and macro-structure, as well as the number of active sites, followed by a chemical treatment with NaOH or citric acid improving the biosorbent selectivity for different pollutants. For the special case of Cu^{2+} the adsorption capacity were up to 7 times higher than those obtained by commercial activated carbons. Thus, it is feasible to use these materials as adsorbents of low cost for wastewater treatment processes. Romero-Cano L.A., Gonzalez-Gutierrez L., Baldenegro-Perez L.A. *Industrial Crops and Products* 84 (2016) 344–349.

Contact Us

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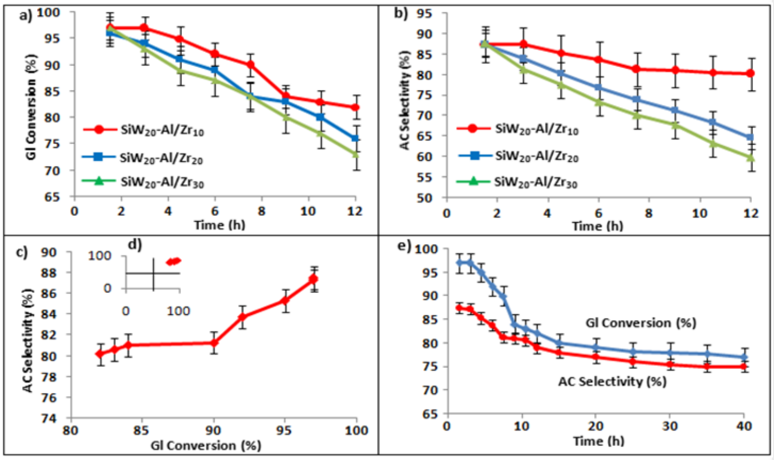
"Catalyst screening, kinetic and mass transfer studies of glycerol dehydration to acrolein over supported HSiW solid acid catalysts"

The dehydration of glycerol to acrolein over a series of supported silicotungstic acid on aluminium oxide nanoparticles and zirconium oxide catalyst (SiW_x-Al/Zr_y) has been investigated. The characterization results revealed the specific surface area of the final series of catalysts were more than 77.30 m^2/ g with uniform pore diameter of size 19-20 nm. The highest acrolein selectivity achieved was 87.3% at 97.1% glycerol conversion over SiW_{20}-Al/Zr_{10} catalyst. The prepared catalysts were highly active and selective for acrolein production even after 40 h. In addition, the results of the kinetic study demonstrated that glycerol dehydration to acrolein followed first-order rate law. The activation energy (Ea) and pre-exponential factor (A) were calculated as 47 kJ/mol and 2.2×10^7 s^{-1}, respectively. Finally, Mears criterion (C_M<0.15) and Weisz-Prater criterion (C_{WP}<<1) confirmed the absence of external and internal diffusions over the pellet sizes d_p< 5 µm.



(a) Glycerol conversion versus time and (b) Acrolein selectivity versus time for SiW20-Al/Zr10, SiW20-Al/Zr20, SiW20-Al/Zr30 samples at 300 ˚C, 12 h reaction time, 2 ml/h glycerol feed, and 20 ml/min carrier gas flow (c) Acrolein selectivity versus glycerol conversion only for the most stable and active sample (SiW20-Al/Zr10), and (d) Overall selectivity versus conversion related to the SiW20-Al/Zr10 sample (e) Long-term stability investigation of SiW20-Al/Zr10 sample in 40 h.

Results

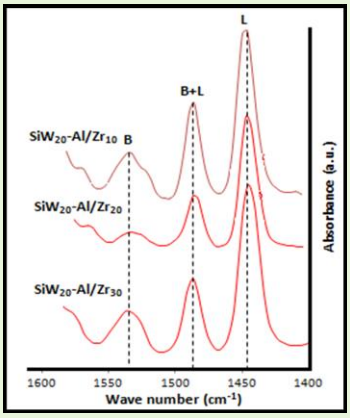


Fig. 1 Standard FTIR spectra's of pyridine adsorbed on prepared catalysts (SiW20-Al/Zr10, SiW20-Al/Zr20, and SiW20-Al/Zr30) at 150 ˚C

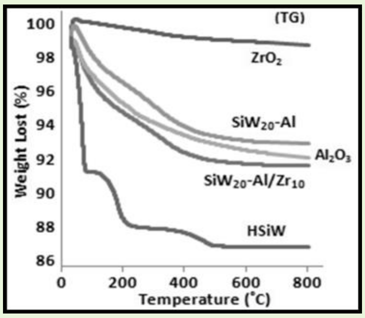


Fig. 2 TG plots for bulk samples and supported HSiW catalysts

Research Impact

The results of this study published in 5 peer reviewed ISI Journals (Renewable and Sustainable Energy Reviews, Catalysis Today, The Taiwan Institute of Chemical Engineers, Industrial and Engineering Chemistry Research, and Journal of Industrial and Engineering Chemistry) and presented in one conference (CHISA 2015, Prague, Czech Republic).

Contact Us

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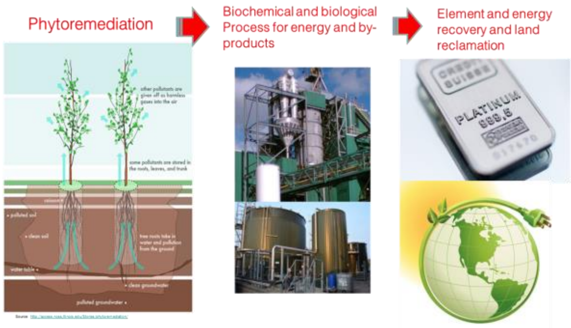
EPSRC “Cleaning Land for Wealth – CL4W”

The goal of the project is to revalue phytoremediation as a land remediation technology. CL4W investigates the potentials of using crops grown on heavy metal contaminated land for energy production and to develop an engineered bioprocess to produce high valued co-products, therefore improving the economic viability of such clean-up project.

More than 400 million hectares of land around the world has been left contaminated and abandoned because of the lack of a financial incentive to pay for the clean-up, remaining a hazard to the environment and public health. New research has demonstrated the combined benefit of growing crops on contaminated land to both remediate land to make it safer for agriculture or development, and provide a payback in terms of energy.

Recent research to exploit the plant uptake of elements, thermochemical biomass conversion, the emission of contaminants during energy production processes, and better recovery of metals, has transformed the idea of traditional phytoremediation into an approach with major benefits. The lignocellulosic biomass produced during phytoremediation can be thermochemically converted into heat and electricity. And the metals retrieved during the thermochemical process are concentrated, making it easier to recover.



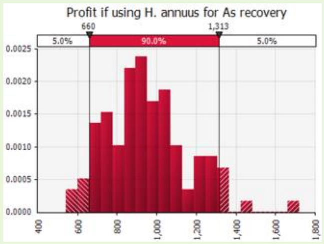
Integration of bioenergy production with plant based land remediation

Research Impact

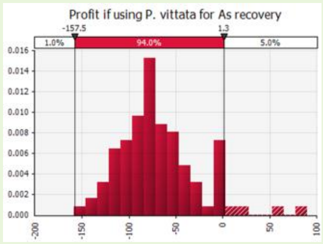
If all the contaminated land stock was used to produce energy crops, it would provide 10% of the of the world’s energy needs. Even without achieving the whole potential of the technology, phytoremediation is better than the conventional approach. It is cheaper, has better performance for permanent removal of contaminants, and requires low energy input. There is then the energy produced to be considered. In addition, many of the metals that contaminate soils are valuable and scarce natural resources. Recovery of these elements is critical for the sustainability of a number of industries.

Selected Key Outputs

1. Decision tool developed to evaluate the economic feasibility of integrated metals/energy recovery and remediation process. Model incorporates wide range of variables (Biomass yield, bioaccumulation factor, energy and commodity values etc.) and calculates profit margin and probability of achieving these margins

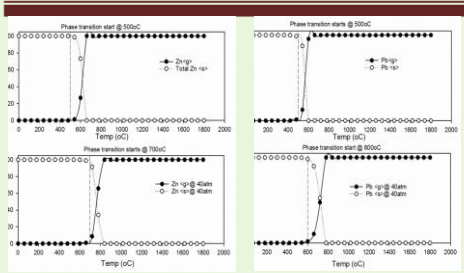


When using low biomass yield Pteris vittata. High risk (41% probability) of failing to achieve positive margin, 57% probability of achieving low margin from £0-120 per ha.



