Institution: Coventry University		
Unit of Assessment: 12		
Title of case study: Recycling E-Waste though Bioleaching: Turning Motherboards into Gold, and other Precious Metals		
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:**
Sebastien Farnaud	Professor of Enterprise and Innovation in Healthcare Technology	2016-Present
John Graves	Associate Professor	2008-Present
Mahsa Baniasadi	Research Assistant	2018-Present
Derek Renshaw	Professor in Endocrine Physiology	2014-Present
Period when the claimed impact occurred: August 2013-July2020		
Is this case study continued from a case study submitted in 2014? No		

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

Over 50 million tonnes of electronic waste are generated globally each year. With only 20% formally recycled, e-waste is routinely shipped overseas for disposal where it is burned through inefficient extraction processes, exposing workers and ecosystems to toxic by-products. Worldwide, rare metals including gold, silver, copper and platinum worth an estimated €55bn are lost annually.

CU researchers have developed an innovative, efficient and green solution, using bioleaching to recover precious metals from e-waste. This has transformed the commercial capacities of IT waste company N2S, revolutionised UK industry within the 'circular economy', whilst tackling environmental issues, and tightening security surrounding e-waste disposal.

2. Underpinning research (indicative maximum 500 words)

Bioleaching is a process whereby microorganisms are used to extract metals from a solid. It is a natural process, which has long been used in the mining industry but of limited application in other domains. Innovative cross-disciplinary work at Coventry University, carried out in a KTP with Network 2 Supplies Ltd. (G1), has led to important new research enabling the application of bioleaching to e-waste.

Professor Sebastien Farnaud of CU's Faculty of Health and Life Sciences has decades of experience in the area of iron metabolism and delivery. Farnaud and Renshaw utilised their knowledge surrounding iron oxidisation (R1) to instigate a new project to adapt the practice of bioleaching to industrial metal recovery for the first time and facilitate commercial application of the process. A transdisciplinary 'Bioleaching Group' was formed at CU that brought together the microbiological approach established by Farnaud and Renshaw with the research knowledge on

electrowinning and metallisation from Associate Professor John Graves (R2), and Environmental biotechnology from Dr Mahsa Baniasadi (R3). Microbiological and biochemical expertise was combined to extensive research on chemical engineering, which led to the development of a wholly innovative process whereby for the first time, recuperation methods could be added to recycling bioleaching applications in a closed-loop system.

In October 2018 Farnaud, Renshaw, Graves and Baniasadi began a KTP funded by InnovateUK (£231,687, 2018-2021) with the company N2S (Network 2 Supplies), the UK's market leader in IT lifecycle services. N2S is a professional services company specialising in optimising supply chain economics for businesses in the finance, telco, media and government sectors, a UK sector leader in handling Waste Electrical and Electronic Equipment (WEEE). N2S's previous scrap recycling process involved the company dismantling electronic equipment, removing the easily accessible high value metal components from the printed circuit boards (PCBs), and exporting what was left to Asia. The exact nature and quantity of all precious metals such as gold, platinum, palladium and rare-earth metals still encapsulated within e-waste processed abroad was unknown.

CU researchers identified the need for a sustainable cost-effective non-toxic alternative, for precious metal recovery, which could be carried out within the UK. Whereas e-waste bioleaching has been investigated by a few academic research groups, generally the solubilised metals remain in a soluble mixture, which is therefore not readily available. The breakthrough solution was delivered through the addition of engineering approaches to the microbiological extraction, enabling researchers to further purify the extracted metals selectively. The combination of electrowinning by Dr John Graves to bioleaching, enabled a complete closed-loop system for a 'circular economy', as demonstrated by the production of a high quality copper foil, with 99 + % purity from PCB bioleaching (R5).

Drawing on CU expertise in microbiology and electro-chemistry, brought together with industrial chemists and those at the front end of e-waste management, an in-house bioleaching capability for the recovery of precious metals from e-waste was developed with N2S (R4). An innovative 'closed loop system' was devised, through which precious metals could be both extracted from electronic waste in solution, and then 'recovered' through electro-chemical processes (R5).

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

R1. Mehta K; Greenwell P, Renshaw D, Busbridge M, Garcia-Maya M, Farnaud S, Patel V*. (2016). Characterization of hepcidin response to holotransferrin in novel recombinant TfR1 HepG2 cells. Blood Cells, Molecules and Diseases. 61(10):37-45. https://doi.org/10.1016/j.bcmd.2016.06.008

R2. Wu, L., Graves, J. E., & Cobley, A. J. (2018). Mechanism for the development of Sn-Cu alloy coatings produced by pulsed current electrodeposition. Materials Letters, 217. https://doi.org/10.1016/j.matlet.2018.01.094

R3. Mahsa Baniasadi, Farzaneh VakilChap, Nazizn Bahaloo-Horeh, Seyyed Mohammad Mousavi, Sebastien Farnaud. (2019). Advances in bioleaching as a sustainable method for metal recovery from e-waste: A review. Journal of Industrial and Engineering Chemistry 76, 75-90. https://doi.org/10.1016/j.jiec.2019.03.047

R4. F. Vakilchap, S. M. Mousavi, M. Baniasadi, S. Farnaud. Development and evolution of biocyanidation in metal recovery from solid waste: a review. Reviews in Environmental Science and Bio/Technology 19, 509–530 (2020). https://doi.org/10.1007/s11157-020-09544-y

R5. M. Baniasadi, J. Graves, D. Ray, A.L. De Silva, D. Renshaw and S. Farnaud. (2020). Closed-loop Recycling of Copper from Waste Printed Circuit Boards using Bioleaching and

Electrowinning processes. Waste and Biomass Valorisation. https://doi.org/10.1007/s12649-020-01128-9

G1. Renshaw, D. (PI), Farnaud, S., Graves, J. (2018-21) 'Network 2 Supplies Ltd & Coventry University'. Innovate UK, KTP. Total Funding: £249,363

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

CU research has pioneered the application of bioleaching to e-waste processing at an industrial scale – transforming the capacity and services offered by KTP partner N2S, and informing national guidance and strategies on remediation of waste in the ICT sector. Our process has been described as "groundbreaking" by certification body ADISA (S6).

