Economic Value Generation and Social Welfare in Mexico by Waste Biorefining

Jhuma Sadhukhan
University of Surrey (Surrey) and Imperial College London (IC), UK
National Research Institute of Forestry, Agriculture and Livestock (INIFAP) and Instituto Mexicano del Petróleo (IMP), Mexico

Newton Research Collaboration Programme

12 months | **Mexico** | **Incoming/outgoing**

OBJECTIVES OF THE EXCHANGE

Problem statement – one sentence to state what the research exchange has tackled

You **must** discuss

- Original objectives
- What has now been enabled by the exchange

(100-200 words)

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

RESEARCH UNDERTAKEN

You **must** discuss:

- How the original objectives have been met/if they weren't met was something different achieved instead
- What the subsequent main achievements have been

You may wish to discuss/include:

- If there were any problems and describe how these were overcome
- Your work package objectives and how each one has been achieved
- Learnings and challenges
- Diagrams and photographs (if unable to add to the template please reference on a separate page)

(400-500 words)

The orginal objectives have been met. In addition, new important research elements have been identified and progressed. The subsequent main achievements have been discussed in each workpackage. Detailed discussions in the form of working drafts for peer-reviewed archived journal publications are included in the Appendix.

WP1: INIFAP and Surrey have analysed biomass physical attributes that determine bioenergy and biorefinery feasibility in Mexico. The spatial distributions of available agricultural and forestry biomass in Mexico have been created using geographic information system for 2457 Mexican municipalities and 31 states.

WP1 has generated a working draft "Assessment of agriculture and forestry residues for bioenergy production in Mexico" for peer-reviewed archived journal publication, in Biomass & Bioenergy of Elsevier, enclosed in Appendix A. Assessed biomass has a potential of contributing 6.85% of the total energy production in Mexico. This is an enhancement from identified prospect of bioenergy by 4.14% by the SENER. This study has identified locations with a high bioenergy generation potential. The determining factors have been easy accessability and dense biomass availability. For remote locations, pelletising biomass at distributed scales and then transporting biomass pellets to bioenergy generation facility are foreseen. Consultations with industries on further R&D and implementation are ongoing.

WP2: IC and IMP have undertaken experimental studies for proof of concept generation on liquefaction of biomass under supercritical conditions. The study findings are detailed in Appendix B.

WP3: Surrey, INIFAP and IMP have investigated the techno-economic and environmental feasibility of biochemical conversion of lignocelluloses available in Mexico into bioethanol. The conceptual design of the integrated biorefinery system consists of three sections: 1) pretreatment, enzymatic hydrolysis, fermentation and bioethanol purification, 2) wastewater treatment and anaerobic digestion and 3) combined heat and power (CHP) system. Wet analysis including compositions of constituents of hemicellulose, cellulose, lignin, ash and moisture has been collated for 19 forestry and 13 agricultural lignocelluloses in Mexico (WP1) and used as input variables to the models for techno-economic and carbon footprint analyses of their conversions into the products. Lignocelluloses included in the analyses, pinus and wood species, agave, sugarcane and apple bagasse, rice and barley husks, wheat straw, grass species, coffee pulp, corn stover and sweet sorghum stalks, are selected on the basis of rational judgement on their yields, land availability and ease of collection from the field. The planned bioethanol projects in Mexico although are considering first generation feedstocks, WP3 has generated scopes for retrofitted engineering solutions that could be adopted by the companies as part of their mid- to long-term plans for expansion or even for converting the plants to second generation feedstock by processing the crop and forestry residues. In order to inform such companies, detailed techno-economic analysis, environmental impact assessment and integration of process alternatives have been carried out in this research project. WP3 has generated a working draft "Techno-Economic and Carbon Footprint Analyses of Biochemical Conversion of Lignocelluloses in Mexico to Ethanol" for peer-reviewed archived journal publication, in Chemical Engineering Research & Design of Elsevier, enclosed in Appendix C.

WP4: Surrey and IMP have investigated optimal process flowsheets using simulation / modelling approach in Aspen Plus and Excel, mass/energy balances, and size of unit operations based on environmental (carbon & resource footprint) and economic criteria. Two publications generated from this WP are given in Appendices D and E.

WP5: By applying hard-core systematic Process Integration principles, a gap between optimal integrated design and current design has been identified and a stage-wise investment strategy versus retrofit options have been recommended. This WP is expected to lead two peer-reviewed archived journal publications, working drafts of which are enclosed in Appendices F and G.

