Institution: University of the West of England, Bristol		
Unit of Assessment: 6		
Title of case study: Transforming water quality testing, treatment and biocides		
Period when the underpinning research was undertaken: 2006 – 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:**
Darren Reynolds	Professor in Health and Environment	2000 – present
Robin Thorn	Associate Professor in Molecular Life Sciences	2010 – present
Period when the claimed impact occurred: 2015 – 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Research at UWE Bristol has enabled the development of novel technologies for in-situ fluorescence-based sensing of water quality along with new methods for water treatment. Together these have underpinned the monitoring of water safety, including the work of the Environment Agency, the use of biocides in the provision of safe water, and the wider application of biocides to agri-food and food products. Collaborative research has led to the development of new commercial products for water quality sensing and water treatment that are now being manufactured and deployed by UK businesses with wide-wide ranging benefits. This has, in turn, led to the development of new products and markets, business expansion and increased revenues. Novel biocides underpinned by UWE research have also supported a wide range of services including care homes and an emergency food distribution community initiative in the context of the COVID-19 pandemic.

2. Underpinning research

Water quality sensing

Organic matter in aquatic systems can come from a multitude of sources, from agricultural run-off from farms to the metabolic activity of microbes living in the water. The fluorescent properties of this organic matter can be used to understand its characteristics, including where it has likely come from and its composition. The technique, known as aquatic organic matter fluorescence (AOMF), uses light to excite the particles of organic matter, enabling information be garnered about those particles based on how they return to their non-excited state – a near instantaneous process. Research conducted at UWE by Professor Darren Reynolds has helped to develop this sensor technology for in situ monitoring of microbial processes in aquatic systems over time (**R1**). Reynolds has contributed to and compiled evidence to show that simple fluorometers can be a reliable and effective way of real-time monitoring in wastewater treatment works (**R2**).

Associate Professor Robin Thorn, an applied microbiologist, further developed this sensor technology by mapping fluorescence to the metabolic activity of microorganisms present in the water, including those bacteria capable of causing disease (**R3, G1, G2**). Prior to this, fluorescence was linked to microbial counts only, but by demonstrating that it was indeed mapped to their metabolic products, the research introduced new layers of information that were key to understanding water quality. Among other things, fluorescence provides insight into the composition of the microbial community instantaneously – something that would have previously taken days, due to the requirement for microbial culture of water samples within the laboratory.

Reynolds and Thorn also worked with an industry partner to develop the algorithms necessary to correct for site-specific parameters, enabling water quality comparisons across locations to be compared like-for-like – a capability that was essential for commercialisation. Due to the commercial sensitivity of these algorithms, this work has not been published. Reynolds and Thorn further developed the understanding and application of AOMF in water quality sensing – vastly reducing the time it takes to detect and respond to events that ultimately lead to the deterioration of water quality and aquatic life.

Water quality treatment

Electrochemically Activated Solutions (ECAS) and their biocidal properties have been researched and developed for over 15 years at UWE. ECAS are produced by passing a weak salt solution through two electrodes; this forms a solution of excited products with antimicrobial properties. Funded by a Home Office grant (**G3**), Reynolds developed ECAS for use in the decontamination of spaces and materials. The research demonstrated that ECAS are effective, fast-acting and green biocides that can be used to control and reduce microbial contamination of materials, food and water. They also reduced the formation of carcinogenic compounds ('trihalomethanes') in drinking water treatment processes caused by conventional disinfection treatments (**R4**, **G4**). Reynolds and Thorn have integrated ECAS into a scaled drinking water treatment system, which for the first time couples on-site, *in situ* generation of ECAS with ultrafiltration (**R5**, **G2**, **G4**). The application of ECAS technology to agri-food water systems has resulted in the control of key food spoilage organisms, thereby extending the shelf-life of fresh food produce as part of a wider water quality management system (**R6**, **G5**).

Reynolds and Thorn have also helped develop the use of engineered microbial biofilms for water treatment systems. These systems provide an alternative to chemical disinfection in the management of key aquatic pathogens, enabling complete control of algae and algal films. In 2016, the researchers collaborated with an industrial partner, Clear Water Revival Ltd, to optimise their existing biofilm system for controlling nutrients and pathogens in the water and stabilised the system so that it could maintain its performance over time (**G6**).

3. References to the research

R1 Coble, P., Lead, J., Baker, A., Reynolds, D. and Spencer, R. (2014) *Aquatic Organic Matter Fluorescence.* Cambridge Environmental Chemistry Series. Cambridge University Press. https://doi.org/10.1017/CBO9781139045452

R2 Carstea, E., Bridgeman, J., Baker, A. and Reynolds, D. (2016) Fluorescence spectroscopy for wastewater monitoring: A review. *Water Research*. 95, pp. 205-219. https://doi.org/10.1016/j.watres.2016.03.021

R3 Fox, B., Thorn, R., Anesio, A. and Reynolds, D. (2017) The in situ bacterial production of fluorescent organic matter; an investigation at a species level. *Water Research.* 125, pp. 350–359. https://doi.org/10.1016/j.watres.2017.08.040