Using high biomass yield Helianthus annuus. High certainty (90% probability) of achieving margin between £1132- 2173 per ha

2. Gasification is suitable for plant disposal and its emission is modelled by MTDATA. As, Cd, Zn and Pb are found in gaseous emissions at a low process temperature. High pressure gasification can reduce heavy metal elements in process emissions



Zn solid/gaseous transition under 1 and 40 atm

Pb solid/gaseous transition under 1 and 40 atm

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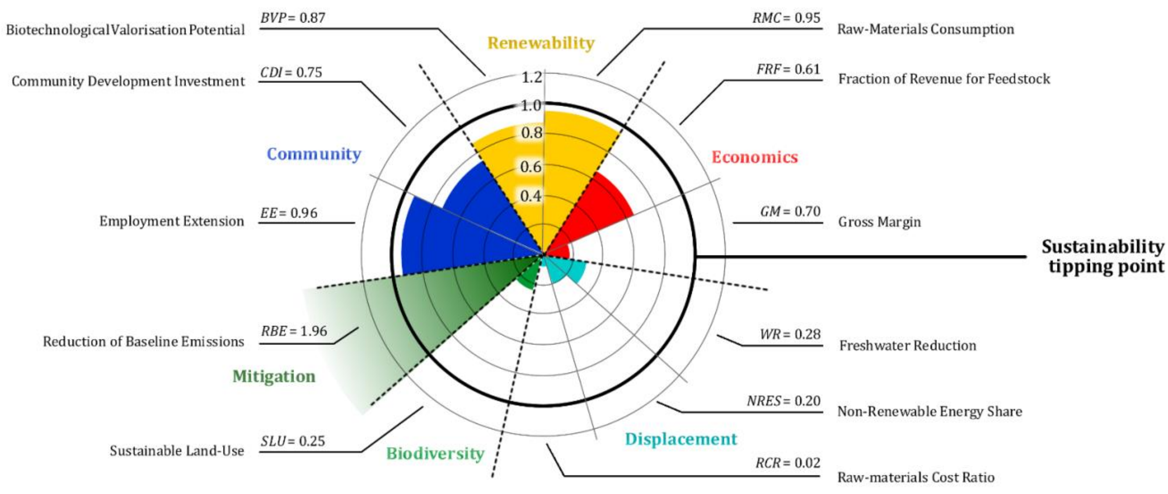
"Conceptual design of a *Jatropha curcas* based biorefinery using sustainability criteria"

This works illustrates a methodology that systematically incorporates economic, environmental, and social indicators in the conceptual design of bioenergy-driven biorefineries. The case study was a *Jatropha curcas* biorefinery, which in its simplest form produces biodiesel and cake (as fertilizer); a total of nine configurations were analysed and compared, producing one or more of the following products in addition to biodiesel: heat and electricity, pyrolytic biochar & bio-oil, biogas, syngas, technical-grade glycerine, and K_3PO_4. Data on agricultural area was gathered from real marginal-land plantations in Yucatan, Mexico. Mass and energy balances were drawn from process simulation (Aspen Plus 8.4). A baseline Life-Cycle Assessment (LCA) was performed (SimaPro v8, CML-IA 2000), using the ecoinvent 3.0 database and data from journal articles. A Techno-Economic Analysis (TEA) was also performed. The results from the LCA and TEA were used to estimate the normalised sustainability indicators proposed by Sacramento (2012, http://dx.doi.org/10.1002/bbb.335) to do the sustainability assessment of the biorefinery configurations.

Results

The largest economic and environmental impacts reside on the use of fertilizers and pesticides. Water demand may be significant depending on the irrigation intensiveness. The best biorefinery configuration shows sustainable performance in all indicators excepting Freshwater Reduction, Non-Renewable Energy Share, and Raw-Materials Cost Ratio. Economic performance is best when biochar-production is maximized.



Sustainability footprint of a biorefinery showing example values and names of the assessed indicators (values lower than one mean sustainable performance).

Research Impact

The employed methodology allows coupling the sustainability analysis and the conceptual design. Every indicator gives information regarding the sustainable or unsustainable characteristics of the plant design. Employing this methodology requires little effort beyond the traditional TEA and a baseline LCA. From this study, it becomes evident that more efficient pesticide and fossil fertilizers application-rates on jatropha plantations can improve significantly the sustainability of the system. Pyrolysis products are the most promising options, although high uncertainty on biochar market-prices may limit financial feasibility depending on the region the biorefinery is placed on.

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"Bioenergy in Integrated Local Production Systems: A Study on the Food-Energy-Water Nexus"

The establishment of local production systems based on renewable resources (e.g. biomass) can alleviate unsustainable resource consumption caused by centralised production based on fossil fuels and large scale distribution infrastructures. The main objective of this work is to develop process systems engineering tools for the design of integrated local production systems. An overarching design framework that allows inclusion of integration possibilities within and across food, energy and water production subsystems has been proposed and is based on mathematical optimisation[1]. The methodology has been illustrated through a case study on the co-design of integrated food, water and energy subsystems using the nexus approach and applied to a designated UK eco-town. By minimising resource consumption (as measured by cumulative exergy consumption[2]), it was found that the energy demands for food and water supply subsystems, and for the eco-town's local population, can be supplied locally using wind, solar and bioenergy with bioenergy contributing to a significant 85% of all energy production (see Figure 1). The framework also demonstrates the advantages of a holistic system design (following a nexus approach) making efficient use of local resources.

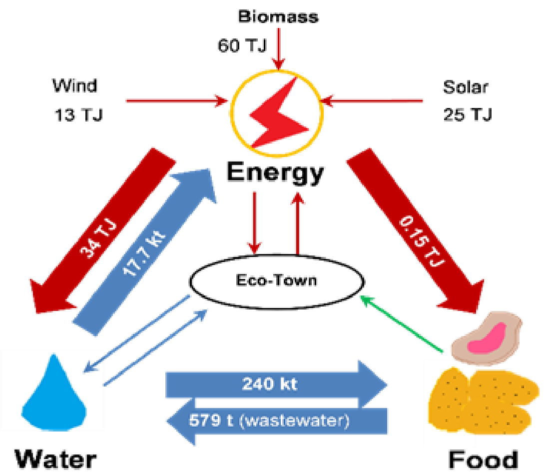

Figure 1. Overall picture of the resource exchange between food, energy and water subsystems in the nexus in the case study.

Results

- Mathematical approach proposed to design local integrated production systems.
- Use of locally available resources to meet local demands sustainably.
- Design of local food, energy and water production system based on the nexus concept.
- Bioenergy is a key enabler of localised production for integrated design of food-energy-water nexus.

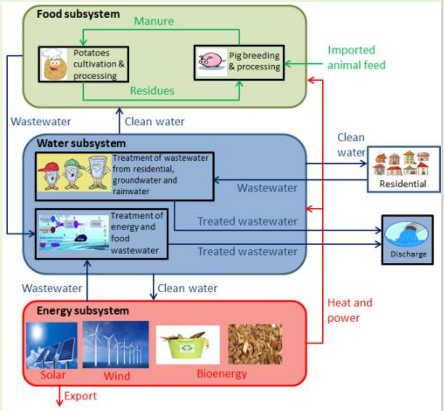

Figure 2. Integrated design of food, energy and water subsystems.

References

1. Leung Pah Hang, MY; Martinez-Hernandez, E; Leach, M; Yang, A. **Designing integrated local production systems: A study on the food-energy-water nexus**. Journal of Cleaner Production 2016, 135: 1065–1084.
2. Leung Pah Hang, MY, Martinez-Hernandez, E, Leach, M., Yang, A. **Towards a coherent multi-level framework for resource accounting**. Journal of Cleaner Production 2016, 125: 204-215.

Research Impact

So far this is the very first work published on co-designing food, energy and water systems using the nexus approach. It is envisaged that this will stimulate similar studies as a way to address the need for conscious integration of the various elements of the food-energy-water nexus.

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"Algae-based biorefinery for integrated CO_2 conversion into value-added products"

To design highly integrated biorefineries for enhanced sustainability, any residual stream must be treated as a stream with potential for energy generation and added value production[1]. This broadens the possibilities for streams such as CO_2, thus avoiding carbon emissions and improving environmental performance. CO_2 can be contained in a feed, intermediate or a product stream at different purities and flow rates and thus its strategic and efficient utilisation should be analysed from a process systems perspective. This work developed a conceptual algae-based biorefinery for CO_2 utilisation for production of biodiesel, bioethanol, succinic acid, fertilizer and bioenergy[2]. In order to achieve highest CO_2 utilisation within the biorefinery, the process integration method of mass pinch analysis was used to find optimum targets for design[3]. 1000 kg h^{-1} of dry algae biomass is used as basis.

