Institution: Liverpool John Moores University (LJMU)		
Unit of Assessment: UOA13		
Title of case study: Low Carbon Solutions		
Period when the underpinning research was undertaken: 2008-present		
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 Andy Shaw	Professor in Microwave Technology	2005 - present
Dr Steve Wylie	Senior Lecturer	2005 - present
Dr Patryk Kot	Reader in Sensor Technologies	2016 - present
Dr Laurence Brady	Senior Lecturer	2007 - present
Dr Mawada Abdellatif	Senior Lecturer	2014 - present
Dr Muhammad Ateeq	Senior Lecturer	2013 - present
Prof Ahmed Al-Shamma'a	Dean of Faculty of Engineering and Technology	2005 - 2019
Period when the claimed impact occurred: Aug 2013 – Dec 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Low carbon solutions are the core research activities undertaken by the Built Environment and Sustainable Technologies (BEST) Research Institute, focusing on carbon reduction technologies through energy from waste, waste management, low carbon planning, sustainable asset and energy efficiency management, and renewable energy.

Impact in the business base has been achieved through the Low Carbon Innovation Hub (LCIH) and Low Carbon Eco-Innovatory (LCEI) initiatives that were formed to support and connect Liverpool City Region (LCR) SMEs with BEST researchers, in order to reduce their carbon footprint by introducing unique solutions and externally funded research grants e.g., EU Fast Track to Innovation (EU-FTI) and Innovate UK to support companies outside of the LCR. The outcome of LCIH led to the generation of 42 additional jobs, safeguarded 30 jobs, and generated an additional £1.76m p.a. in Gross Value Added (GVA) for the LCR economy.

The outcome of LCEI led to the development of 51 new-to-the-firm products and saved 10,081 tonnes of CO_2 in the period of 2015-2019. Beyond the City Region, BEST researchers supported Ashleigh Farms (Environmental) Ltd in the application of an EU-FTI grant that resulted in the plant scale installation of a microwave treatment solution in Ireland for enhanced biogas production from pig slurry (Biowave™). The microwave treatment system was developed by the Unit, with input from Ashleigh Farms and industrial microwave and Radio Frequency (RF) technologies company Sairem, and increased the biogas yield from pig slurry by over 40% while reducing the total CO_2-equivalent output of the farm by 37% per year.

2. Underpinning research

The Built Environment and Sustainable Technologies (BEST) Research Institute comprises research teams from the School of Civil Engineering and Built Environment in the Faculty of Engineering and Technology. BEST aims to address civil engineering and built environment sustainability challenges through the use of novel technologies and management techniques. One area of research activity has been the application of microwaves to different industrial material processes and the improvement of efficiency. Since 2008, the focus of these applications has been on the enhancement of chemical reactions for the processing of liquid waste streams (**EF1**, **UR4**). The challenge of this research was to model and develop differing microwave reactors that selectively heat a specific chemical within the stream on a continuous flow basis and that can auto

tune during the process maintaining maximum energy transfer. One example is the recovery and conversion of waste oils or Fats Oils and Grease (FOG) to an oil with a low acidic value, enabling the recovered waste oil to form part of a biodiesel production process for transport fuels. A second element involved the development of methods to apply microwaves to solid waste streams to convert these to energy (**UR5**, **EF3**). The research challenge involved the development of a microwave atmospheric plasma torch that can be operated in a modified atmosphere (low oxygen <10%) and still operate whilst in a combustion chamber. The waste streams explored have been Municipal Solid Waste and screenings from a United Utilities-operated wastewater treatment works. A third research challenge for the technology was to pre-treat a waste stream with microwaves to add as a retrofit to conventional anaerobic digesters (**EF2**), specifically with waste streams that require co-mixing with other substrates to maintain a healthy balance of the bacteria in the digester. This research technique underpinned a successful on-farm pilot of an integrated novel microwave pre-treatment system for the efficient production of biogas from the anaerobic digestion of pig manure to create a sustainable waste management system (**EF4**). The outcome for all of these research streams was the development of high-power microwave systems that provided companies with new and niche solutions in terms of using microwave technology as a new form of focused and highly efficient heating to reduce waste to landfill. At the same time, researchers within BEST were focusing their research efforts on understanding how climate change would affect reservoirs and catchment areas and utilising artificial intelligence to model this (**UR6**).

