RESOURCE RECOVERY FROM WASTE ANNUAL CONFERENCE 2019

16th January 2019, One Great George Street, London

NERC SCIENCE OF THE ENVIRONMENT

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Department for Environment Food & Rural Affairs

Resource Recovery from Waste Annual Conference 2019

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RESOURCE RECOVERY FOR A CLEAN, LOW-CARBON AND RESOURCE EFFICIENT ECONOMY

Introduction

Welcome to the Resource Recovery from Waste Conference 2019.

The final conference for the Resource Recovery from Waste (RRfW) programme will bring together five years' of research to highlight the relevance of resource recovery for a clean, low-carbon and resource efficient economy.

The conference will showcase the key achievements of the RRfW programme covering: technologies and approaches to recover resources from industrial, mining and organic wastes; novel assessment tools to optimise the value created in resource recovery systems across multiple domains (economic, technical, environmental and social); and recommendations for the transition to a circular economy based on academic, government and industry perspectives. For background on the RRfW programme and some of the radical ideas coming out of this work, please see pages 16-17.

The conference will highlight where changes in policy are required to realise the full benefits envisaged for the UK economy, society and environment: some key policy messages from the RRfW programme are summarised here on page 18.

Finally, the conference will look forward to identify future research and innovation challenges for the circular economy. To get you thinking, some challenges identified by RRfW are presented on page 19.

Please share your thoughts during the day on Twitter using #RRfW2019

We hope the conference will inspire you to continue contributing to resource recovery and the transition towards a circular economy!

Schedule

The Smeaton, Council and Brunel rooms are located on the ground floor of One Great George Street, just off the main foyer.

Time (hrs)	Item	Chair / Location
9:00	*Arrival and registration*	Reception
9.30	**Conference opening and welcome**: • **Phil Purnell, University of Leeds** • **Beth House, Natural Environment Research Council**	Smeaton room
9:40	**Keynote: Laura Sandys, Challenging Ideas** "Moving the Dial on the Circular Economy: Show Not Tell"	Smeaton room Chair: Phil Purnell, University of Leeds
10:00	**RRfW project showcase**. • **Ian Head, Newcastle University** "Bioelectrochemical systems for resource recovery and integrated waste management systems" • **Lynne Macaskie, University of Birmingham** "Microbial synthesis of metallic nanoparticles: multiple opportunities and selected case histories for valorization of wastes into value products." • **Will Mayes, University of Hull** "Resource recovery and remediation of alkaline wastes"	Smeaton room Chair: Anne Velenturf, University of Leeds
11:00	*Refreshment break*	Brunel / Council Rooms
11:30	**RRfW project showcase**. • **Devin Sapsford, University of Cardiff** "*In situ* recovery of resources from waste repositories" • **Alfonso Lag Brotons, Lancaster University** "From waste to fertilisers/soil conditioners – Cycling the value of anaerobic digestate and biomass ash" • **Phil Purnell, University of Leeds** "Modelling environmental, social, economic and technical value changes in systems of systems: the CVORR approach"	Smeaton room Chair: Anne Velenturf, University of Leeds
12:30	*Lunch: networking and exhibition*	Brunel / Council Rooms

Time (hrs)	Item	Chair / Location
14:00	**Perspectives on resource recovery from industry**. • **Peter Quinn, Tata Steel Europe** "Resource efficiency challenges in the steel industry" • **Mark Sommerfeld, Renewable Energy Association** "Energy from waste and resource recovery within an evolving bioeconomy"	Smeaton room Chair: Rachel Marshall, Lancaster University
14:50	**Keynote: Phil Purnell, University of Leeds** "Resource recovery from waste: the transition towards a circular economy"	Smeaton room Chair: Rachel Marshall, Lancaster University
15:10	*Refreshment break*	Brunel / Council Rooms
15:40	**Perspectives on resource recovery from government**. • **Tom Murray, Defra** "Our waste, our resources: delivering a resource efficient future"	Smeaton room Chair: Anne Velenturf, University of Leeds
16:00	**Panel discussion** on future research and innovation challenges for resource recovery. Panel members: • **Andy Rees, Welsh Government** • **Adam Read, SUEZ** • **Jim Wharfe, Environmental Consultant** • **Jacqui Murray, Innovate UK**	Smeaton room Chair: Libby Peake, Green Alliance.
16:40	**Keynote: Ned Garnett, Natural Environment Research Council** "Reflections on the RRfW programme and the future funding landscape"	Smeaton room Chair: Phil Purnell, University of Leeds
16:55	**Closing remarks**: **Phil Purnell, University of Leeds**	Smeaton room
17:00	*Drinks reception in exhibition space: join us to toast the success of the RRfW programme and carry on conversations*	Brunel / Council rooms
18.30	Event close	