References

1. Sadhukhan, J, Ng, KS, Martinez-Hernandez, E. *Biorefineries and Chemical Processes: Design, Integration and Sustainability Analysis.* Wiley, 2014.
2. Sadhukhan, J; Ng, KS; Martinez-Hernandez, E. Chapter 9. *Process Systems Engineering Tools for Biomass Polygeneration Systems with Carbon Capture and Reuse.* In: Process Design Strategies for Biomass Conversion Systems. Wiley, 2016.
3. Martinez-Hernandez, E; Sadhukhan, J; Campbell, GM. *Integration of bioethanol as an in-process material in biorefineries using mass pinch analysis.* Applied Energy 2013; 104:517-526.

Results

- CO_2 can be efficiently utilised in an integrated algae-based biorefinery.
- Design target is to process only 50% of CO_2 processed initially for near-zero CO_2 emissions from the process (Figure 2). This is because other CO_2 streams generated in the biorefinery are available at higher purity than the flue gas used as feed for algae cultivation.
- Process integration is a key enabler of efficient and more sustainable CO_2 utilisation and advanced algae-based biorefineries.

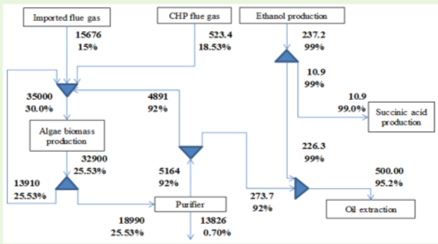

Figure 2. Integrated design for CO_2 utilisation in an algae-based biorefinery.

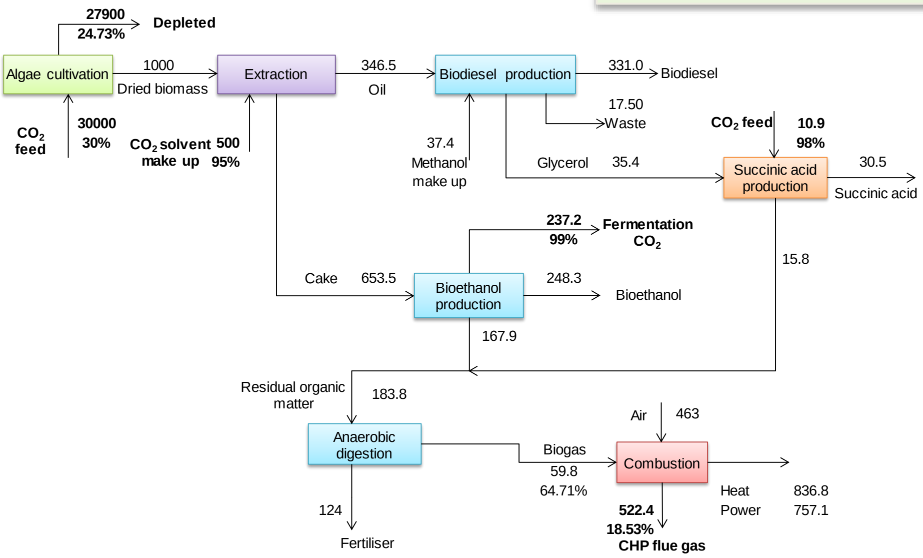

Figure 1. Algae-based biorefinery process flowsheet before integration of CO_2 streams.

Research Impact

So far this is the very first work published on integrated utilisation of CO_2 in an advanced, multi-product algae-based biorefinery. It is envisaged that this will stimulate similar studies for efficient integration of biorefineries to make them more efficient for enhanced sustainability.

Contact us

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"Wood wastes and sludge as an energy source for Mazandaran Wood and Paper Industries (MWPI)"

On the basis of the collected data from Mazandaran Wood and Paper Industries (MWPI), it is estimated that the energy demand may be an important issue for this integrated pulp & paper mill in the near future due to: start-up of a new fiber line of old corrugated cartons (OCC) pulp at August 2015 with annual capacity of 400000 ton per year and establishing a new DIP pulp mill in 2016, for partial displacement of wood- based neutral-sulfite semi-chemical (NSSC) and chemi-mechanical pulp (CMP) virgin pulps, respectively, and a plan to establish a 3rd paper machine in the coming 2-3 years.

Therefore, it is anticipated that annual capacity of black liquor production will be noticeably decreased in the future due to lower rate of wood consumption, while the necessity of energy and fuel will be greatly increased. In addition, while the inorganic/organic ratio of black liquor is very high, their concentration in black liquor is much lower than that of Kraft black liquor because of very high average pulping yield (about 80%). Therefore, the black liquor may not be considered as the first resource priority of energy production in the MWPI.

As the result, the solid wastes including chips preparation residues from mixed hardwood logs and possibly the sludges from the wastewater treatment plant (WWTP) may be considered as main resource in this research. Therefore, biomass-derived fast pyrolysis oil can be introduced as an alternative new energy potential to replace fossil fuel in the MWPI. Table 1 shows the amounts of wood-based solid wastes which are converted by chipper machines and the sludge of WWTP.

Table1. Wood-based solid wastes from MWPI

Units	Amount	
Wood chips preparation unit	*bark & saw dust*	**140***ton / day*
	over size	*40 ton / day*
	fine	**60** *ton / day*
Wastewater treatment plant	*Sludge (organic + inorganic)*: **40** *ton (oven dry) / day*	

Research Impact

In existing practice, considerable amounts of energy are used in sugarcane bagasse and converting hardwood logs into wood chips while wood residues (bark, saw dust and fine fiber) are disposed into nearby stream thereby polluting the environment severely. Reduction of these environmental pollutants by sustainable conversion of waste biomasses into clean energy (biofuel, chemicals) is of paramount interest to Iranian companies for not only self-sustaining the biomass management, but also exporting excess biomass or energy to the market. Since there is a lot of biomass residues around the factories, it will additionally create green jobs and educate local population on growing their own economy and living standard by effective co-production of energy and fuel at affordable costs in the future. A lot of bagasse wastes and also wood wastes of MWPI (available in 200 ton/day) can be used in varied applications for renewable biofuel and bioenergy production in Iran.

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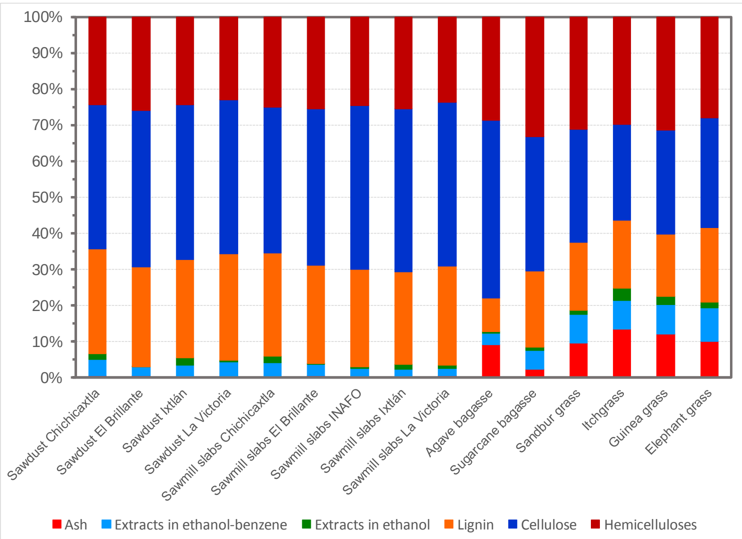
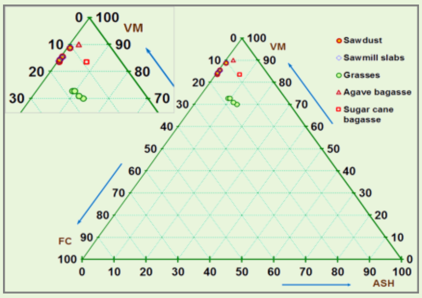
"Physicochemical traits of sawmill residues, grasses and bagasse of sugar cane and agave"

There are several biomass feedstocks in Mexico that can be used for bioenergy or biorefinery production. However, there is still a limited information about the physical and chemical traits of the biomass feedstocks, available amounts per year and the location per type of biomass. The aim of this research was to determine the physicochemical traits of some biomass, focusing on sawmill residues, four fast growing tropical grasses, sugar cane bagasse and tequila agave bagasse. Estimation of biomass was also carried out with mapping of the biomass. Biomass samples were collected at different locations and processed according to ASTM and TAPPI standards to determine their main chemical composition, proximal analysis and gross heat value. Field sampling of grasses was performed to evaluate yield production of biomass. Official historical records of production were obtained at municipality level for the last five years to estimate sawmill residues, sugar cane bagasse and tequila agave bagasse. Geographical information system techniques were applied for mapping the amount of dry biomass produced per year.