This underpinning research and technology, coupled with a regional government commitment to shift towards a low carbon economy across all LCR sectors, led to the funding and formation of the LCIH (2013-2015) (**EF5**) with the purpose of connecting local businesses in the City Region with University researchers to tackle specific challenges related to improving efficiencies and carbon footprints. Examples of the research challenges posed by businesses included Matrix Polymers, which required researchers to explore the possibility of a new microwave sensor to characterise polymers (**UR2**) and a similar challenge for Ames Goldsmith UK Ltd with the characterisation of silver-based products (**UR1**). Another example involved Radwraps, where the challenge was to assess the thermal performance of a new technology to customise domestic radiators (**UR3**). The LCIH initiative exceeded the initial set targets by 10% and supported 52 SMEs across the region, with the case studies and positive testimonials from the companies leading to the successful award of the follow-up LCEI project (2016-2019) (**EF6**).

3. References to the research

Underpinning Research (UR) outputs (all papers have been through a rigorous peer-review process):

UR1. Ateeq, M., Shaw, A., Garrett, R., & Dickson, P. (2017). "A Proof of Concept Study on Utilising a Non-invasive Microwave Analysis Technique to Characterise Silver Based Materials in Aqueous Solution." Sensing and Imaging: An International Journal, 18(1), 26 pages. Doi:10.1007/s11220-017-0162-y

UR2. Ateeq, M., Shaw, A., Wang, L., & Dickson, P. (2016). "An innovative microwave cavity sensor for non-destructive characterisation of polymers." Sensors & Actuators: A. Physical, 251, 156-166. Doi:10.1016/j.sna.2016.10.019

UR3. Brady, L. J., Abdellatif, M., Cullen, J., Maddocks, J., & Al – Shamma'a, A. (2016). "An investigation into the effect of decorative covers on the heat output from LPHW Radiators." Energy and Buildings, 133, 414-422. Doi:10.1016/j.enbuild.2016.09.065

UR4. Wali, W. A., Hassan, K. H., Cullen, J. D., Shaw, A., & Al-Shamma'A, A. I. (2013). "Real time monitoring and intelligent control for novel advanced microwave biodiesel reactor."

Measurement: Journal of the International Measurement Confederation, 46(1), 823-839. Doi:10.1016/j.measurement.2012.10.004

UR5. Lupa, C. J., Wylie, S. R., Shaw, A., Al-Shamma'a, A., Sweetman, A. J., & Herbert, B. M. J. (2013). "Gas evolution and syngas heating value from advanced thermal treatment of waste using microwave-induced plasma." Renewable Energy, 50, 1065-1072. Doi:10.1016/j.renene.2012.09.006

UR6. Abdellatif, M., Atherton, W., & Alkhaddar, R. (2013). "Application of the stochastic model for temporal rainfall disaggregation for hydrological studies in north western England." Journal of Hydroinformatics, 15(2), 555-567. doi:10.2166/hydro.2012.090

External Funding (EF)

EF1. Prof Ahmed Al-Shamma'a, Prof Andy Shaw, "Second Generation of Bio-Oils Pilot Plant Using Atmospheric Microwave Reactor of Free Fatty Acids", TSB, £643k, 2008-2010.

EF2. Prof Ahmed Al-Shamma'a, Prof Andy Shaw, "PLAGASMIC, Advanced Microwave Plasma Gasification of pig and cow manure for cost-effective biogas generation", EU-FP7-SME (315604), €1.135m, 2012-2014.

EF3. Prof Andy Shaw, Prof Ahmed Al-Shamma'a and Dr Steve Wylie, "Development, Design and Deployment of a Demonstration Scale Microwave Plasma Gasification Plant for the Generation of low Carbon Energy from Waste Pre-market demonstrator", TSB, £1.1m, 2012-2016.