Talk sessions

Moving the dial on the circular economy: Show not Tell.

Laura Sandys, CEO, Challenging Ideas

The Resources and Waste strategy is a great start to shaping an ambitious circular economy, addressing resources as assets and building a strong capability to manage our waste more effectively. However, it is down to us – the sector, the academics and the entrepreneurs – to bring the strategy to life. We need to recognise that to meet the ambition we need to re-engineer our economy, bring more skills and expertise into the sector and modernise. Data, new technologies, new business models will be the revolution that we need. Show not Tell!

Speaker biography: Laura Sandys runs the 21st Century Energy Regulatory Commission with Imperial College and is Deputy Chair of the Food Standards Agency. She is working on the Resources Sector Deal and wrote when in Parliament "Sweating Our Assets" which was one of the first Parliamentary articulations of resource productivity. She is on the CCUS Council and Taskforce as well as having served as a member of the Advisory Panel for the Government's Cost of Energy Review. She is co-founder of POWERful Women, a Visiting Senior Fellow at Kings College and a Fellow of the Energy Institute. She was previously a Member of Parliament for South Thanet and was a member of the Energy and Climate Change Select Committee and Parliamentary Private Secretary to the Minister for Energy and Climate Change.

Bioelectrochemical systems for resource recovery and integrated waste management systems

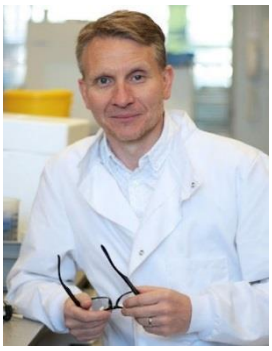
Ian Head, Professor of Environmental Microbiology, Newcastle University

Bioelectrochemical systems (BES) can convert chemical energy into electrical energy, which can be used to power low energy electrical devices or drive useful reactions such as reduction of CO_2 to organic compounds or reduction of metal ions. One attractive characteristic of BES is that they can use a range of waste streams as fuels and the use of wastewater to generate electricity in microbial fuel cells has been demonstrated on numerous occasions. It has been estimated that the global, annual inventory of domestic wastewater contains around 600 – 1200 TWh of energy. Only a fraction of this energy can be recovered using BES and consequently BES are not currently competitive with other systems for energy recovery from wastewater, such as biogas production from anaerobic digestion. Consequently, other modes of resource recovery from waste using BES have been developed.

We have developed a BES capable of recovering metallic copper from wastestreams from malt whisky distilling that contain low ppm levels of copper ions. Controlling the electrical potential of the cathode allows the system to be tuned to recover different copper species including cuprous oxide which can be used as a catalyst for CO_2 reduction. Moreover, we have demonstrated that known electrogenic metal-reducing bacteria such as *Shewanella*

oneidensis can deposit nanoparticulate copper, which has catalytic activity in click-chemistry applications, opening the door to high value product recovery from copper containing wastestreams.

In principle around 50 tonnes of copper, with a value of approximately £0.25 M, could be recovered from all malt whisky distilling operations in the UK. However, in addition to financial benefits, the environmental value of copper removal from wastestreams is not insignificant. Copper is a toxic metal and one of the 13 metals included in the US EPA's priority pollutant list. This has direct benefits from the removal of a toxic material from wastewater, but would also reduce the metal burden in sewage sludge where metals typically become concentrated.



