Institution: 10007140 Birmingham City University		
Unit of Assessment: UoA12 Engineering		
Title of case study: Mobilising the Bio-economy: Transforming waste to energy processes and practices		
Period when the underpinning research was undertaken: 2012-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Prof. Lynsey Melville	Professor of Environmental Engineering. Lead of Bioresources and Bioeconomy Research Group (BBRG)	2008-Present
Dr Sri Suhartini	Research Fellow (BBRG)	2014-2017
Dr Roshni Paul	Research Assistant (BBRG)	2013-Present
Dr Khondokar Mizanur Rahman	Research Assistant (BBRG)	2015-Present
Period when the claimed impact occurred: 2016-2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Despite its extraordinary potential, the adoption of Anaerobic Digestion (AD) in many countries is hindered by under-performing systems, poorly integrated supply chains and a lack of supportive financial and policy instruments for bioenergy production. The Bioresource and Bioeconomy Research Group (BBRG) has addressed these challenges through several projects. BBRG's work with Doosan has significantly improved a technology which converts waste material into biogas, leading to >£1,000,000 of investment and 3 new clients with income generation estimated at approximately £5,000,000. The Group's design consultancy and analysis on Kingdom Bioengery's (KBE) AD pre-treatment process has led to increased commercial adoption and new market avenues for KBE. This improved process has already improved bioenergy production for a hospital in Vellore, South India. Research on the generation of biogas from seaweed in Indonesia has led to development of a policy roadmap for the country, as well as new guidelines for seaweed farmers to properly utilise AD processes.

2. Underpinning research

AD utilises bacteria to convert organic waste into biogas, a sustainable alternative to natural gas. Optimisation of this process requires a secure and consistent supply of suitable waste materials. Some waste materials are difficult for bacteria to digest and require either pre-treatment to breakdown the material or specialised digesters to improve digestion. Most digesters require a mix of material to operate effectively this requires identifying under-utilised waste streams from various sources. Process design and improvements have to be economically viable and environmentally sustainable if they are to be widely adopted. BBRG research has successfully addressed these challenges.

Enhancing biogas production through optimised pre-treatment.

Bacterial cells found in municipal wastewater sludges are challenging to break down during anaerobic digestion. Doosan Enpure Ltd. have a technology which focuses intense sonication to enhance the breakdown of this cellular organic material. BBRG's research and testing determined the optimal operating conditions for this technology which resulted in significant improvements in AD performance. This included an increase in soluble chemical oxygen demand (an indicator of organic degradation) of 800% and an increase in methane production of up to 15.5% **(R01)**. The optimised technology was trialled at lab-scale as well as pilot-scale at Springhill AD plant operated by Vale Green Energy Ltd. in Worcestershire. The work

enabled Doosan Enpure Ltd. to calibrate and optimise the device and identify important operational considerations for the treatment of alternative waste streams.

Transforming the treatment of food waste through technology innovation.
Lignin and cellulose (a common component of crop residues and food waste) are also challenging compounds to breakdown during AD. Systems used in developing countries are poorly designed and operated leading to low performance and excess residues which have to be removed by hand **(R02)**. One solution is to retrofit a pre-digester to enhance breakdown of the material prior to AD. These can also be expensive and prone to failure. Kingdom Bioenergy Ltd. approached BBRG to improve the design and operation of one such system being used in Vellore, South India **(RG01)**.

The BCU team developed a number of prototypes and tested their performance at lab scale. The research provided an improved design and operating protocol, which dramatically increased the technology's market feasibility and effectiveness. The design was improved by inclusion of a suspended internal reactor and the system was operated in upflow mode. The design enabled easier loading removal of food waste and debris and the operation led to improved fluid transfer through the material The efficacy of this design was demonstrated via the destruction of volatile organic solids in the waste (measured as soluble chemical oxygen demand). This was found to increase by up to 400% over the period of the trials. The solution is scalable and can be retrofitted to existing low performance AD plants at low cost.

Advancing waste to energy practices in developing countries.
Indonesia is the second largest producer of macroalgae (seaweed) globally. To meet increasing demand, Indonesian fish farmers have diversified their business to grow macroalgae for the Agar industry. However, BBRG's research identified that between 50-80% of this crop goes to waste. Research has demonstrated that novel biomass such as micro and macroalgae is not only suitable for conversion to biogas but can also enhance digestion of other waste materials during AD **(R02, R03, R04, R05, R06)**. The digestibility, operational considerations and the techno-economics of converting macroalgae biomass into sustainable energy has been demonstrated through a Newton Funded programme with partners in Indonesia **(RG02)** . This work was informed by a PhD program and several EU funded projects **(RG03, RG04, RG05)**.

Results have shown that the most common native species has favourable characteristics and high potential for energy conversion (up to 0.212m^3CH_4/kg VS added) and can be mixed with other local wastes to generate biogas for heat and power **(R05)**. The quality of the seaweed (and its biogas potential) can be improved through washing and improved storage following harvest. Modelling of data, demonstrated that direct use of biomethane (rather conversion to heat and power) was the most viable application with an energy balance of up to 2.36GJ biomethane per ton of seaweed.