EF4. Prof Ahmed Al-Shamma'a, Prof Andy Shaw, Dr Patryk Kot, "BioWave", EU FTI (691404), €170k allocated to LJMU, out of €1.36m, 2016-2018.

EF5. Prof Ahmed Al-Shamma'a and Paul Dickson, "Low Carbon Innovation Hub", EU-ERDF, £1.1m, 2013-2015.

EF6. Prof Ahmed Al-Shamma'a and Paul Dickson, "Low Carbon Eco-Innovatory", EU-ERDF, £2.58m, 2016-2019.

4. Details of the impact

Impact has been achieved through: (i) The formation of the LCIH, which has assisted 52 SMEs and led to the generation of 42 additional jobs, safeguarded 30 jobs, and generated an additional £1.76m p.a. in Gross Value Added (GVA) for the LCR economy; (ii) the LCEI, which has assisted 164 enterprises, 38 being new enterprises, 52 new-to-the-firm products, and saved 10,081 tonnes of CO_2 from 2016-2019; and (iii) the plant scale installation of a microwave treatment solution for enhanced biogas production from pig slurry (Biowave™). The developed system increased the biogas yield from pig slurry by over 40% and reduced the total CO_2 equivalent output of the farm by 37% per year.

(i) Low Carbon Innovation Hub (LCIH)

The underpinning research started in 2008, focused on the use of bespoke microwave reactors to enhance chemical reactions for the processing of liquid waste streams (**EF1**, **UR4**) as a batch and continuous process. This research also led to developing methods to apply microwaves to solid waste streams to convert these to energy (**UR5**, **EF3**), and to enhance waste streams using microwave reactors to break down the high moisture content wastes and reduce the need for co-mixing in anaerobic digesters (**EF2**). This capability along with the emerging use of microwave technologies as sensors (**UR1**, **UR2**) for real time monitoring and control as well as the modelling capabilities (**UR6**) led to the successful grant application and formation of the LCIH (**EF5**). Within the period 2013 to 2015, LCIH assisted 52 SMEs that led to the generation of 42 additional jobs,

safeguarded 30 jobs, and generated an additional £1.76m p.a. in Gross Value Added (GVA) for the LCR economy (**CS1**).

An example of a company supported through the LCIH is RainCatcher Ltd, a business specialising in the design of rainwater harvesting (RWH) systems. The LJMU team through the LCIH created an online calculator tool that would estimate the future rainfall patterns along with other parameters to determine the best RWH solution for the application. The solution had to consider different roof areas and the climate change effect and change in future rainfall for three periods 2020s, 2050s and 2080s under two greenhouse emissions (high (A1F1) and low (B1)) SRES scenarios in NW of England. This was completed using an artificial neural network simulation.

A further example was with Radwraps Ltd, who had developed novel magnetic decorative coverings for radiators replacing the conventional casings such as wooden surrounds currently used, as an alternative method of reducing surface touch temperature and enhancing appearance. The company assist required was to examine how the heat output from a radiator is affected by the application of the covering compared to the conventional covering. A series of tests were run in the BEST research laboratories and in the research houses, with the results showing that the magnetically applied radiator cover efficiency increased by 13–20% relative to the traditional radiator wooden cover. In terms of space-heating, this can reduce the energy input needed to achieve thermal comfort. This demonstrated that magnetic radiator covers can offer improved heating system energy performance and the product has now been successfully released to the market with the creation of 5 jobs in the region.

(ii) Low Carbon Eco Innovatory (LCEI)

The continued research and development from the underpinning research, coupled with the LCIH positive outcomes, and the unique access SMEs were able to gain to the academic specialist knowledge, experience and testing and research facilities, led to the successful collaborative grant application (**EF6**) with the University of Liverpool and Lancaster University and LJMU as the lead partner. Within the reporting period 2016 to 2019, the external independent assessors reported that the level of carbon savings achieved was 10,081 tonnes, with 75% of respondents in the Project Evaluation suggesting that these carbon savings would not have occurred without the LCEI (**CS2**). Within this period, 164 enterprises were assisted and 52 new-to-the-firm products created. LJMU's contribution to this was 104 enterprises assisted with 44 new-to-the-firm products.