***Speaker biography*:** Ian Head is Professor of Environmental Microbiology in the School of Natural and Environmental Sciences, Newcastle University. He works extensively at the interface of engineering and biological systems and has published more than 100 papers in peer reviewed journals. His work on bioelectrochemical systems (BES), such as microbial fuel cells, stretches back to 2005 and has explored factors that govern electricity generation, development of electrogenic microbial communities, the use of BES as sensors, BES for CO_2 reduction to organic compounds and for removal and recovery of metals. He is a Fellow of the Royal Society of Biology and a member of both the European and American Academies of Microbiology.

Microbial synthesis of metallic nanoparticles: multiple opportunities and selected case histories for valorization of wastes into value products

Lynne Macaskie, Professor of Applied Microbiology, University of Birmingham

The use of microorganisms to remove metals from liquid wastes dates back to the 1970s. Until now metal recovery from the biomass was not cost-effective. Resource depletion, high CO_2 impact of primary ore extraction, increasing scarcity and prices and high strategic relevance of some metals (e.g. Cu, Co, V) and especially rare earths (REEs) and platinum group metals (PGMs) has shifted the focus towards recovery from secondary sources. At the same time nuclear power is expanding, increasing the price of uranium. U and REEs co-occur in ores and U-mine tailings ponds are an abundant reserve of REEs but separation from U (and also Th in ores) must be achieved.

The goal of B^3 is 'Beyond Biorecovery': not simply metal scavenging but biorefinery of wastes into neo-biomaterials with applications in green chemistry, low carbon energy and environment. Highlights of B^3 include:

- Development of a novel biotechnology ("sulfur-enhanced bioleaching") for extracting and recovering transition and precious metals from mineral wastes.
- A bioprocess harnessing biogenic H_2S to metal recovery (as metal sulfides) from acid mine drainage (AMD) water, with selective recovery of Cu (high value) and Zn (lower value). Zinc sulfide quantum dots 'upgrade' sunlight, converting unused light wavelengths into photosynthetically-active ones to boost algal growth for production of oils and biomass.

- Immobilised bacteria making nanobiomineral metal phosphates in a continuous accumulation process, separating REEs, uranium and thorium. REE phosphates are catalytically active, which is under examination.
- Using bacteria to reduce PGMs to scaffolded metallic nanoparticles with high catalytic activity. Many secondary PGMs are recycled but road dust is not, even though its PGM concentration can mimic a low grade ore. Leachates from road dust were biorefined into active neo-catalysts for multiple applications.
- Energy from biomass processes generate liquid fuel precursors in waste. Leftover bacteria from the AMD-Cu/Zn recovery process made PGM neo-catalysts to upgrade biomass hydrolysate.

The presentation will highlight some selected case histories.

***Speaker biography*:** Lynne Macaskie trained in microbial biochemistry (London) moving to the University of Oxford (postdoctoral, then faculty staff in Department of Biochemistry) and since 1991 has held a lectureship and personal Chair at the University of Birmingham. Her interests centre on bacterially-manufactured nanoparticles for decontamination processes and precious metal neo-catalysts for clean energy, green chemistry and environment. She developed bio-hydrogen via fermentation of food wastes. Her recent focus is on bioprocess integration for multi-value waste upgrading.

Resource recovery and remediation of alkaline wastes

Will Mayes, Reader in Environmental Science, University of Hull

This talk will give an overview of the findings of the 'Resource Recovery and Remediation of Alkaline Wastes' (R3AW) project, which aimed to improve the technical basis for minimising environmental impacts and recovering value from globally significant alkaline industrial residues such as steel slags and bauxite processing residue. The talk covers technical developments which include: (1) an improved understanding of the geochemical processes controlling the release of critical elements like vanadium from steel slag, highlighting the potential environmental risks of uncontrolled disposal of slag and how these can be minimised, (2) technologies for metal recovery from highly alkaline steel slag and bauxite residue leachates that have been demonstrated for the first time, (3) details on the physical structures and biological communities that can promote lowering of pH in alkaline waters towards regulatory limits.