Novel Industrial Bioleaching Application

CU research has contributed to innovation for KTP partner N2S, enhancing the capacity of the company to deliver new services in WEEE disposal. Before the collaboration, N2S were only able to process the larger component metals within PCB boards at their own site, having to send the remainder overseas for further processing. CU research provided N2S with 'an innovative end-to-end solution for WEEE disposal', which has allowed them to fully adopt the circular economy principle' (S2) where precious metals can be recovered onsite (S1). This 'adds an additional layer of security to WEEE disposal' which is entirely novel, as the company can 'closely track how any WEEE containing sensitive information is processed' rather than sending it overseas(S2). They are now the only company in the UK to offer a bioleaching service for the recovery of precious metals, providing a level of metals recovery from e-waste which was previously 'unimaginable, based on the sector's standard processes' (S4).

N2S have filed a patent for the bioleaching process, which achieves faster, higher yields of precious metals than other less efficient metals recovery methods, without the need of toxic chemical nor high energy consumption, resulting in more efficient production. In 2018 N2S established a microbiology plant on premises (S1), and the company have made 'significant and strategic investments' in the use of bioleaching to 'process all WEEE entirely within the UK (S2).This includes a 2019 expansion of capacity through a second bioleaching laboratory, reconfigured as a scale-up facility for the extraction of noble metals on site. A 'small number of additional roles' have already been created at the company to facilitate these new processes, with more planned (S1). At a local level, manufacturers have gained work designing and delivering new in-house technology, including specific machinery (S1). In addition a novel process for gold extraction has been developed between CU and N2S, where the precious metal can be extracted in-house without any external input; there is a patent pending for this technology, and N2S have designed a second laboratory dedicated solely to gold extraction for commercial use (S1).

Commercial-Environmental Innovation

N2S' adoption of the entirely novel process of industrial bioleaching has enhanced their strategy, and changed the business to achieve environmental objectives. The N2S Director states that CU's research has 'shaped the direction of the company' and enabled it to develop 'into a business known for sustainability' (S2). With uptake of bioleaching as a core service, N2S identify that the business now has 'negative carbon emissions' (S2), and is working towards UN SDGs 6 (Clean Water and Sanitation), 12 (Responsible Consumption and Production) and 13 (Climate Action). The new industrial bioleaching processes developed by CU and N2S were identified by the 'Support the Goals' initiative as a case study for business support of the UN SDGs (S5), and the work – also referred to as 'urban mining' – was highlighted in 'How Green is our Digital', a 2020 white paper by UKAuthority and Microsoft (S3).

Industrial application bioleaching by N2S is revolutionising the reverse logistics sector, as an example of resource-use efficiency in response to the ever-increasing mass of IT waste produced annually. Recognised by Defra for their unique provision of the innovatively sustainable process (S7), CU's research has provided N2S with 'a significant commercial advantage over our competitors', and 'opened many doors' for them with 'customers who want to meet sustainability targets' (S2). The 'ground-breaking' solution provided by CU research has 'changed industry ideas of what is possible in materials recovery', showing the 'real-world application' of a process with a 'level of efficiency and sustainability' which was previously 'unimaginable' (S6).

Informing National Guidance

The development of this industrial bioleaching application has led N2S to be recognised as 'thought-leaders' within WEE recycling, and as a direct result in 2019 N2S were invited to become founder members of Defra's Defra e-Sustainability Alliance (DeSA) alongside 13 other organisations including IBM, Vodaphone and Microsoft (S1, 2). The Sustainability and Smart Cities lead for Microsoft Public Sector UK has remarked how N2S' membership of the group, 'drawing on their work with Coventry…has helped educate and raise awareness' of the 'potential of bioleaching' as an applied solution (S4).

CU's research has informed guidance on ICT waste. Defra incorporated the industrial application of bioleaching as a key example of innovation and 'best practice' within their guidance document 'Helping businesses create a greener, more sustainable future through ICT' published October 2019 (S7, p.7). This guide represents a new policy for technology recycling, and specifically identifies bioleaching as a key new service to enable future remediation of waste in the ICT sector, and the CU/N2S team presented their bioleaching application its launch by Defra in October 2019.

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

S1. Testimonial. Commercial Director, Network 2 Supplies.

S2. Testimonial. Director, Network 2 Supplies.

S3. Report. 'How Green is our Digital? Local government, urban and rural digital infrastructure and sustainability today'. UkAuthority, Microsoft, February 2020. <https://www.ukauthority.com/articles/uka-launches-how-green-is-our-digital-report/> [Accessed 26.02.21]

S4. Testimonial. Sustainability and Smart Cities Lead, Microsoft Public Sector UK.

S5. Article. 'How Can a Company Use Bugs to Reduce Electronic Waste', Support the Goals Initiative Website. https://supportthegoals.org/how-can-a-company-use-bugs-to-reduce-electronic-waste/ [Accessed 31.12.20]

S6. Testimonial, Steve Mellings, CEO ADISA (Accreditation program for IT asset disposal companies, recognised by UK Government).

S7. Guidance. 'Helping businesses create a greener, more sustainable future through ICT', Industry Guide, Defra (October 2019). <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/840765/defra-industry-guide-ict-sustainability.pdf> [Accessed 26.02.21]