

Institution: University of Wolverhampton		
Unit of Assessment: 12 Engineering		
Title of case study: Improving environmental sustainability through the synthesis of novel biodegradable polymers		
Period when the underpinning research was undertaken: 2014 - 2018		
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:
Professor Iza Radecka	Professor of Biotechnology	2000 - Present
Professor Marek Kowalczyk	Professor of Synthetic Polymer Chemistry	2013 - 2019
Professor David Hill	Professor of Microbiology	1987 - 2019
Dr Daniel Keddie	Senior Lecturer in Organic Chemistry	2015 - Present
Dr Fideline Tcheunbou-Magaia	Senior Lecturer in Chemical Engineering	2016 - Present
Period when the claimed impact occurred: 2014 - 2020		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of the impact Since 2014, the biotechnology research team at the University of Wolverhampton has made significant contributions in the area of biodegradable polymers and sustainable cleaning systems. Through the use of industrial wastes as novel carbon sources for the development of new bio-based polymeric materials, and the development of integrated bio/chemical processes various impacts [I] have been realised including: • The contribution to innovation and design of the eco parts cleaning system the ROwasher. • The development of fully biodegradable packaging for cosmetics for the Small & Medium-Sized Enterprise (SME) Prima Makeup Ltd. • Influencing government policy by contributing to the "Review of standards for biodegradable plastic carrier bags" report laid in Parliament in 2015. • Appearances on various media platforms, highlighting the importance of reducing waste to the general public.		
2. Underpinning research World-wide, humans have so far produced over 6 billion tonnes of plastic waste, with only 9% of this recycled, often into low-value products. Since 2007, Prof Iza Radecka has led a team at the University of Wolverhampton, with the mission of investigating alternative plastic and biopolymer products. The team has helped to drive forward the agenda around environmentally friendly solutions, including biodegradable plastics and utilisation of post-customer plastic wastes. The research has yielded the following findings: <u>F1. Converting industrial waste into polymeric materials</u> The use of waste oil and waste plastic as carbon sources for the production of added-value products is a great opportunity for reducing the environmental impact of non-biodegradable plastic wastes. Our multidisciplinary collaborative research in bioremediation and applied chemistry has developed a viable integrated biotechnological/chemical process allowing us to transform waste biorefinery by-products into value-added biodegradable, non-toxic natural bioplastics such as polyhydroxyalkanoate (PHA) [R1 & R2]. This process not only leads to environmental benefits, but can also reduce the production costs of PHAs. Biodegradable polymers can be used in the areas		

of agriculture, cosmetics, medicine and compostable plastic packaging [R1 & R2].

F2. Improvement of biodegradable oligomers

We recently developed a combined extraction-chemical transformation approach of PHA-containing biomass using non-chlorinated solvents or ionic liquid media. In this method, the PHA in the cells is extracted into an ionic liquid medium, and simultaneously undergoes a (trans)esterification reaction with the bioactive compound containing either carboxyl or hydroxyl functionality in the medium to form bioactive conjugates [R3]. The work focused on the herbicide oligomers, and demonstrated its efficacy to suppress broadleaf weed growth without significant phytotoxicity to crop species, the results of which are important for commercial use in high-value crop systems [R4].

F3. Development of biodegradable cosmetic packaging

The use of biobased plastics is of great importance for many applications. An interesting alternative to conventional plastic packaging for cosmetics would be the use of biodegradable polymers. Blending biodegradable thermoplastic polylactide (PLA) with polyhydroxyalkanoate (PHA) enables the formulation of mechanically superior materials with good biodegradation properties. PLA and PHA are already used for traditional extrusion processes, but now can also be used in the three-dimensional (3D) printing process. Therefore (bio)degradable polymers open up new possibilities for 3D technology [R5]. Our research in the area of biodegradable polymers can provide new opportunities for the packaging industry.

F4. Sustainable cleaning systems

Microorganisms are often used within biofilters to facilitate rapid bioremediation of chemical waste. Results from research conducted using immobilised cells have demonstrated that these microorganisms can be trapped within a 3D polymer matrix [R6]. The structure of the filter helps to tailor the rate of biodegradation of pollutants by serving as a protective layer limiting exposure of the microorganisms to toxic external conditions, at the same time enhancing bioremediation [R6].

3. References to the research

All papers below have gone through stringent peer review processes before publication.

R1. Radecka, I., Irorere, V., Jiang, G., Hill, D., Williams, C., Adamus, G., Kwiecien, M., Marek, A.A., Zawadiak, J., Johnston, B., Kowalczyk, M. (2016). Oxidised Polyethylene Wax As A Potential Carbon Source For PHA Production. *Materials*, 9, 367. <https://www.doi.org/10.3390/ma9050367>.