One of the key outputs of the research was a PESTLE analysis which identified the key Political, Environmental, Social, Technical, Legal and Economic challenges and opportunities for the valorisation of macroalgae biomass in Indonesia. This review identified that the waste from industrial processing held the greatest opportunity for valorisation. In addition, household and animal wastes could be better managed and co-digested with seaweed at the community level (reducing environmental impacts and offering sustainable clean energy). The research highlighted a need for stronger policy support for AD and biogas and demonstration of AD at community level to increase confidence of farming communities adopting the technology. The PESTLE analysis was evaluated and validated via national stakeholder workshops.

3. References to the research (indicative maximum of six references)

The research publications listed below have undergone rigorous peer review processes prior to publication in well reputed journals and international conferences within the field of

bioenergy. Reference R03 was supported by a BBSRC travel bursary to enable the lead author to present the publication.

R01. Suhartini, S., Melville, L. and Amato, T. (2017) Pre-treatment of thickened waste activated sludge (TWAS) for enhanced biogas production via the application of a novel radial horn sonication technology. *Water Science and Technology*. 75(9): p. 2179-2193. https://doi.org/10.2166/WST.2017.069

R02. S. Suhartini, I. Nurika, R. Paul, and L. Melville, (2020) Estimation of Biogas Production and the Emission Savings from Anaerobic Digestion of Fruit-based Agro-industrial Waste and Agricultural crops residues," *BioEnergy Research.* https://doi.org/10.1007/s12155-020-10209-5

R03. Paul, R., Melville, L. & Sulu, M. (2016). Anaerobic digestion of micro and macro algae, pre-treatment and co-digestion-biomass - a review for a better practice. *International Journal of Environmental Science and Development,* 7. 646-650. https://doi.org/10.18178/ijesd.2016.7.9.855

R04. Paul, R., Suhartini, S., Sulu, M., Melville, L., (2017) Feasibility of Seaweed and Agricultural Crop waste residues as co-digestion feedstock, International Water Association (IWA) World Conference on Anaerobic Digestion, Beijing, China, October 2017. http://www.open-access.bcu.ac.uk/7029/

R05. Suhartini, S., Nurika, I., Rahmah, N. L., Paul, R. & Melville, L. Potential of Gracilaria. sp. as a single or co-digestion feedstock for biogas production. In: IOP, ed. International Conference of Biomass and Bioenergy, (2020) Indonesia. IOP. https://doi.org/10.1088/1755-1315/460/1/012032

R06. Stiles, W. A. V., Styles, D., Chapman, S. P., Esteves, S., Bywater, A., Melville, L., Silkina, A., Lupatsch, I., Fuentes Grünewald, C., Lovitt, R., Chaloner, T., Bull, A., Morris, C. & Llewellyn, C. A. (2018). Using microalgae in the circular economy to valorise anaerobic digestate: challenges and opportunities. *Bioresource Technology,* 267, 732-742. https://doi.org/10.1016/j.biortech.2018.07.100

Grants

Grant **RG02** (MacroBio) was one of only 18% of projects funded in this call. Grant **RG04** was one of only 30 projets funded under priority 2 Interreg IVb and was awarded 3rd largest budget overall.

RG01. BBSRC (2017-2018) Counter Flow Leach Bed Reactor Design and Optimisation. Co-Investigator- Dr K.M. Rahman. Partners Kingdom Bioenergy Ltd. (Project Budget £20,000, BCU budget £10,000)

RG02. British Council, Newton Fund Institutional Links Award (2019-2020) MacroBio - Sustainable utilisation of Macroalgae in Indonesia (Project budget £79,000).

RG03. EU Interreg IVb Algae AD Project (2017 to present) Work Package Leader (total project value £4,890,000 BCU budget £493,637)

RG04. EU Interreg IVb EnAlgae Project (2012-2015) Work Package Leader (Total project value £8,739,370, BCU budget £610,235)

RG05. EU Interreg IVb BioeNWE Project (2012-2015) Work Package Leader (Total project value £10,541,534 BCU budget £716,447)

4. Details of the impact

Enhancing biogas production through optimised pre-treatment.

Doosan Enpure Ltd. is a global leader in providing water, wastewater and renewable energy solutions. BBRG research proved that their sonication technology had superior performance (in terms of percentage increase in biogas relative to power input) compared to all other technologies reported in the literature **(R01)**. The Managing Director of Doosan Enpure reported that: '*The research […] enabled the company to make significant improvements in the way the device is installed and operated in the field and was instrumental in providing new technical guidelines for this technology.*' **(S01)** In addition, he stated, '*The findings from this*

research provided Doosan Enpure Ltd. with critical information to inform strategic decisions about future potential markets.' **(S01)**

As a direct result of the work completed by BBRG, Doosan Enpure Ltd. received direct investment of >£1,000,000 for ongoing research and development for this application at pilot-scale. This allowed the company to undertake long-term research and development to aid market growth. The Business Development Manager said; '*So successful were the results that Doosan committed to a >£1,000,000 R&D project to build and operate a full-size agricultural AD plant sonix™ system. This is now in full operation progressing towards completion of a robust six-month trial demonstrating the benefits of the process.*' **(S02)**

In addition, the Managing Director commented; '*Further investment in the region of 50K was also allocated to a new trial with a UK water utility. Overall, this was a significant allocation of Doosan's corporate budget. This allowed us to undertake longer term developmental activities to further inform the design and operation and aid market growth and diversification*' **(S01)**.

