Institution: Liverpool John Moores University

Unit of Assessment: UoA 16

Title of case study: Impact on the use of novel microwave systems for converting waste into energy

1. Summary of the impact (indicative maximum 100 words)

The demand for biofuels and alternative energies is increasing globally as a sustainable source of energy is sought for the future. Energy from crops is no longer a viable option due to the increase in wheat prices. Scientists at the BEST Research Institute have managed to bridge the gap by using novel and unique microwave systems for converting waste (biomass, food, animal) into energy. Our advances in this area have generated considerable interest from both national (e.g., United Utilities PLC, Balfour Beatty PLC, Biofuels Wales Ltd, Stopford Projects Ltd, Longma Clean Energy Ltd) and international (e.g., RIKEN-Japan, Fraunhofer-Germany, Sairem-France, Acondaqua-Spain, Ashleigh Farms-Ireland) companies. This has resulted in several collaborative, funded projects leading to industrial adoption of our microwave technologies.

2. Underpinning research (indicative maximum 500 words)

At present biofuels commercially produced from crops (or feedstock) grown in tropical settings can produce large quantities of fuel more easily than those cultivated in temperate climates. The studies carried out by the Organisation for Economic Co-operation and Development (OECD) show that to achieve a 10% biofuel share in the European transport sector (the main reason for the EU failing to meet Kyoto targets, which states that by the end of the period 2008-2012 the EU level of greenhouse gas emissions should be 8% below 1990 levels) it would be necessary to use 72% of European agricultural land for growth of first generation feed-stocks.

To meet this challenge, we developed second generation biofuels from waste. We have used novel microwave technologies, to address the requirement to reduce fossil fuel use while providing a sustainable energy for the future. Furthermore, the Institute recognised the need for diversity to ensure energy security and has therefore developed advanced alternative energy technologies which convert a range of waste products into energy. Not only does this tackle the issue of energy production, it also reduces the burden of waste materials sent to landfill.

This research, undertaken since 2008, has attracted a keen interest both nationally and internationally, with €3.5M in funding provided by the EU and £2.6M from the Technology Strategy Board (TSB) in order to continue the development of our unique microwave plasma gasification system while a further €8M proposal has been submitted to the EU as part of the last FP7 call on Eco Innovation to build an industrial scale up process with exploitation plan led by United Utilities. The reason for such interest is clear when one considers the potential energy output of similar systems (per tonne of waste) such as Municipal Solid Waste plants (685 kWh/tonne) and plasma arc gasification plants (816 kWh/tonne). By comparison, the microwave plasma gasification technology developed at LJMU, when at full scale, has the potential to produce up to 2000 kWh/tonne. This is mainly due to the fact that the plasma-arc process consumes about 80% of the energy generated while the microwave gasification process only consumes 20% of the energy generated.

Three related examples of work within the Institute are: (1) biodiesel production from waste oil, (2) bioethanol production from low-grade biomass and (3) the development of a mobile gasification system. All these applications are using advanced and niche microwave technologies with proven high efficiency in comparison with conventional thermal heating.

2.1. Biodiesel production from waste oil *(2008-11)*

Work led by Al-Shamma'a in collaboration with industrial partners from Longma Clean Energy Ltd, Xpertrule Software Ltd and Catering Waste Solutions Ltd developed a novel microwave reactor with associated fuzzy control system, for conversion of waste oils into biodiesel [1,2]. Such oils are typically high in free fatty acids, which is highly corrosive to engines and generators; however other conversion methods require many processing steps in addition to significant energy input. This research, which was supported by the EU, TSB and Carbon Connections (grants 1-3 in [6]),

overcame these obstacles and resulted in the production of a fully automated system for biodiesel generation. The system provided significant benefits over existing technology, including the following:

- Reduction in the number of processing steps required for input waste oil;
- Tolerance to feedstock contamination, leading to fewer waste by-products;
- Low input energy requirements;
- Significant reduction in catalyst requirement;
- Low capital and operating cost leading to suitability for on-site fuel conditioning.

2.2. Bioethanol production from low-grade biomass *(2010-12)*

The European FP7 Research for the Benefit of SMEs funded research project (grant 4 in [6]), MICROGRASS, led by Al-Shamma'a and Shaw, which drove the development of an advanced microwave reactor [3] for the processing of low-grade biomass material, such as grass. The developed technology utilises a novel microwave plasma approach to induce the breakdown of cellulose structures and lignin which provides rapid release of sugars for fermentation, thus enhancing bioethanol production. This resulted in a method which is less energy-intensive (requiring approx. 90% less energy than current systems), less time-consuming and also less reliant upon additional chemicals. The work was conducted in conjunction with Biofuel Wales Ltd and the Fraunhofer Institute-Germany, Dara-Spain, Dipolar-Sweden, Technosam-Romania. Our role was the full co-ordination of the project and the development of the novel microwave reactor.