Main chemical composition, proximal analysis and gross heat values is variable among the biomass types. Grasses and agave bagasse have a higher amount of ash (7.3-13.3%) than sawmill residues and sugar cane bagasse.



Results



Proximal analysis of biomass

Gross heat values

Common name	Gross Heat Value (MJ/Kg)
Sawdust Chichicaxtla	17.88
Sawdust El Brillante	18.30
Sawdust Ixtlán	17.65
Sawdust La Victoria	18.64
Sawmill slabs Chichicaxtla	18.25
Sawmill slabs El Brillante	18.71
Sawmill slabs Ixtlán	17.71
Sawmill slabs La Victoria	18.37
Sandbur grass	18.87
Itchgrass	17.52
Guinea grass	18.17
Elephant grass	18.32
Agave bagasse	15.53
Sugarcane bagasse	19.11

Dry biomass yield of grasses was between 9.4 and 12.9 ton/year. Estimated dry biomass is about 5.59 Million ton/year for sugar bagasse, 1.5 Million ton/year for sawmill residues and 134 660 ton/year for agave tequila bagasse. These three residues have an energy potential of 166.7 PJ.

Research Impact

Material properties are important in assessing the suitability of a biomass feedstock for a given conversion process. Moisture content, gross heat value, volatile matter, ash content and fixed carbon are important in thermochemical processing, while the amount of cellulose, hemicellulose and lignin are of primary concern in biological and chemical conversion. The results provide information for assessing different scenarios for setting up a biomass processing industry.

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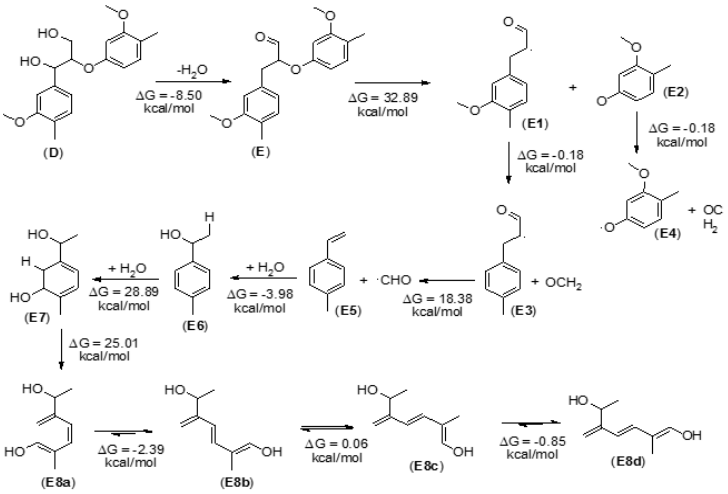
“Pyrolysis of lignin: A theoretical-experimental approach”

The main goal of this study is to establish through of a theoretical-experimental analysis, the influence of the heating form (slow and fast pyrolysis) on the type and content of organic products generated during the lignin pyrolysis. To achieve these goals, the study has been divided in two sections: i) theoretical considerations and ii) experimental tests.

Theoretical considerations: In this section is identified the most likely route for the fragmentation of lignin, through of its most prominent intrinsic characteristic, the breaking of β-O-4 linkages (**scheme 1**). The study also predicts, thermochemical feasibility of the main products of pyrolysis and establishes the energy barriers at each step or stage.

Experimental tests: The first step is to make a thermal study, using simultaneous thermos-analytical techniques (TGA-DSC) and infrared spectroscopy (FTIR), to identify the most relevant thermal events and its temperature intervals. The procedure includes the slow pyrolysis (heating rate < 0.05 °C s^{-1}) and fast pyrolysis (heating rate > 1000 °C s^{-1}), as well as identification of the organics products in each stage, in order to evaluate the influence of the heating rate on the selectivity toward aromatic or aliphatic compounds.



Scheme 1. Chemical route proposed as the most likely one for the thermal decomposition of β-O-4 linkages in lignin.

Research Impact

Nowadays, the disposal of any waste is a worry in the area of environmental protection and sustainability. Lignin typically lies as the main constituent of large residual streams in e.g. the pulp and paper sector and (future) cellulose ethanol plants and biorefineries. It has a heterogeneous and recalcitrant structure that depends on plant species and growth conditions. Their natural complexity and high stability of lignin bonds, makes it a byproduct difficult to process and with a low commercial value. However, it is the second most abundant natural biopolymer containing valuable aromatic (phenolic) structures. Hence the importance of develop and optimizing new methods and process to convert lignin into diverse high value products.

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New Biorefiner

This section is dedicated to members presenting their profile and story about becoming 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.

Polygeneration: The Future Sustainable Industrial System Concept

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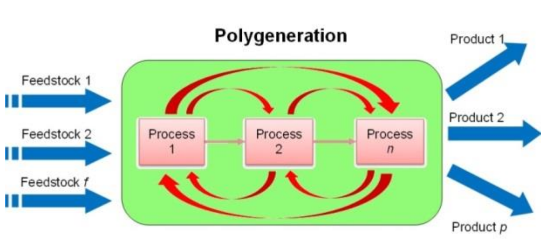
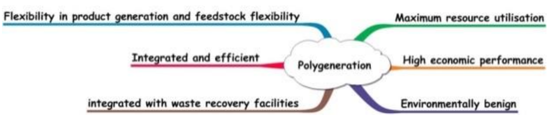
The Centre for Environmental Strategy (CES) in University of Surrey is an international acclaimed institution specialising in sustainable socio-economic and environmental development. My roles as a Research Fellow in the Centre are to provide process integration, techno-economic analysis and life cycle assessment expertise in bridging the gap between engineering design and sustainability and addressing the challenges during the transition from fossil fuels to bio-renewable energy. With this vision in mind, I have defined my research into three primary areas: (1) integrated biorefinery systems; (2) decarbonised energy systems and (3) resource recovery from waste and wastewater. Throughout my PhD and industrial experience, I have carried out a number of research and consultancy projects in conceptual process design and integration with the aims of enhancing energy efficiency while lowering environmental impacts. I have collated my work in sustainable biorefinery system design in my recent co-authored textbook "*Biorefineries and Chemical Processes: Design, Integration and Sustainability Analysis*".

My research work will have an impact on shaping sustainable industrial systems design and practice. My current research project investigates the techno-economic feasibilities and environmental impacts of resource recovery from wastewater using bioelectrochemical systems (i.e. microbial electrosynthesis) – an emerging wastewater treatment technology with the capabilities of recovering valuable materials such as metals, chemicals and electricity from wastewater. Recovering metal from secondary resources such as zinc from steel plant and copper from distillery sites in wastewater streams is the main focus of this project [1]. Improving waste management and unlocking opportunities in waste recovery into added value products such as chemicals, refuse derived fuel, fertiliser and energy are also part of the objective of the research work [2]. The project is funded by Natural Environment Research Council (NERC) within the Resource Recovery from Waste (RRfW) and in partnership with the Newcastle University, University of South Wales, University of Manchester, Tata Steel and Chivas Brothers [3]. This project has added an important element to the subject of polygeneration and has important implication to the society in terms of social, economic and environmental benefits. Polygeneration is the next generation prototype of industrial system design with great potential of realising a resource efficient and low-carbon environment.