R4 Clayton, G., Thorn, R., Reynolds, D. (2019) Comparison of Trihalomethane Formation Using Chlorine-Based Disinfectants Within a Model System; Applications Within Point-of-Use Drinking Water Treatment. *Frontiers in Environmental Science* 7:35. https://doi.org/10.3389/fenvs.2019.00035

R5 Clayton, G., Thorn, R., Reynolds, D. (2019) Development of a novel off-grid drinking

water production system integrating electrochemically activated solutions and ultrafiltration membranes. *Journal of Water Process Engineering.* 30, Article 100480. https://doi.org/10.1016/j.jwpe.2017.08.018
R6 Thorn, R., Pendred, J., Reynolds, D. (2017) Assessing the antimicrobial potential of aerosolised electrochemically activated solutions (ECAS) for reducing the microbial bio-burden on fresh food produce held under cooled or cold storage conditions. *Food Microbiology*. 68, pp. 41-50. https://doi.org/10.1016/j.fm.2017.06.018

Evidence of the quality of the underpinning research

G1 Reynolds, D. *Development of a Novel Fluorosensor to measure microbial quality and ecological health of freshwater systems*, Natural Environmental Research Council, 2013 – 2016, £68,671.
G2 Reynolds, D. *The development and implementation of sensors and treatment technologies for freshwater systems in India*, British Council, 2018 – 2021, £343,242.
G3 Reynolds, D. *Chemical Breakdown and Biological Decontamination Using Electrochemically Activated Water,* Home Office, 2005 – 2008, £267,207.
G4 Reynolds, D. *The development of off-grid water treatment technologies for the production of drinking water and the recovery of agricultural wastes*, Portsmouth Aviation Ltd, 2015 -2018, £36,515.
G5 Reynolds, D. *Microbial Management of Fresh Produce Preservation, Protection & Intervention*, Technology Strategy Board, 2013 – 2014, £97,500.
G6 Reynolds, D. *The use of biofilms for the control of waterborne pathogens*, Innovate UK, 2016, £49,394.

4. Details of the impact

Water quality sensing research at the core of new commercial products

UWE's AOMF research (**R1**, **R2**, **R3**) underpins sensing products commercialised by Chelsea Technologies (CT) (**S1**). These new water quality sensors provide real-time, highly sensitive measurements for assessing the biological/microbial quality of freshwater and are being used by water companies, environmental monitoring offices, and NGOs. As of February 2020, the value of sales of these systems by CT exceeded GBP750,000 (**S1**, p2). The interference correction algorithms developed in collaboration with UWE (**G1**) have been used to develop CT's technology for new applications in the maritime sector. Their Technical Director stated that *'[they] have also been applied to monitoring wash water from exhaust gas scrubber systems, providing a unique product in a highly regulated market that has contributed around GBP4,000,000 to turnover in the last year alone*' (**S1**, p2).

Water quality sensing technology provides better data for environment work

Starting in 2015, the environmental charity Westcountry Rivers Trust (WRT) began to deploy water sensing technologies that were underpinned by UWE research (**R1**, **R2**, **R3**). These sensors were situated across a number of catchments, in collaboration with South West Water, Devon Wildlife Trust and the Environment Agency (**S2**). These systems were also deployed across 11 catchments in Devon and Cornwall between 2015 and 2020 as part of the GBP11,000,000 programme, Upstream Thinking. With these new sensors, WRT is able to collect data with better spatial and temporal resolution, improving the quality of the data used to inform their work. The Senior Data and Evidence Officer at WRT noted that monitoring via the new system would *'inform the Environment Agency's strategy for working with landowners and the water industry in these catchments to improve water quality'* (**S2**, p2).

ECAS research underpins the development of new commercial products

UK businesses in the water provision sector have commercialised ECAS under the trade names ‘Paqualyte’ and ‘ESOL’. Over the last five years, Reynolds and Thorn have worked with Portsmouth Aviation to develop a ‘Paqualyte’ drinking water treatment system (**S3**). The Managing Director at Portsmouth Aviation noted that UWE’s research (**R4**, **R5**) was pivotal in the ‘*essential business diversification of Portsmouth Aviation, leading to the creation of a new company – Portsmouth Aqua*’ (**S3**, p1) in January 2016. UWE research has enabled Portsmouth Aqua to develop plans to provide 1.7 billion litres of drinking water per annum to communities where existing technologies are either financially unviable or logistically impossible to deliver, generating a projected GBP3,200,000 in revenue per annum for the business (**S3**, p2), but also importantly bringing significant health benefits to those communities.

Bridge Biotechnology Ltd developed UWE’s ECAS technology under the trade name ‘ESOL’. In 2016, ESOL was approved for the disinfection of drinking water by the Drinking Water Inspectorate (DWI) (**S4**, p18, 49). This enabled the biocide to be used for the provision of potable water in the UK. ESOL is now used for disinfection of drinking water, swimming pools, and control/prevention of legionella and biofilms (**S5**). The company’s managing director noted that UWE’s research ‘*on the effectiveness of ESOL against various pathogens has allowed us to identify the sectors in which ESOL would make a significant, positive impact*’ (**S5**).