IMPACTS AND OUTCOMES

You **must** discuss:

- How your research exchange has/will enable societal and economic development in the partner country
- Research impacts such as dissemination activities (joint papers as a result of the exchange, conferences given on the research, improved teaching, further funding etc). Quantitative data is required. Please refer to the guidance notes

You may wish to discuss/include:What long-term impacts your research exchange will make (in the partner country, to wider society, to the international engineering community); If the collaboration has improved partner country research (eg are they pursuing research in a new area); Opportunities enabled by the exchange; How the exchange has been beneficial to the organisations/people involved; Photographs (400-500 words)

Wastes or biomass and their management systems are suggested to have links to a range of health effects including cancer, asthma, breathing difficulties, and birth defects. In Mexico, waste valorization so as to recover added-value products in a sustainable manner is not available. This project has shown a number of techniques and integrated systems for waste valorisation into added value products also by eliminating outlets to landfill. A paradigm-shift has been achieved in waste conversion techniques, by game-changer, high-tech, eco-innovative solutions, enabling the country's capacity to carry out excellent research in engineering, to reduce emission, and health effects, and close the loop. Each pollutant that has a cost to the society today can be transformed into an added-value product for the society, thereby reducing the demand for virgin resources. Appendices A-F have shown recovery of bio-based products, such as food and pharmaceutical ingredients, fine, specialty and platform chemicals, polymers and fibres, biofuel and bioenergy in chronological order of sustainability potential encompassing triple bottom line social-environmental-economic criteria, by the displacement of fossil resources. These products have to be produced in an integrated system, called biorefinery, to achieve highest resource efficiency and sustainability. The knowledge gained is being taken forward in the form of further R&D by the partner countries.

7 joint publications are the outcomes from this Newton Collaborative Research Programme. 5 of them were originally mentioned in the proposal. 6 drafts including two already published are given in Appendices A-F. There is another new direction for the 7th paper, lignin valorisation, not planned in the original proposal. Bioprocess development does not explicitly deal with process retrofit. Process retrofit allows cost-optimal expansion and in-process recovery. This project has delivered working drafts and publications in high-profile peer-reviewed journals on synthesis, retrofit engineering by means of techno-economic assessments within sustainability framework and research and training materials to deal with complexities by smart-engineering solutions. Wherever opportunities existed, presentations and exhibitions were displayed, e.g. RAEng event in Sep, 2016, Centre for Environment and Sustainability research showcase at Surrey, NERC Annual Conference, International Bioenergy and Biorefinery Forum of IBEST (http://www.theibest.org/1st-international-forum) These presentations have been separately attached.

This project has enabled capacity building and undertaking of excellent research in engineering at IMP and INIFAP. The project has led to the development of engineering methodology and protocols in Mexico. IMP and INIFAP are the main research labs for bioprocess and biomass development of the Mexican Government. Engineering to convert a stand-alone bioprocess into an integrated biorefinery has been missing – this project therefore seeds engineering thinking in real terms. This project has generated scopes for retrofitted engineering solutions that could be adopted by the industries as part of their mid- to long-term plans for expansion or even for converting the plants to second generation feedstock by processing the crop and forestry residues. Consultations with industries on further R&D and implementation are ongoing. Bioenergy, pelletising, bioethanol, levulinic acid and lactic acid productios in integrated biorefineries are being discussed with industreis.

FUTURE PLANS

- If there are plans for continuing the collaboration (funding proposals/links between institutions or researchers, further exchange visits, exchange of PhD students); You may wish to discuss: What you think will have been enabled by the exchange in 5 years' time; (100-200 words)

A key take-home message regarding sustainable bio-economy iterated the importance of international research exchange programmes like this. The key areas where this project has contributed are: Advancing biorefinery engineering; Waste-stocks and resource recovery; Sustainability and circular-economy. These are also the most important global issues that will lead to major engineering/social innovations over next few decades and will be of interest to the DAC listed countries. We are keen to continue joint collaboration under the GCRF scheme. Bioenergy and alternative systems such as biorefineries will have an important role to play in poverty alleviation, job creations and security of resources in these countries. IBEST also organised http://www.theibest.org/1st-international-forum supported by the HEFCE Newton fund aimed at understanding the role of and scopes for alternative systems being researched and developed in the UK, in poverty alleviation in developing countries. In this Forum, Cinvestav and ASA Gob Mexico have participated and we matched our findings in bioethanol and aviation biofuel prospects in Mexico. This research has shown higher earnings to farmers, workers and low income families for example than these research groups, by the application of synthetic biology, green chemistry, process integration and sustainability analyses. Nevertheless, these led to capacity building. The smooth running and passion exuded by the organisers is a testament to their commitments to push forward this important research area to tackle climate change and yield societal benefit. IBEST is a prominent testament, a Hub of professionals across all disciplines, determined to Promote and develop Biorefinery Engineering; Communicate the best practices; Provide support to practitioners of Biorefinery Engineering; Foster excellence and esteem and the delivery of benefits to society. Since its creation in 2015, supported by the Newton funding scheme and UK Research Councils, the Institution of Biorefinery Engineers, Scientists and Technologists (IBEST), has grown internationally to include over 60+ member organisations. Our organisation bases include South-East Asia, South America and African countries. This suggests a wider interest beyond this exchange visit programme and profound commitments to advance the field.

ROYAL ACADEMY OF ENGINEERING

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