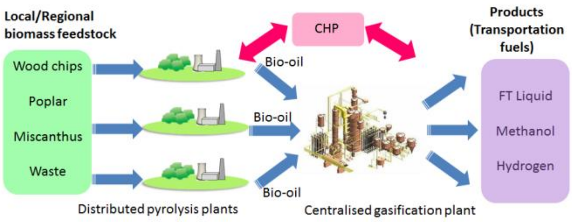


Polygeneration advocates a highly flexible system in terms of generation of multiple products and utilisation of various feedstocks, highly integrated and energy efficient, high economic performance and environmentally benign system, and also with the capabilities of maximising resource utilisation and recovery[4,5,6]. Biorefinery is an example of polygeneration of which it is a facility with integrated, efficient and flexible conversion of biomass feedstocks, through a combination of physical, chemical, biochemical and thermochemical processes, into multiple products. The biorefinery concept was analogous to the complex crude oil refineries adopting the process engineering principles applied in their designs, such as feedstock fractionation, multiple value-added productions, process flexibility and integration [7]. Enhancing the economic performance of



biorefinery is the key challenge during the commercialisation stage. Energy products such as heat, electricity and biofuel are considered as low value product while biochemicals and biomaterials (e.g. polymers) are high value products. However, the revenue potential for energy products is higher compared to biochemical and biomaterials because of their high volume production. Hence, devising a strategy to realise an economic competitive biorefinery system through multi-product generation and added-value production using materials from waste streams are vital, in parallel with the recent advocate for circular economy.

My PhD research has contributed towards developing concepts associated with biorefinery and decarbonised polygeneration systems, as well as exploring niche problem areas with a view to improving energy efficiency and improving economic margins while minimising any concomitant environmental impact [8]. I have systematically applied process integration strategies in combining decarbonisation processes into coal- and biomass thermochemical conversion systems to establish highly integrated polygeneration systems. My first publication in this area ("*Ng, K.S., Lopez, Y., Campbell, G.M., Sadhukhan, J., 2010. Heat integration and analysis of decarbonised IGCC sites. Chem Eng Res Des., 88 (2): 170-188.*"), in which I proposed the strategies of combining energy integration and decarbonisation strategies in a gasification plant, was awarded the Junior Moulton Medal. Distributed processing of bio-oil via fast pyrolysis and followed by centralised gasification processing of bio-oil into syngas are highly advocated in my studies. It has been found that the integrated gasification of bio-oil system coupled with Fischer-Tropsch liquid or methanol synthesis and combined heat and power (CHP) production can achieve high energy and economic performances [9,10].



Further development in integrated biorefinery system design, decarbonised energy systems and resource recovery will be envisaged and I welcome any opportunities for collaboration in these fields.

Profile URLs

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Short Biography:

Kok Siew completed his MEng Chemical Engineering with Chemistry at the University of Manchester in 2008. He later gained his PhD from the Centre for Process Integration (CPI), The University of Manchester in 2011. Kok Siew has industrial experience as a consultant in Process Integration Limited, UK, 2011-2013. He has involved in a diverse range of consultancy projects in the UK, Europe and China including refrigeration system for LNG processes, upgrading of gasoline feedstock into chemicals, water system integration in refinery and steel plant. He had also taken up a leading role in an EU-funded project on water system in steel plant. He was Guest Editor of two IChemE special issue journals: Chemical Engineering Research and Design (Title: Biorefinery Value Chain Creation) and Sustainable Production and Consumption (Title: Sustainable Availability and Utilisation of Wastes) in 2016. Kok Siew is proactive in establishing links with developing countries to address the issues related to energy and climate change. He has organised British Council / Newton Fund Researcher Links workshop in Mexico (2015) and Malaysia (2016).

References

1. Ng, K.S., Head, I., Premier, G.C., Scott, K., Yu, E., Lloyd, J., Sadhukhan, J., 2016. A multilevel sustainability analysis of zinc recovery from wastes. Resour Conserv Recy. 113: 88 – 105.
2. Sadhukhan, J., Ng, K.S., Martinez Hernandez, E., 2016. Novel integrated mechanical biological chemical treatment (MBCT) systems for the production of levulinic acid from fraction of municipal solid waste: A comprehensive techno-economic analysis. Bioresource Technol, 215: 131-143.
3. Microbial Electrochemical Technology for Resource Recovery (METEORR). http://www.meteorr.ac.uk/
4. Ng, K.S., Zhang, N., Sadhukhan, J., 2013. Techno-economic analysis of polygeneration systems with carbon capture and storage and CO2 reuse. Chem. Eng. J. 219: 96-108.
5. Ng, K.S., Martinez Hernandez, E., 2016. A systematic framework for energetic, environmental and economic (3E) assessment and design of polygeneration systems, Chem Eng Res Des, 106: 1-25.
6. A graphical CO_2 emission treatment intensity assessment for energy and economic analyses of integrated decarbonised production systems. Comput Chem Eng, 45: 1-14.
7. Sadhukhan, J., Ng, K.S., Martinez Hernandez, E., 2014. Biorefineries and chemical processes: design, integration and sustainability analysis, Wiley.
8. Ng, K.S., 2011. Decarbonised polygeneration from fossil and biomass resources. PhD Thesis. The University of Manchester.
9. Ng, K.S., Sadhukhan, J., 2011. Techno-economic performance analysis of bio-oil based Fischer-Tropsch and CHP synthesis platform. Biomass Bioenergy, 35 (7): 3218-3234.
10. Ng, K.S., Sadhukhan, J., 2011. Process integration and economic analysis of bio-oil platform for the production of methanol and combined heat and power. Biomass Bioenergy, 35 (3): 1153-1169.

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Biorefinery in Mexico City

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My name is Natalia Crystel Celis Pérez and I studied Chemical Engineering at the National Autonomous University of Mexico (UNAM). Since my first year in university at my thermodynamics class, I was so impressed with how the energy can be transformed in different ways to generate power, to move cars, airplanes and to make computers work. Everything around us involves energy. My passion for energy and my interest in environmental problems such as climate change and waste disposal led me to do my thesis about a guide to implement a three platform (C6 sugar, oil, biogas) biorefinery for ethanol, biodiesel and biogas from lignocellullose, oily and organic residues. The raw materials include waste paper (WP), waste cooking oils (WCO) and organic fraction of municipal solid waste (OFMSW). The proposed location of the biorefinery is in an area near the local landfill "Bordo Poniente", where the municipal solid waste will be taken to be used as raw material, and close to the new international airport that is being built, where the biorefinery products will be delivered. The biorefinery process options being explored are illustrated in Figure 1.

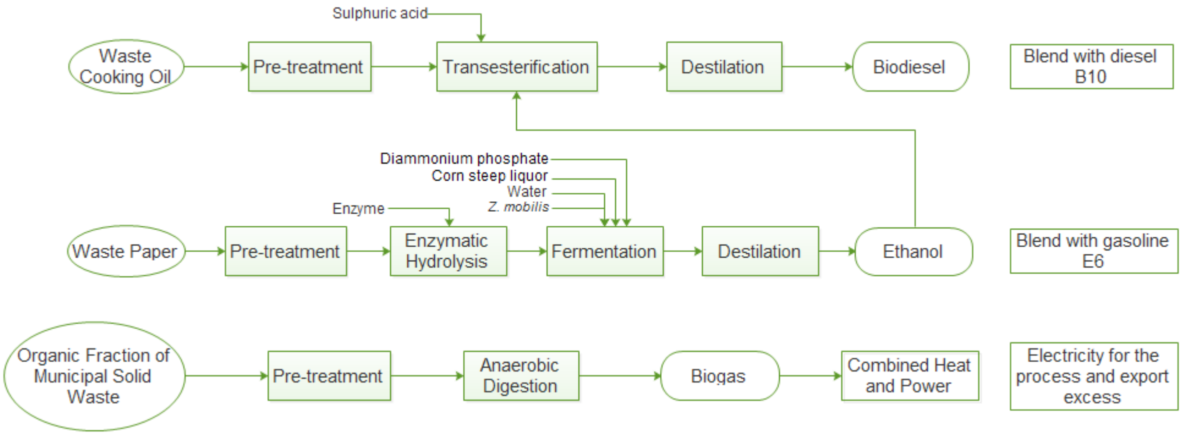

Figure 1. Diagram of the biorefinery configuration.

Table 1 shows that the energy potentially obtained from the possible biofuel products is mainly contributed by the energy from biogas, followed by ethanol and diesel. The objective of my projects is to provide guidelines for what Mexico needs to implement a biorefinery with those features.

Table 1. Main features of the new urban biorefinery from Mexico City's waste.

Biofuel	Raw material	Capacity	Generation Rate	Energy MW
Biogas	OFMSW	1000 ton/day	120 m3/ton	51.39
Biodiesel	WCO	236 L/day	0.94 L_{WCO}	0.09
Ethanol	WP	1000 ton/day	0.226 ton/ton_{WP}	49.89

Biogas and biodiesel

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The mission of the Faculty of Chemistry at the National Autonomous University of Mexico (UNAM) is offering technological services to public and private sectors of our country to promote the progress of Mexican society and its sustainable development. Our vision is to consolidate a group of experienced researchers and engineers in the study and resolution of fundamental problems in industry, in the area of processes and environmental engineering as well as the development of technological innovations and training high level human resources.