The talk will also highlight the potential benefits of alkaline residues in both atmospheric carbon uptake and land rehabilitation. Our field investigations have provided clear evidence that the full benefits of legacy steel and iron wastes for atmospheric carbon uptake are not currently being realised, while long term assessment of bauxite residue rehabilitation has highlighted the effectiveness of low-cost amendments in developing functioning soils. In addition to the technical developments, the talk will cover our policy-focussed work. Extensive in-depth interviews with key producers in the steel slag production, management and after-use chain have highlighted the key challenges that need to be overcome for new

resource recovery technologies for steel by-products to be implemented. These centre on inflexibility in regulation driven primarily by environmental protection, as well as complex liability issues with long-standing downstream user agreements and changing ownership of sites. The talk concludes by highlighting future research priorities and practical ways to improve prospects for valorisation of alkaline wastes.

***Speaker biography*:** Dr Will Mayes is a Reader in Environmental Science at the University of Hull who co-led the R3AW project with Dr Ian Burke, Associate Professor in Environmental Geochemistry at the University of Leeds. Will's research focuses on improving management of industrial wastes and waste waters to minimise environmental impacts and maximise scope for resource recovery.

In situ recovery of resources from waste repositories

Devin Sapsford, Reader in Environmental Engineering, University of Cardiff

Despite dominating global waste arisings by mass, industrial and mining wastes are overlooked in current circular economy discourse which tends to focus on recycling of post-consumer goods.

Conventional pyro- and hydrometallurgical reprocessing technology for recovery of resources from industrial and mining wastes can be energy and carbon-intensive. *In situ* recovery of resources from wastes offers a promising low-intensity approach to resource recovery from such wastes.

Value in these wastes can be realised through directly recovering resources (e.g. metals leached) or indirectly via later recovery of decontaminated residual waste (e.g. for aggregate), or recovery of valuable land or landscape. Accurately assessing the deportment of the value is important for informing decision making.

This talk summarises work carried out under the INSPIRE project and focuses on the development of a range of novel microbiological, nanomaterial-based, and electrokinetic *in situ* technologies for recovery of resources from wastes.

***Speaker biography*:** Dr Devin Sapsford is a Reader in Environmental Engineering within the Cardiff School of Engineering, Cardiff University and specialises in research into the application of geochemistry for engineering solutions for the treatment of contaminants in water and soil and resource recovery from wastes.

From waste to fertilisers/soil conditioners – Cycling the value of anaerobic digestate and biomass ash

Alfonso Lag Brotons, Senior Research Associate, Lancaster University

The AVAnD project focused on improving the circularity of nutrients in the agrifood systems, specifically those contained in bioenergy generation (anaerobic digestion, thermal transformation) by-products (anaerobic digestate and biomass ash, respectively). To do so,

these materials were combined and treated/managed to be/act as fertilisers/soil conditioners.

Digestate-ash blends, dosed according to agricultural best available practice, resulted in plant productivity (winter wheat) comparable to that of conventional inorganic fertilisers, both at glasshouse and field scales. At this dosage, we did not observe negative effects on soil biota (earthworms & soil microorganisms). Furthermore, we detected that the net carbon balance (soil C gain versus loss) was negative for conventional fertilisers and positive for the blends. The management and both soil/crop type conditioned the responses observed.

In spite of the potentiality of products derived from waste streams (here digestate, ash and/or their blends) to act as soil conditioners/fertilisers, the regulations on waste streams utilisation (e.g. End of Waste) are currently rigid. Forthcoming EU regulations on fertilisers and recent UK waste-related strategy could ease this path, by simplifying the mechanisms and by increasing the resource efficiency, respectively.

The AVAnD project has provided evidences to support the expected environmental benefits (e.g. greater C storage; substitution of inorganic fertilisers), but also the increase in resource efficiency (improved nutrient cycling; marketable product potential). It has also informed policy-makers (e.g. Defra Report) on its study case and has serve as the foundation for subsequent follow-on research related to resource recovery (AVAnD 2; RECIRCULATE).

***Speaker biography*:** Dr Alfonso Jose Lag Brotons is interested in soil protection, waste management and bio-energy production, being these aspects oriented towards the achievement of sustainable agrosystems. He participated in the NERC funded research project AVAnD to develop sustainable fertilisers from bio-energy residues and currently is working towards contributing in achieving sustainable water access in Sub-Saharan Africa (RECIRCULATE), by managing waste streams to recover resources (energy/soil conditioners).