In 2013, through a collaborative research grant (**G5**), UWE helped Bridge Biotechnology Ltd demonstrate that ESOL could extend the shelf-life of fresh food produce. This helped the company exploit ECAS technology for a new application. The company started to work with salad producer JW European Ltd to create their brand name Smartleaf, which uses ESOL to keep their harvested produce safe and fresh. Since using ESOL, JW European Ltd’s rocket sales have increased by 29%. Lidl supermarkets have extended their ‘best before’ date for Smartleaf products by one day (**S6**); the UK charity Waste and Resources Action Programme estimates that extending the shelf life of key products such as salad by just one day could prevent up to 250,000 tonnes of household food waste in the UK annually (**S7**).

ECAS technology (**R4**, **R5**, **G2**, **G3**, **G4**) has also been commercially exploited by the cleaning solutions company Centrego Ltd, which has developed an international market for the ECAS Technology. Customers of Centrego include the NHS, academia and large corporate companies such as Apple and Goldman Sachs (**S8**, p1). Centrego’s Managing Director acknowledged that UWE research ‘*provided the scientific underpinning for our developed technology*’, and that the ‘*scientific credibility*’ afforded by the research ‘*has led directly to strengthening the commercial viability of Centrego*’ (**S8**, p1). Centrego noted the *‘enormous commercial and PR value of’ UWE ‘research outputs on ECA solutions*’, which provided ‘*evidence of the efficacy, contact time, and regrowth performance*’ of the technology (**S8**, p1). Building on UWE research, Centrego have increased revenue by GBP220,000, increased margins by 22% and profitability by 56% in 2019 alone, with a projected turnover of GBP1,000,000 in 2020 (**S8**, p1).

COVID-19: ECAS research supports organisations including care homes, an emergency food distribution initiative, and a major air defence company

ECAS technology has been deployed in care homes in response to COVID-19. More than 1100 litres of ECAS were provided to Cedar Care Homes during the early stages of the pandemic in the UK, when commercially available sanitisers were in limited supply (**S9**). Cedar Care, who run 14 care homes in the South West and North West, commented that '*the ECAS sanitiser has been invaluable to our decontamination and cleaning processes… helping us to keep our residents and staff safe*' (**S9**).

ECAS technology supported the Community Care Package initiative, a free food delivery service in Bristol delivering food packages to people unable to get to a shop or struggling financially during COVID-19. The community initiative has delivered over 20,000 boxes of food to over 5000 people. When commercially available sanitisers were in limited supply, ECAS supplied by UWE facilitated the safe decontamination of packaging, surfaces and vehicles, and diluted ECAS allowed decontamination of produce entering the distribution centres and the hand sanitisation of packers and drivers (**S10**). The Director at Community Care Package commented that: *'Since March [2020]…this ongoing project has raised over £100,000 pounds to distribute fruit, vegetables, bread and other produce to the most needy and vulnerable in Bristol and beyond. All this would not have been possible without a dependable supply of safe, environmentally friendly sanitiser, and UWE has so far provided 350 litres to our charity free of charge'* (**S10**).

ECAS technology also provided hand sanitiser and disinfectant for a major air defence company with a workforce of over 4,000 staff, during the early stages of the pandemic in the UK. A Facilities Operations Manager noted '*hand sanitiser and effective disinfectant was in short supply, and our local facilities team struggled to source adequate supplies. In excess of 500 litres were provided to us (free of charge) and this has been invaluable to us as an organisation in the most difficult of times*' (**S11**).

Water treatment research leads to expansion and increased revenue for UK business
UWE's research collaboration with Clear Water Revival Ltd (**G6**) has led to the installation of 40 chemical-free swimming pool filtration systems in the UK. The company has been able to undergo a dramatic expansion, adding 12FTE to their staff. They have experienced a 500% increase in revenue (from GBP250,000 to GBP1,500,000), filed two patents, and created a new company to supply chlorine free filtrations systems (Hydrolize Ltd.) (**S12**). The move away from the use of chlorine-based disinfection systems to biological based systems is disruptive in an industry context, providing significant health benefits and reducing the environmental impact of this market sector (**S12**).

5. Sources to corroborate the impact

S1 Testimonial from the Technical Director of Chelsea Technologies Ltd
S2 Testimonial from the Senior Data and Evidence Officer at Westcountry Rivers Trust
S3 Testimonial from the Managing Director of Portsmouth Aviation
S4 Drinking Water Inspectorate *List of approved products for use in public water supply in the United Kingdom* April 2016
S5 Testimonial from the Managing Director of Bridge Biotechnology
S6 Bridge Biotechnology website detailing partnership with JW European and Smart Leaf
S7 Waste and Resources Action Programme website
S8 Testimonial from the Managing Director of Centrego Ltd
S9 Testimonial from Compliance and Training Officer at Cedar Care Homes
S10 Testimonial from the Director of Community Care Package
S11 Testimonial from a major air defence company (details provided in corroborating source)
S12 Testimonial from Company Founder and Secretary at Clear Water Revival