BIOGAS AND BIODIESEL

The Unit of Research Projects and Environmental Engineering (UPIIA in Spanish) focuses on the production of biogas to generate electrical energy from municipal solid waste by using wet and dry anaerobic digestion technologies. A pilot plant with capacity of processing 600 kg/d has been installed and has started operation at UNAM Campus on Cuautitlán Izcalli, State of Mexico, Mexico.
The group has also started a feasibility study of production of biodiesel from Jatropha Curcas oil. The use of homogeneous or heterogeneous catalyst is being used in order to get the highest conversion of reaction to produce high purity biodiesel and co-products.

Biogas: The aim of our research on biogas production is to validate the parameters obtained in operation of pilot plant in order to achieve successful design at commercial and industrial scales; and the developing of a Mexican atlas to locate suitable places for this biogas technology.

Methodology: Characterization of OFMSW (organic fraction of municipal solid waste) in Mexican municipalities and 4 delegations Mexico City were made. Laboratory work was developed to obtain parameters such as residence times, conditions of pressure and temperature with two reactors with volume capacity of 5 liters. Basic and detailed Engineering and construction and installation of the plant capacity 600kg/d was developed and compares dry and wet anaerobic digestion technologies. The pilot plant could be used to experiment with other residues such as the Mexican *Nopal* biomass.

Biodiesel: The objective of our research on biodiesel production is to support the Biodiesel production from biomass (Jatropha Curcas, waste oil or animal fat) in order to reduce imports of fossil fuels such as diesel and gasoline, which is about 40% the domestic use of fuels in Mexico. This could help reducing the amount of pollution gases, mainly CO_2 and others.

Achieving link with the energy industry in Mexico from the use of biomass as feedstock and mapping those locations with high potential and availability of biomass and identify locations for installation of one or more plants producing biogas or biodiesel.

Researchers:
Dr. Alfonso Durán Moreno General Coordinator to UPIIA, J. Arturo Moreno Xochicale. Process Engineer, and Professor Faculty of Chemistry at UNAM; M. E. Germán Basurto, Process Engineer at a Biogas Pilot Plant; Chem. Eng. Hector Patricio, Process Supervisor at a Biogas Pilot; Chem. Eng. Frantz Blanco, Process Engineer at a Biogas Pilot; A. Karen Brito, Chemical Engineering student working on a Biodiesel project; Crystel Celis Chemical Engineer student working on a Bio-Refinery Guide for Design and Construction.

Integrated biorefineries and bioelectrochemical systems for the production of biofuels and valuable chemicals

Dr Mobolaji Shemfe

Centre for Environmental Strategy

University of Surrey

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Dr Shemfe recently obtained his PhD from Cranfield University. His doctoral research focused on the techno-economic and environmental life cycle assessment of advanced biofuels production via fast pyrolysis of biomass and bio-oil upgrading via conventional oil refinery technologies (see illustration in Figure 1). His work provides fresh insights into the process, economics and environmental factors that influence the viability of biofuel production from fast pyrolysis-derived oils using bio-oil hydroprocessing and zeolite cracking.

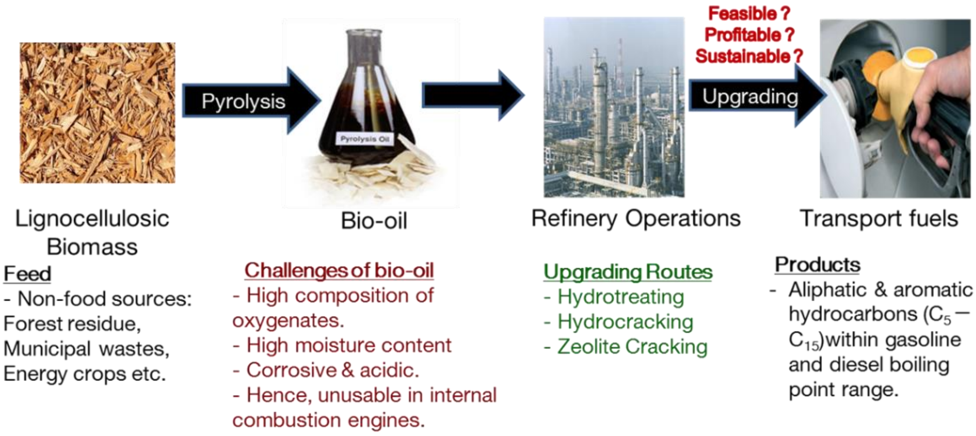

Figure 1 Biofuel production from fast pyrolysis-derived oils via hydroprocessing and zeolite cracking

The abstract of his PhD thesis is as follows:

"Biofuels have been identified as one of several GHG emission strategies to reduce the use of fossil fuels in the transport sector. Fast pyrolysis of biomass is one approach to producing second generation biofuels. The bio-oil product of fast pyrolysis can be upgraded into essential gasoline and diesel range products with conventional refinery technologies. Thus, it is important to assess their techno- economic and environmental performance at an early stage prior to commercialisation. This research was conducted with the goal of evaluating and comparing the techno-economic and environmental viability of the production of biofuels from fast pyrolysis of biomass and upgrading of bio-oil via two refinery technologies, viz. hydroprocessing and zeolite cracking. In order to achieve this aim, process models of fast pyrolysis of biomass and bio-oil upgrading via hydroprocessing and zeolite cracking were developed. The fast pyrolysis model was based on multi-step kinetic models. In addition, lumped kinetic models of the hydrodeoxygenation reactions of bio-oil were implemented. The models were validated against experimental measurements with good prediction and formed the foundation for the development of a 72 t/day fast pyrolysis plant model in Aspen Plus®. Several strategies were proposed for the two pathways to enhance energy efficiency and profitability. All in all, the results revealed that the hydroprocessing route is 16% more efficient than the zeolite cracking pathway.

Moreover, the hydroprocessing route resulted in a minimum fuel selling price of 15% lower than that from the zeolite cracking pathway. Sensitivity analysis revealed that the techno-economic and environmental performance of both pathways depends on several process, economic and environmental parameters. In particular, biofuel yield, operating cost and income tax were identified as the most sensitive techno-economic parameters, while changes in nitrogen feed gas to the pyrolysis reactor and fuel yield had the most environmental impact. It was concluded that hydroprocessing is a more suitable upgrading pathway than zeolite cracking in terms of economic viability, energy efficiency, and GHG emissions per energy content of fuel produced."

Table 1 and Figure 2 show snapshots of results from his PhD thesis.

Table 1 Comparative techno-economic performance for fast pyrolysis systems

Conversion process	η (%)	TCI	MFSP (£/GGE)	Fuel yield (kg/h)	Electricity (kW)
Fast Pyrolysis (FP)	66.3	£5.6m	-	-	-
FP + Electricity from char combustion (ECC)	68.4	£6.5m	-	-	0.24
FP + ECC + Bio-oil hydroprocessing	62%	£16.5m	6.3	594	0.24
FP + zeolite cracking (ZC) with 2PRG	54%	£13.2m	7.48	448	0.896
FP + ZC + 1PRGC	52%	£12.1m	7.20	448	0.747

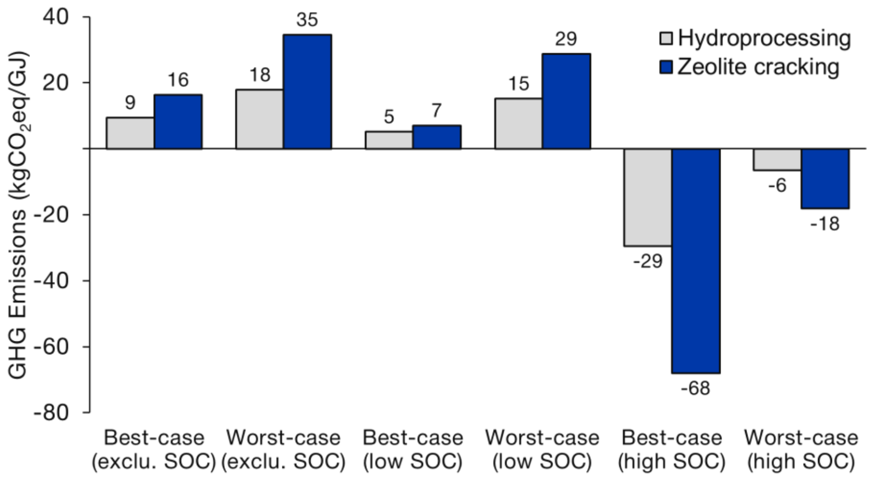

Figure 2 Comparative GHG emissions from hydroprocessing and zeolite cracking

Check the following published articles for further reading on his PhD work:

1. M. Shemfe, S. Gu, and P. Ranganathan, "Techno-economic performance analysis of biofuel production and miniature electric power generation from biomass fast pyrolysis and bio-oil upgrading," Fuel, vol. 143, no. 0, pp. 361–372, Jan. 2015.
2. M. B. Shemfe, B. Fidalgo, and S. Gu, "Heat integration for bio-oil hydroprocessing coupled with aqueous phase steam reforming," Chem. Eng. Res. Des., Sep. 2015.
3. M. B. Shemfe, C. Whittaker, S. Gu, and B. Fidalgo, "Comparative evaluation of GHG emissions from the use of Miscanthus for bio-hydrocarbon production via fast pyrolysis and bio-oil upgrading," Appl. Energy, vol. 176, pp. 22–33, 2016.

After completing his PhD, he joined the Centre for Environmental Strategy (CES) as Research Fellow in an **EPSRC project Liquid Fuel and bioEnergy Supply from CO2 Reduction (LifesCO2R)** in June 2016. CES is a renowned interdisciplinary research centre based at the University of Surrey, with research activities focused on systems analysis to develop policy-relevant solutions to global issues within the perimeters of techno-economic, ecological and societal constraints. The EPSRC research project at CES centres on assessing the life cycle sustainability of microbial electrosynthesis (MES) for the cathodic reduction of carbon dioxide into biofuels and biochemicals (see Figures 3 & 4 for illustrations). Biorefineries generate a plethora of low-value waste that impairs their energy and conversion efficiencies. MES can enhance the polygeneration potential of biorefineries, and consequently their energy and conversion efficiencies, by converting low-value waste streams and carbon dioxide into high-value products. Moreover, the recovery of valuable products from biorefineries wastes using MES offers significant environmental benefits through synergetic waste reduction and pollution control. The sustainability research group is spearheaded by Dr Jhuma Sadhukhan. The project is being conducted as a cross-disciplinary research effort in collaboration with other academic institutions, including Newcastle University, Universities of Sheffield, Oxford and University of Glamorgan.

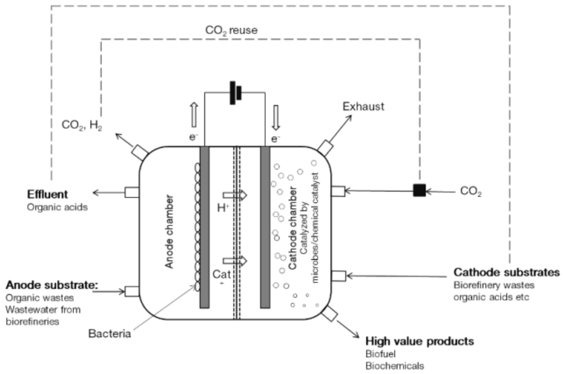

Figure 3 Microbial electrosynthesis for CO_2 reuse to produce high value products from organic waste.

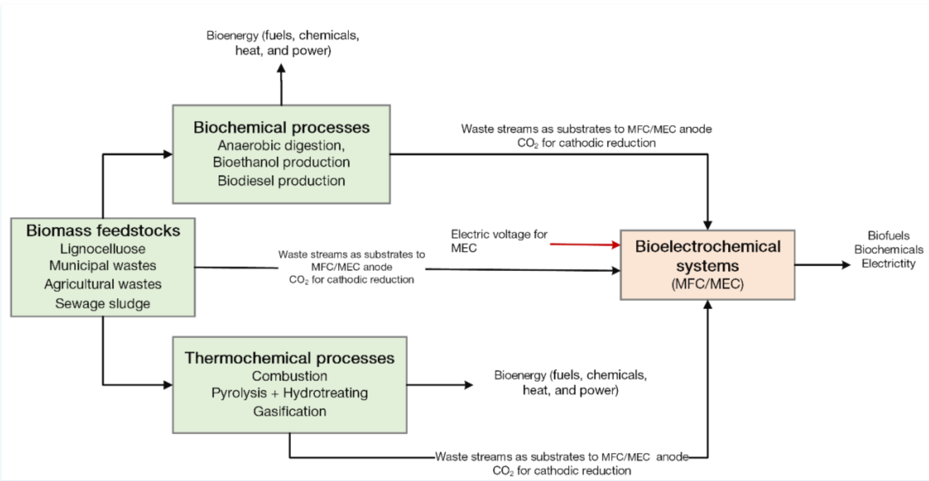

Figure 4 Microbial electrosynthesis (or bioelectrochemical) systems for the production of biofuels and valuable chemicals

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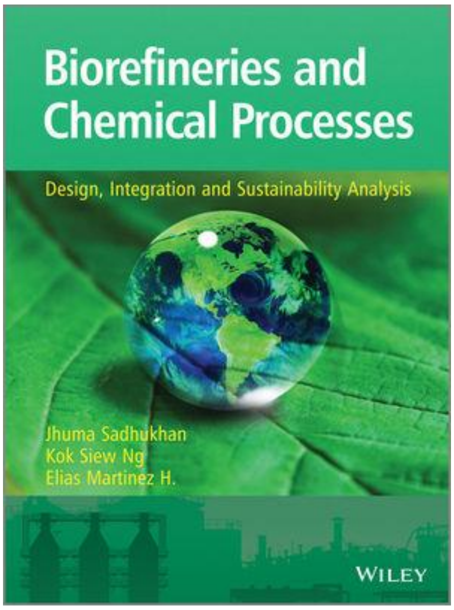
Book showcase

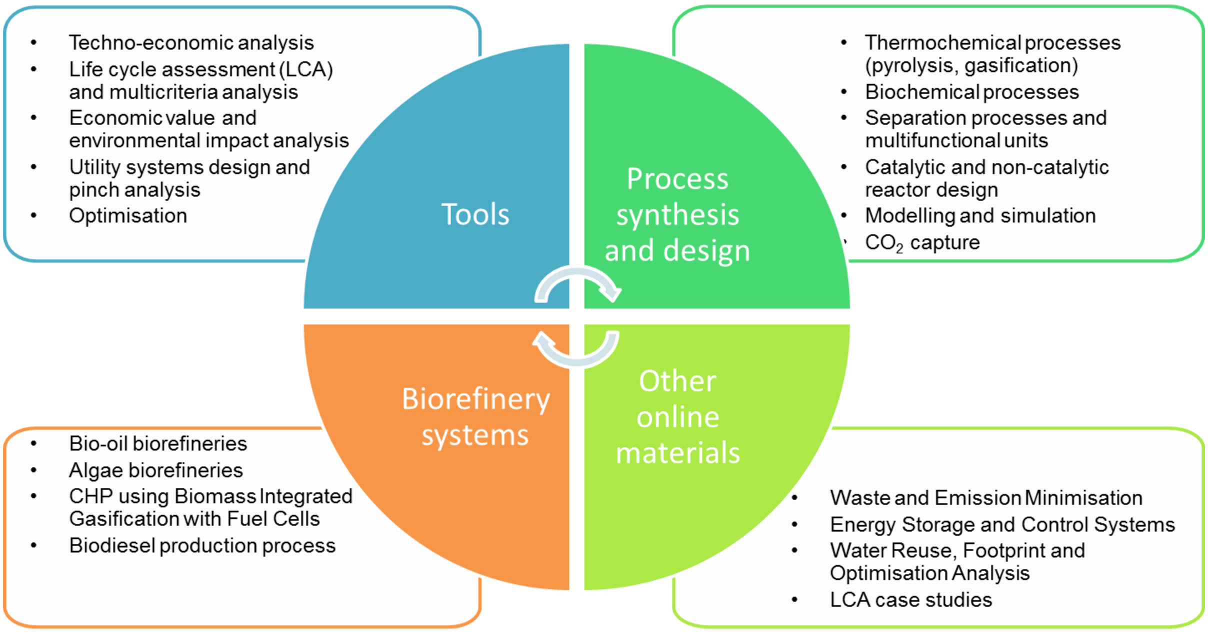


Biorefineries and Chemical Processes: Design, Integration and Sustainability Analysis

Building upon extensive research in biorefinery, the first advanced textbook which is designed to bridge the gap between engineering design and sustainability assessment for advanced students and practicing process designers and engineers has proudly released by a team of UK researchers Dr. Jhuma Sadhukhan, Dr. Kok Siew Ng and Dr. Elias Martinez Hernandez.