This research also directly led to new clients in 2 countries (UK and South Korea) for Doosan Enpure Ltd. with an additional income generation estimated at £5,000,000 over the period 2016-2020 **(S01)**.

Transforming the treatment of food waste through technology innovation.
BBRG's findings were instrumental in delivering the design and operating protocol of a scalable technology that can be easily and cheaply retrofit to existing AD plants, particularly in developing countries. This technology, developed in collaboration with KBE Ltd., has improved their commercial advantage and reach.

The design is simple and low cost compared to other commercially available alternatives. With regards to the research, the Managing Director of KBE Ltd. stated; '*The design which evolved from this research makes this process much easier leading to cost and time savings for the operators*.' He also added; '*The design and SOP evolving from this research has enabled my company and my commercial partners to develop commercially attractive alternatives*.' **(S03)**

The research has also informed process improvements on a full-scale plant at a Hospital in India. The Managing Director stated that '*The first stage AD system at CMC Vellore was designed to be capable of generating 300m^3/d of biogas […]. The BCU designed system has allowed a wider range of feedstocks to be used in the AD system, thus allowing this target to be approached.'* **(S03)**

Advancing waste to energy practices in developing countries.
This research led to new practice guidelines for macroalgae farmers, which is helping to change the perception of organic wastes and improve the management of waste materials in communities, as well as improve the handling and storage of biomass. The Indonesian Seaweed Association (ARLI) is a forum of farmers, traders, processors, exporters, NGO's and cooperatives and currently represents 106 members across the country. In reference to this research, the Director of Public Relations (ARLI) stated: '*This work has helped to raise awareness of this problem and change perception and practices of managing the waste seaweed at community level.'* **(S04)**.

An online workshop and survey in December 2020 collated feedback on the impacts of the research. Of the 14 national stakeholders who completed the survey, 71% agreed or strongly agreed that the research had contributed to improving waste management practices at the community level **(S08)**.

The founder of a seaweed farming cooperative of 72 fishermen in Java, stated that; *'Prior to the research my community knew nothing about the process of AD. This study and the research team have raised awareness of biogas production amongst fishermen and residents.*

The waste seaweed used to be thrown away but now we understand that washing and storing is very important and waste seaweed can be used for energy.' **(S05)**

The PESTLE analysis was a significant output from the research and its dissemination and validation by a group of leading national stakeholders has stimulated debate at a national level and led to the development of a working group (BioHUB) and translation of this research into a policy roadmap for the country.

The Ministry of Marine Affairs and Fisheries (MMAF) is the leading national governmental body in this area. A senior researcher at MMAF stated; *'The research has been instrumental in bringing together key national stakeholders and this has stimulated a dialogue at national level. [….] the research of BBRG has highlighted the potential scale of increased waste generation from the growth of the sector and proposed technical solutions to address this through the production of biogas. The information and evidence from this work is contributing to new analysis of this issue at government level'* **(S06)**.

The leading national body for science and technology, the Indonesian Institute of Science (LIPI), stated; *'The findings from the research provide insights for our organisation, to take initiative in projects to support the seaweed and biogas sectors in Indonesia*.' Senior Researcher (LIPI) **(S07)**.

5. Sources to corroborate the impact (indicative maximum of 10 references)

S01. Letter provided by Doosan Enpure Ltd. to corroborate economic indicators of research impact and any metrics for employment and market share/ diversification (and other impacts not yet considered here) **[Named Corroborator 001]**

S02. Doosan. *Doosan moves to site scale plant trials of its sonixTM feedstock pre-treatment system for anaerobic digestion*. 2019; Available from: https://www.doosanenpure.com/news/doosan-moves-to-site-scale-plant-trials-of-its-sonixtm-feedstock-pre-treatment-system-for-anaerobic-digestion.html.

S03. Letter provided by Kingdom Bioenergy Ltd. to corroborate evidence of impact of scaled prototype and implementation in India **[Named Corroborator 002]**

S04. Testimonials from BioHub member -Director of public relations, National Seaweed Association of Indonesia (ARLI) **[Named Corroborator 003]**

S05. Testimonial of BioHub member – Founder of seaweed farming cooperative, Puolerto, Java, Indonesia

S06. Testimonial of BioHub Member – Senior Researcher, Ministry of Marine Affairs and Fisheries, Indonesia **[Named Corroborator 004]**

S07. Testimonial of Biohub Member – Senior Researcher, Indonesian Institute of Science (LIPI) **[Named Corroborator 005]**

S08. Survey from online virtual stakeholder event