R2. Johnston, B., Radecka, I., Hill, D., Chiellini, E., Ilieva, V., Sikorska, W., Musioł, M., Zięba, M., A. Marek, A.A., Keddie, D., Mendrek, B., Darbar, S., Adamus, G., Kowalczyk, M. (2018). The Microbial Production of Polyhydroxyalkanoates from Waste Polystyrene Fragments Attained Using Oxidative Degradation. *Polymers*, 10(9), 957. <https://www.doi.org/10.3390/polym10090957>. (REF 2 Output).

R3. Kwiecień, I., Radecka, I., Kowalczyk, M. Adamus, G. (2015). Transesterification of PHA to Oligomers Covalently Bonded with (Bio)Active Compounds Containing Either Carboxyl or Hydroxyl Functionalities. *PLoS One*. Mar 17;10(3):e0120149. <https://www.doi.org/10.1371/journal.pone.0120149>. (REF 2 Output).

R4. Kwiecień, I., Adamus, G. Jiang, G., Radecka, I., Baldwin, T., Khan, H., Johnston, B., Pennetta, V., Hill, D., Bretz, I., Kowalczyk, M. (2018) Biodegradable PBAT/PLA blend with bioactive MCPA-PHBV conjugate suppresses weed growth. *Biomacromolecules*, 19, 511-520. <https://www.doi.org/10.1021/acs.biomac.7b01636>. (REF 2 Output)

R5. Gonzalez-Ausejoa, J., Rydz, J., Musioł, M., Sikorska, W., Sobota, M., Włodarczyk, J., Adamus, G., Janeczek, H., Kwiecień, I., Hercog, A., Johnston, B., Khan, H.R., Kannappan, V., Jones, K.R., Morris, M.R., Jiang, G., Radecka, I., Kowalczyk, M. (2018). A comparative study of three-dimensional printing directions: The degradation and toxicological profile of a PLA/PHA blend.

Polymer Degradation and Stability, 152, 191-207.

<https://www.doi.org/10.1016/j.polymdegradstab.2018.04.024>. (REF 2 Output).

R6. Low, W-L., Lee, C., Wilkes, M., Roberts, C. & Hill, D.J. (2014). Development of a rapid, effective method for seeding biofiltration systems using alginate bead-immobilised cells.

International Journal of Chemical & Environmental Engineering, 5(1), 29-32.

<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.677.8603&rep=rep1&type=pdf>

Underpinning Grants

Radecka, I., Kowalczyk, M., & Tcheunbou-Magaia, F. Biosynthesis, characterization, functionalization and advanced applications of PHA oligomers. Awarded by the Schlumberger Foundation. Initial award GBP37,320, renewed three times to a total of GBP111,960. 2018 - 2021. Underpins R3.

Oakes, I. Environmental Technologies Resource Efficiency Support Service (ENTRESS). ERDF. GBP604,770. 2018 – 2021. Supported project with Prima Makeup Ltd [I2].

4. Details of the impact

I1. Impacts on public policy

Based on our extensive research into biodegradable polymers and the obtained knowledge of the relationship between structure, properties and function of advanced biodegradable polymeric materials, our research team has been able to produce examples of environmentally degradable packages. This has enabled us to establish a National Information Point (NIP UK) for sustainable plastics in the UK (<https://sites.google.com/site/plasticeuk/about-the-nip>), with the aim of informing the public about biodegradable plastic standards. Following this, in July 2014, we were invited to become a member of the stakeholder advisory group (Carrier Bags Team) at the Department of Farming and Rural Affairs (DEFRA) on the development of biodegradable plastic bag standards, and an exemption from the 5p (GBP0.5) charge for single use carrier bags [C1]. We were involved in discussions around the criteria for inclusion within a standard, the cost implications, test methods as well as technologies and innovation within the sector. The Senior Executive Officer for Environment Quality said “Professor Radecka played a key role in this group and her work contributed to a report on biodegradable bags” [C2]. The Secretary of State presented the report in Parliament on the 17th December 2015 [C3]. The urgent need for development of new biodegradability standards for biodegradable bags has been identified in order to give consumers and the recycling industry confidence that things labelled as biodegradable, really are.