About the book

As the range of feedstocks, process technologies and products expand, biorefineries will become increasingly complex manufacturing systems. "Biorefineries and Chemical Processes: Design, Integration and Sustainability Analysis" presents process modelling and integration, and whole system life cycle analysis tools for the synthesis, design, operation and sustainable development of biorefinery and chemical processes.



Overview of the comprehensive book contents

Additional material can be found in the online companion website, consisting of four case studies, additional exercises and examples, together with three supplementary chapters which address waste and emission minimization, energy storage and control systems, and the optimization and reuse of water.

http://www.wiley.com/legacy/wileychi/sadhukhan/

The book has received excellent feedback since its release:

"This book is designed as an advanced text for final year and post graduate chemical engineers as well as for the teaching staff. It deals with the specialized subject matter thoroughly with good explanations of the chemistries involved and emphasizes where conventional chemical engineering principles differ from those needed to design biorefinery plant. Admirably, an "economic analysis" chapter is provided and includes the standard discounted cash flow method for evaluating the ongoing financial viability of any production unit." – Springer (Chromatographia, DOI 10.1007/s10337-015-2843-9).

"This book aims to bridge the gap between engineering and sustainability in bio-based processes, with the help of analytical tools for economic and environmental assessment – and it succeeds in doing so. The reader will also learn how to apply these tools, thanks to the numerous problems elaborated and solved using software like ASPEN, MATLAB and GaBi (for LCA). In conclusion, this book introduces the reader to the rapidly-developing industry of biorefineries, with a multi-disciplinary approach. It is a good resource for undergraduate and post-graduate students who want to learn about biorefineries; it can also be valuable for researchers who are looking to practically apply these analytical tools in their work." – Green Processing & Synthesis (Green Process Synth 2015; 4: 65–66)

Professor Grant Campbell (Huddersfield) says about the book "It looks so substantial (in the literal sense of containing a lots of tangible substance) and so high quality! The scope and quality of the resources, including the additional web material, are extensive, and the pedagogical innovations and presentation are creative and empowering. I believe it has the potential to be a game-changer by giving a basis for educating the biorefinery engineers who will actually bring about the power and contribution that biorefineries, correctly conceived, designed and operated, can deliver."

Launching of the book

The book was released in October 2014 and was officially launched during the 24th European Biomass Conference and Exhibition (EUBCE) at Amsterdam, The Netherlands on 8th June 2016 (see page 18). The book is available in paperback and e-book versions and can be purchased via the official Wiley website at http://eu.wiley.com/WileyCDA/WileyTitle/productCd-1119990866.html

About the authors

Dr. Jhuma Sadhukhan
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Dr Jhuma Sadhukhan was the Principal Investigator of the British Councils UK/Malaysia and UK/Mexico Researchers Links Workshops on biorefineries and she is the Founder of the Institution of Biorefinery Engineers, Scientists and Technologists (IBEST). She is a Fellow of the Institution of Chemical Engineers (FIChemE), Chartered Engineer (CEng), Chartered Scientist (CSci), an Academic at Surrey, a Visiting Academic at Imperial College, London and was previously an Academic at The University of Manchester, UK. With extensive industrial experience as Process Systems Engineer with MW Kellogg Ltd. and Technip, she brings unique expertise in sustainability and engineering systems. She is sustainability theme leader of numerous UK Research Councils funded multidisciplinary consortia. She is the recipient of the IChemE Moulton Medal 2010 (with Dr Kok Siew Ng) and Hanson medal 2006. She with Nottingham Malaysia was a Finalist in the WBM Bio Business Award 2015. She is external examiner of University (Newcastle and Bath) courses on Sustainable Chemical Engineering and serves the Editorial board of Sustainable Production and Consumption journal of Elsevier. She with Dr Elias Martinez-Hernandez and Dr Kok Siew Ng edited a Special Issue on Biorefinery Value Chain Creation, Volume 107, pages 1-280, Chemical Engineering Research & Design, IChemE / Elsevier, 2016.

Dr. Kok Siew Ng
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Dr Kok Siew Ng completed his MEng Chemical Engineering with Chemistry at the University of Manchester in 2008. He later gained his PhD from the Centre for Process Integration (CPI), The University of Manchester in 2011. Kok Siew has industrial experience as a consultant in Process Integration Limited, UK, 2011-2013. He has involved in a diverse range of consultancy projects in the UK, Europe and China including refrigeration system for LNG processes, upgrading of gasoline feedstock into chemicals, water system integration in refinery and steel plant. He had also taken up a leading role in an EU-funded project on water system in steel plant. He was Guest Editor of two IChemE special issue journals: Chemical Engineering Research and Design (Title: Biorefinery Value Chain Creation) and Sustainable Production and Consumption (Title: Sustainable Availability and Utilisation of Wastes) in 2016. Kok Siew is proactive in establishing links with developing countries to address the issues related to energy and climate change. He has organised British Council / Newton Fund Researcher Links workshop in Mexico (2015) and Malaysia (2016).

Dr. Elias Martinez Hernandez
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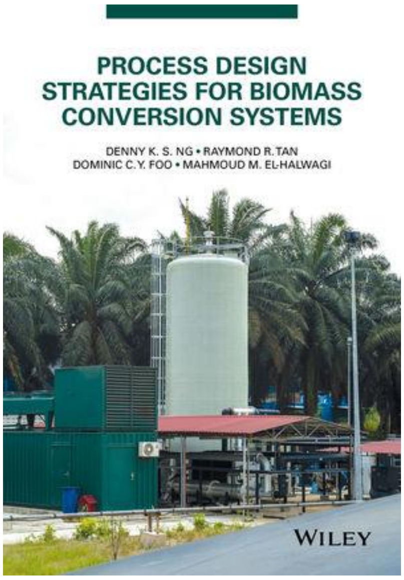
Dr Elias Martinez Hernandez is a Chemical Engineer by the National Autonomous University of Mexico and obtained his PhD from the University of Manchester, UK. He recently joined the University of Bath as a lecturer in Chemical Engineering. Between 2013 and 2016, Elias worked as a Research Fellow at the University of Surrey in the Centre for Environmental Strategy and then at University of Oxford in the Department of Engineering Science. He has published on process integration and sustainability of biorefineries, impact of bioenergy production on ecosystem services and urban biorefinery for waste processing. More recently, he co-authored the very first paper on co-designing food, energy and water systems using a holistic optimisation approach. Elias pioneered the promotion of biorefinery research and collaboration between UK and developing countries and he masterminded the workshop held in Mexico in 2015, and supported the organisation of the one in Malaysia. He is also a developer of user friendly software and website applications to implement analysis tools and to communicate results to wider audiences. Elias' areas of research include bioenergy, biorefineries and renewable energy integration, life cycle assessment, food-energy-water nexus, waste processing and circular economy.



Process Design Strategies for Biomass Conversion Systems

A team of international researchers, Professor Denny KS Ng (The University of Nottingham Malaysia), Professor Raymond R. Tan (De La Salle University, The Philippines), Professor Dominic CY Foo (The University of Nottingham Malaysia) and Professor Mahmoud M El-Halwagi (Texas A&M University) have released an edited book in February 2016. This book covers recent developments in process systems engineering (PSE) for efficient resource use in biomass conversion systems. It provides an overview of process development in biomass conversion systems with focus on biorefineries involving the production and coproduction of fuels, heating, cooling, and chemicals. The scope includes grassroots and retrofitting applications. In order to reach high levels of processing efficiency, it also covers techniques and applications of natural-resource (mass and energy) conservation. Technical, economic, environmental, and social aspects of biorefineries are discussed and reconciled. The assessment scales vary from unit- to process- and life-cycle or supply chain levels. The chapters are written by leading experts from around the world, and present an integrated set of contributions. Providing a comprehensive, multi-dimensional analysis of various aspects of bioenergy systems, the book is suitable for both academic researchers and energy professionals in industries.

The book is available in hardcover and e-book and can be purchased via Wiley official website http://eu.wiley.com/WileyCDA/WileyTitle/productCd-1118699157,subjectCd-AG90.html

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