2.3. The development of a mobile gasification system *(2008-2013)*

Since 2008, work led by Al-Shamma'a and Shaw, has also considered an alternative energy source to biofuels in gasification and/or pyrolysis. Such systems can fulfil a dual purpose: energy production and waste processing. The notion of waste-to-energy systems has gained significant popularity due to global energy and waste management issues. Thus the system developed at the Institute, in collaboration with Stopford Projects Ltd, has the potential of addressing the needs of industry in generating additional energy while also helping to process biomass waste (e.g. food) which would otherwise be sent to landfill. To date, a fully automated laboratory scale advanced microwave plasma system [4,5] has been successfully tested and evaluated. Our role in the project was to design, construct and test the microwave plasma reactor. Initially this work was funded by the Merseyside Special Investment Fund and the TSB (grants 5-7 in [6]), but received International exposure in 2012 when funding from the EU FP7 programme (grant 8 in [6]) was granted to apply the technology to the challenge of processing agricultural animal waste with partners from Ashleigh Farms-Ireland, Acondaqua-Spain and Sairem-France. Our role is the full co-ordination of the project and the development of the novel microwave reactor. The success of this project has led Ashleigh Farms to secure €10M, in 2013, to increase their farm capacity from 12000 pigs to 42000 and meeting the Irish government Renewables Obligation Certificate (ROC) commitment.

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

[1] W. Wali, A. Al-Shamma'a, "Online Genetic-Anfis Temperature Control For Advanced Microwave Biodiesel Reactor", Journal of Process Control, vol:22, 1256–1272,. http://dx.doi.org/10.1016/j.jprocont.2012.05.013.

[2] W.A. Wali, K.H. Hassan, J.D. Cullen, A. Shaw, A.I. Al-Shamma'a, "Real time monitoring and intelligent control for novel advanced microwave biodiesel reactor", Measurement, vol. 46, iss. 1, pp. 823-839, DOI: 10.1016/j.measurement.2012.10.004, 2013.

[3] Patent: A. Al-Shamma'a, D.A. Phipps, A. Stavrenides, "Method for Enhancement of Enzyme Activity", PCT/GB2012/052052, August 2012.

[4] Patent: A. Al-Shamma'a and R.A. Al-Khaddar, "Pyrolysis Reactor And Process For Disposal of Waste Materials", PCT/GB2010/050869, August 2010.

[5] C.J. Lupa, S.R. Wylie, A. Shaw, A. Al-Shamma'a, A. Sweetman, "Gas evolution and syngas heating value from advanced thermal treatment of waste using microwave-induced plasma", Renewable Energy, vol. 50, pp. 1065-1072, DOI: 10.1016/j.renene.2012.09.006, 2013.

[6] **Research Grants:**
The PI for all the research grants is Al-Shamma'a (BEST Director).

No	Title	Source	Value	Year
1	The High Efficiency Recycling of Biofuel Waste Products	Carbon Connections	£58k	2008-2009
2	Second Generation of Bio-Oils Pilot Plant Using Atmospheric Microwave Reactor of Free Fatty Acids	TSB	£680k	2009-2011
3	A Multipurpose Industrial Chemical Reactor using Tuneable Frequency Microwaves	EU-FP7	€1.1M	2007-2009
4	Release of Sugars from Cellulosic Biomass by Microwave Plasma Technology for the Production of Bio-ethanol	EU-FP7	€1.05M	2010-2012
5	Microwave Plasma Pyrolysis for Recycling Waste	MSIF (VC)	£113k	2008-2009
6	Investigating the feasibility of using highly efficient microwave induced plasma for advanced gasification technologies	TSB	£112k	2010-2011
7	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	£1.75M	2012-2015
8	Advanced Microwave Plasma Gasification of Pig and Cow Manure for Cost-Effective Biogas Generation	EU-FP7	€1.135M	2012-2014

4. Details of the impact (indicative maximum 750 words)

BEST expertise has developed world leading technologies with tremendous international commercial potential and real environmental benefits. These provide alternative sustainable energy sources by converting waste into energy and in the process also diverting waste away from landfill. Already there have been two successful patent applications resulting from these technologies, PCT/GB2012/052052 and PCT/GB2010/050869. These have also resulted in £175k in funding for LJMU from licensing agreements, and a number of partner companies securing £8.85M of funding to enable their exploitation. See below for case studies and testimonials.