An example of a company supported through the LCEI is the Used Kitchen Exchange (UKE), a business who specialise in the resale of used (second-hand) and ex-display kitchens. The business founders developed the concept after finding a lack of support for ethical consumers wanting to buy or sell a pre-used kitchen. The kitchen industry operates within linear working methods with the majority of used and ex-display kitchens ending up in landfill. UKE approached the LCEI to devise a way of calculating how much carbon is saved when a kitchen is reused, with the aim of changing how the industry operates and pioneering sustainability.

Much of the data required did not exist so LCEI academic researchers developed a bespoke lifecycle carbon assessment and carbon calculator to quantify the embodied carbon and waste carbon emissions in a typical kitchen. UKE can now quantify and compare the environmental and financial benefits of buying or selling a used kitchen, thus communicating a strong message to end users and supply chain. UKE subsequently reported that in the last 24 months they have saved 1700 kitchens from landfill (**CS3**), a saving of 10,200 kg of CO_2.

Following on from the LCEI support, UKE have continued their collaboration with LJMU through the Clean Growth UK team, securing a Management Knowledge Transfer Partnership (Innovate UK

(12236), 2020-2023, £120,659). *"The work that LCEI has undertaken will allow us to quantify and demonstrate how the kitchen industry can operate more sustainably. We're thrilled to have been selected for the mKTP grant and equally delighted at the prospect of partnering with one of our local universities to reach our ambitious expansion goals. Through growth in awareness and business expansion, we are going to normalise the sale and purchase of pre-owned kitchens. It will bring cost effective kitchens to the marketplace, while driving massive environmental savings. It's a win-win for everyone."* (**CS4**, **CS5**)

(iii) Biowave™

The underpinning research started in 2008 culminated in the successful EU-FP7-SME grant (**EF2**), which focused on researching the enhancement of pig slurry waste streams without the need of co-mixing with additional (and uneconomic) carbon matter in anaerobic digesters. This coupled with the low carbon initiatives led to Ashleigh Farms (Environmental) Ltd awarded an EU-Horizon 2020-FTI grant (**EF4**) with LJMU as technical subcontractors. This funding was to take the underpinning research and microwave principle conducted in **EF2** to plant scale sited at the farm in Ireland.

The Biowave™ (**EF4**) project has generated significant impact by developing at commercial scale, a patent pending microwave treatment system for enhanced biogas production from pig farm slurry. Project trials demonstrated an improvement in biogas production, removing the necessity to add organic material and increasing the biogas yield from slurry by over 40%, offering farmers a means to utilise ever-growing amounts of slurry. *"Organic material is pumped to the system and microwave energy disrupts the cell structure within the material making it significantly more digestible – resulting in higher biogas yields and faster anaerobic digestion."* (**CS6**)

The microwave technology was installed in 2018 at Ashleigh Farms, Dungarvan, Ireland where a 1-3m^3/hr microwave processing system is connected directly to a 270,000m^3 AD tank. *"Today the biogas plant handles approx. 9,000m^3 of slurry from the pig houses per year. In 2018, approx. 70,000m^3 of renewable biogas was produced on site and used for heating. Based on Teagasc published results of 435 kg CO_2 equivalent (eq) per sow per year produced on an Irish pig farm - reducing their CO_2 eq by up to 390 tonnes. This is a reduction of approx. 37% of total CO_2 eq output of the farm per year."* (**CS7**)

5. Sources to corroborate the impact

CS1. "Evaluation of the Low Carbon Innovation Hub", Inner City Solutions Project Evaluation (Sept 2015).

CS2. "Evaluation of the Low Carbon Eco Innovatory", Inner City Solutions Project Evaluation (August 2019).

CS3. Email from founder of Used Kitchen Exchange.

CS4. Used Kitchen Exchange website, https://www.usedkitchenexchange.co.uk/sustainability/

CS5. Clean Growth UK website, https://www.clean-growth.uk/case-studies/used-kitchen-exchange/

CS6. Ashleigh Environmental website, https://www.ashleighenv.com/technology

CS7. Ashleigh Farms website, http://www.ashleighfarms.ie/sustainability/