Modelling environmental, social, economic and technical value changes in systems of systems: the CVORR approach

Phil Purnell, Professor of Materials and Structures, University of Leeds

Complex value optimisation for resource recovery (CVORR) is a method that allows the creation (benefits) and destruction (costs) of value in multiple dimensions owing to interventions in interlinked resource recovery systems to be measured. It is based on a combination of elements from materials flow analysis (MFA), life-cycle sustainability assessment (LCSA) and socio-political narratives based on systems of provision (SoP) concepts.

The three-stage iterative process is outlined here using a case study of the concrete, electricity and steel production systems. These are linked by the use of by-products from steel and electricity production as ‘low carbon’ raw materials for concrete production; changes in production processes in all three sub-systems are affecting the dynamics of the whole system. CVORR shows that complex technical and economic interactions between them cause counter-intuitive effects that will influence their decarbonisation strategies; the

multi-dimensional analysis highlights issues that previous single-dimension techniques fail to address.

The analysis also shows that incompatibility between existing e.g. environmental (LCA) and technical (MFA) approaches is due to the mathematical characteristics of the values they employ, rather than inherent to their associated with different ‘dimensions of value; this can be overcome in CVORR, allowing more integrated assessments to be carried out. The socio-political element of the analysis helps to uncover issues related to offshoring of environmental and social impacts and helps to clarify why the systems behave as they do.

Speaker biography: Phil Purnell is Professor of Materials and Structures at Leeds University School of Civil Engineering, and a co-Director of the University’s Cities interdisciplinary research theme. He is the Convener of the Resource Recovery from Waste programme, and also PI or Co-I on live projects investigating the use of robotics in infrastructure maintenance, project delivery in urban environments, infrastructure materials lifecycles and interdependencies and business models in infrastructure systems, funded from three research councils, industrial partners and policy makers. The portfolio concentrates on work at the interfaces between the engineering, environmental and economic sciences where the difficult global problems facing our 21st century society and its infrastructure reside.

Resource efficiency challenges in the steel industry

Peter Quinn, Head of Climate Change, Tata Steel Europe

Steel is a fundamental material that society will rely on for the foreseeable future that underpins our everyday lives. But integrated steelmaking also consumes large tonnages of raw materials.

The industry has got a great record at improving its resource efficiency; secondary production of steel from scrap accounts for about 25% of all global steel production and the material intensity of primary steel production has improved significantly over the last few decades, with steelmakers finding innovative ways to recirculate iron, carbon and calcium bearing residues back into their processes. Great strides have also been made to find external outlets in other industries for those wastes that cannot readily be recirculated within the process and strong markets have become established for valuable steel industry by-products such as blast furnace slag. To illustrate this success, Tata Steel’s Port Talbot steelworks, which receives over 7 million tonnes of raw materials annually, landfills less than 20 thousand tonnes of waste, which means that over 99.7% of its feedstock is turned into valuable products.

Steelmakers also make a profoundly beneficial impact through the products they make and supply; steel is strong, durable, flexible and infinitely recyclable at the end of its life. It is a foundation material in delivering societal carbon reductions and driving a more circular economy. But, the industry faces a number of resource efficiency challenges:

- Innovation in products that are more durable, for example those with advanced organic and metallic coatings, presents challenges to their recycling at end of life.

- The recirculation of certain internally-arising wastes in steelmaking processes presents challenges in terms of process efficiency and atmospheric emissions.
- Regulatory barriers restrict the opportunities for further industrial symbiosis, such as the use of wastes from other sectors in the steel industry.

With the right policy framework in place, and through targeted R&D to develop innovative solutions to these challenges, the concept of a zero-waste steel industry, producing durable, re-usable and recyclable products to society should be readily achievable. This talk will explore the challenges and the steps we are already engaged in to respond to them in more detail.