Inventure Energy PLC

BEST negotiated a license agreement with Inventure Energy PLC of £175k for the conversion of CO2 emission gases into syngas (carbon monoxide and hydrogen). The company has raised a further £850k to build an industrial scale up process in 2013.

Longma Clean Energy Ltd

The Director of Longma Clean Energy Ltd, one of LJMU's key collaborators in developing an advanced microwave biodiesel production system said: "… the process will have an immediate market within the existing biofuels arena, but more significantly is a key enabling technology for the next generation of biofuels. This is an excellent opportunity for the academic community to apply, for the first time, a highly innovative microwave plasma system in bio-refining reactions. The success of such technology will make the UK SMEs competitive worldwide".

The use of microwaves for biodiesel production was demonstrated by the industrial partners (grant 2 in [6]) including Longma, Catering Waste and Xpertrule in 2010-2011 to improve significantly the efficiency of the process, reducing the time, energy and solvents required. Furthermore, during the collaboration with Longma in 2011 it was found that the microwave system can process a broader range of highly degraded bio-oil feedstock than conventional systems, resulting in less waste. The technology is currently under assessment by an investment group of venture capitalists in the West Midlands, known as Green Frog in collaboration with Longma, who have raised £15m to build various industrial systems (£10M) including LJMU research technology (£5M) at their plant in Hull.

It is planned that the completed systems to be exported around the world and could potentially benefit everyone from householders and businesses who could sell their used oil products for conversion to biodiesel, to farmers in remote areas who could make their own precious fuel at a fraction of the cost.

Biofuel Wales Ltd

The Director of Biofuel Wales Ltd and partner in the €1.05M EU FP7 MICROGRASS project said: "The microwave technology developments meet a key technological need in the European SME bio-fuel sector and provides SMEs farmers with a use for their, at present, non-profitable infertile land". Prior to the development of the microwave system as part of the MICROGRASS project the only available method (i.e. steam explosion) to break down cellulosic biomass (e.g. lignin), was incredibly energy intensive. Thus, the MICROGRASS project has provided an effective, low energy technology for bioethanol production which could allow the EU to satisfy the growing demand for biofuels. Furthermore, it provides this opportunity without competing with food production. Biofuel Wales Ltd has raised the amount of £1.2M to exploit the microwave plasma system at national and international level, after successfully being granted a patent (GB2492861) to protect the intellectual property resulting from the work at LJMU. The company has also secured the sales of the technology rights to Sofiproteol-France with an income generation of £1.8M.

Stopford Projects Ltd

The Research and Innovations Manager of Stopford Projects Ltd said: "…results on the use of microwave plasma have proven the way forward in delivery of a niche and efficient way of developing a new compact and mobile gasifier; such capability currently cannot be achieved via traditional means." Hence, Stopford is currently working with LJMU researchers to develop the industrial pre market demonstrator supported by the TSB to deliver the first microwave plasma gasifier for the treatment of sludge waste generated for example from Untied Utilities and appointed the manufacturing company Finning to commission the unit. This project has created 7 jobs and safe guarded another 3. The company is currently working with the University in commercial and license contract.

Recognition of this benefit led to the work being featured on the BBC One show Sunday Politics (February 2012) as a prime example of cutting-edge energy sector development.

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

1. Director, Longma Clean Energy Ltd, can confirm the use of Microwave flow reactor for the conversion of waste oil into bio diesel as well as the microwave system efficiency in the transesterification reaction.
2. Scientific Editor, Daily Post News Papers, can confirm Microwave technologies, breakthrough, for the production of biodiesel from waste.
3. Director, Biofuel Wales, can confirm the efficient use of microwave technology in industry for the breakdown of the grass lignin for the production of biofuel.
4. Research and Innovations Manager, Stopford Projects Limited, can confirm the niche and efficient use of microwave plasma technology in industry for the recycling of biomass waste into biogas.
5. R. S. Jones, "Method and apparatus for making biofuels or animal foodstuff", GB2492861, August 2013.
6. Stopford, "TSB Carbon Abatement Technology Competition Success", News Article, 2009, Last Accessed: 13th September 2013, Available: http://www.stopford.co.uk/news/news_archive_09-10.html.
7. Stopford, "Microwave Plasma Gasification", Marketing Brochure, 2011, Last Accessed: 13th September 2013, Available: http://www.stopfordenergyandenv.co.uk/docs/Microwave%20Plasma%20-%20Stopford%20-%20ev.pdf.
8. BBC, "BBC One Sunday Politics Northwest", Political Discussion, Last Accessed: 13th September 2013, Available via BBC iPlayer: http://www.bbc.co.uk/programmes/b01cbm7s.