I2. Innovation in new environmentally friendly products

Prima Makeup Ltd

The knowledge and skills in the area of biodegradable polymers [F3] have successfully been shared with the cruelty-free cosmetic SME “Prima Makeup Ltd” via participation in the “Environmental Technologies & Resources Efficiency Support Service” ERDF project EnTRESS which supports the adoption of technologies and processes for the reuse, recycling and recovery of materials and resources [G3]. Prima Makeup sells cosmetics in over 19 countries and through high street partners. After discussion with the company, in 2018 we helped them with 2 products [C4]: completely biodegradable glitter, and a biodegradable packaging solution for their cosmetics [C4]. We suggested which biodegradable polymers would be suitable for their glitter as well as pots/jars for their products. Without our recommendations, their cosmetics would have been marketed in plastic pots or a glass jars. The additional 3D design / prototype helped the company to secure orders and get both cosmetics and packaging into production. Subsequently, following the work with the University of Wolverhampton, Prima Makeup was awarded both “Best Start-up” and “Business of the Year” in the Black Country Chamber of Commerce Awards.

Rozone Ltd

Using the group’s understanding of bioremediation [F1] and biofilters [F4] a project was undertaken between 2017 and 2019 with the commercial cleaning company Rozone, specialising in

environmentally friendly cleaning technologies. The overall aim of the project was for the company to enhance the viability of its existing products by developing a new range of innovative products around the principles of 'low environmental impact cleaning' and to develop the company's own USPs (unique selling points) and IP (intellectual property) within this field. Thanks to the research input from the University of Wolverhampton on the creation of environmentally friendly biofilters using solvent-free technology, Rozone were able to develop their own unique environmentally friendly parts washer, the ROWasher cleaning system.

On their website, Rozone highlights a number of successful case studies of various organisations using the ROWasher. A representative from 1 of Britain's leading power utility companies referred to the ROWasher as having "brought parts back to life" [C5]. An automotive and commercial vehicle company highlighted that the ROWasher "produced powerful cleaning results", managing to remove carbon deposits usually reserved for the likes of aggressive solvent cleaners [C6]. Rozone is highly satisfied with the outcomes of the project in terms of the excellent environmentally friendly product they were able to create, but also in terms of the financial benefit [C7]. Rozone indicated that the "health and safety consideration and compliance on the ROWasher were the strongest in the bioremediating parts washer sector" [C7]. They indicated that up to 31st December 2020 they had sold 247 units of the ROWasher, with a turnover of over GBP206,483. Aside from the ROWasher, the expertise provided to the company by the University of Wolverhampton has also allowed them to design their own suite of cleaning solutions, which were previously purchased under licence from the USA. This has saved the company approximately GBP290,000 up until the end of 2020 [C7]. Through benefiting Rozone financially, and through the subsequent environmental benefits derived from their customers' usage of the Rowasher, this project has been an immense success.

13. Improving public understanding of biodegradable products

The originality of our work and its contribution to the knowledge in the area of biodegradable polymers have been effectively disseminated to the scientific community and general public [F1, F2], mainly since 2017. TV and radio appearances have included: BBC Radio 4's 'Burn That Fat!'; CBC Radio Canada's 'Quirks & Quarks'; BBC Midland's Today; and ABC Brisbane, Australia [C8]. Other news appearances include 2 Guardian articles, a New Scientist article, and 2 BBC News website articles [C8]. In total, along with a number of other media appearances and social media attention, the potential audience has been in the many millions. Public online comments on the Guardian article, "The plastics problem – are natural alternatives doing more harm than good?" suggest the news attention inspires debate around the topic of plastic waste and recycling.

Following these media appearances, in March 2018 we were invited to take part in the first of a new series of events entitled 'Reinventing' hosted by the Hoffmann Centre for Sustainable Resource Economy at Chatham House, London. This event explored new designs, technologies, products and practical solutions that could better meet future social and environmental needs in relation to plastic wastes, and was attended by a number of industry professionals and policy makers [C9].

Overall our research so far, has had substantial impacts on a range of sustainability issues around plastic waste and other key environmental problems. In the future, such technologies will become vital tools in our battle against environmentally costly and unsustainable manufacturing practices.

5. Sources to corroborate the impact

C1. DEFRA email invitation to join a Stakeholder Advisory Group re. biodegradable bag standards

C2. Testimonial from DEFRA Head of Waste Strategy and Regulation

C3. Parliamentary report on biodegradable plastic bags -

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/485904/carrier-bag-biodegradable-report-2015.pdf

C4. Testimonial from owner of Prima Makeup Ltd

C5. Rozone 'ROwasher' website page - <https://www.rozone.co.uk/news/post/automotive-case-study-of-rowasher>

C6. Rozone 'Case Studies' website page - <https://www.rozone.co.uk/news/post/rowasher-case-study-wednesbury-automotive-workshop>

C7. Testimonial from General Manager of Rozone Ltd.

C8. Media database Excel spreadsheet highlighting stories based on published research and potential audience estimates

C9. Info on Hoffmann Centre event - <https://hoffmanncentre.chathamhouse.org/events/2018/3/reinventing-the-plastic-bottle/>