Speaker biography: Peter Quinn has worked at Tata Steel and its predecessor companies for over 25 years, starting off in environmental research before taking on roles in operational management, environmental governance and, for the past ten years, environmental policy and strategy. For the past five years he has been Head of Climate Change and Environmental Policy & Strategy for Tata Steel Europe where his main focus areas have been industrial decarbonisation, environmental impact assessment, product sustainability assessment (e.g. life cycle assessment), CSR reporting, constructive engagement with policy makers in climate and environmental policy development and corporate strategy development. Peter has always been passionate about environmental affairs. With a quarter of a century in the steel industry he remains more convinced than ever of the positive role that the sector plays and can increasingly play in helping to solve a series of 21st century challenges, not least those emerging from the linked themes of climate change and the imperative for society to become far more resource efficient.

Energy from waste and resource recovery within an evolving bioeconomy

Mark Sommerfeld, Policy Manager, Renewable Energy Association

The presentation will be about bioeconomy from a bioenergy perspective, and how residues from power generation/ fuel production (such as digestate and ash) can be valorised better. Policies that could enable this are sitting in different departments such as BEIS and Defra, and realising the full benefits of energy and resource recovery for the UK economy, society and environment will require better collaboration across government. A number of industry/ practical challenges must be addressed through research and innovation.

Speaker biography: Mark Sommerfeld has managed policy and regulation across both generation and retail renewable energy projects for over six years. He joined the Renewable Energy Association in 2015 and is the Bioenergy Policy Manager, which includes administering the REA's Waste to Energy Sector group. The group advocates for a thriving energy from waste industry within a circular economy, along with realising the potential of Advanced Conversion Technologies. He is an Alumni of Cambridge University.

Resource recovery from waste: the transition towards a circular economy

Phil Purnell, Professor of Materials and Structures, University of Leeds

Resource recovery from waste is a key part of engineering a transition from our current linear “take-make-use-dispose” economy towards a circular economy (CE) in which all products are designed to be repaired, refurbished and reused, preserving for as long as possible the service or function that products provide, preventing the dissipation of this technical value into wastes, and drastically reducing demands for raw materials. Multiple governmental, industrial and commercial agencies have repeatedly expressed a desire to move towards CE and/or enumerated the potential economic benefits. Nonetheless, our current RRfW operations are dominated by energy from waste processes and partial recycling of selected fractions of household, commercial and industrial waste, both near the foot of the waste hierarchy.

While technically we are able to undertake processes that better preserve resources and their long-term productivity, many barriers remain. Here, we amplify the business case for RRfW by presenting additional political, strategic and environmental benefits (e.g. materials security, achieving UN Sustainable Development Goals and reducing carbon emissions). We also outline some of the upstream, downstream and contextual policy-related barriers. Some are partially addressed by the new Resources and Waste Strategy (e.g. a cultural preoccupation with treating waste rather than recovering resources, and a focus on the quantity, rather than the quality of resources recovered); other include a lack of market incentives and collaborative structures to drive product design changes, and a lack of infrastructure, public investment and data. While individual policy interventions such as extended producer responsibility measures can lower these barriers, multiple interventions across existing government departments will be required and these should be coordinated by a new body explicitly mandated to promote resource recovery, security and productivity.

Finally, we outline some of the future research challenges identified by the RRfW programme.

Speaker biography: see page 7.

Our waste, our resources: delivering a resource efficient future

Tom Murray, Deputy Head of Resources and Waste Policy, Defra

Recovering resources can prevent waste being generated in the first place and emphasis use of secondary materials rather than extracting new ones from our natural capital stocks. These can generate economic growth but also points towards a more sustainable future that delivers societal benefits. The role of Government is to ensure the correct incentives are in place to present opportunities that stimulates clean growth. In the waste sector there is significant untapped potential to deliver this. Resource recovery is central to it.

On 18 December 2018 the Government published its Resources and Waste Strategy for England. At the heart of the strategy is how we will preserve material resources by reducing waste and promote greater resource efficiency. It builds on the

Government's 25 Year Environment Plan commitment to leave the environment in a better condition for the next generation.

The Strategy identifies policy interventions plus longer-term commitments and ambitions to achieve this. It works through the product lifecycle of production, consumption and how we manage waste. It contains significant commitments to achieve greater circularity; notably including delivering national consistency of materials collected for recycling, extended producer responsibility and deposit return schemes to name a few. The policy principles of these three commitments will be out for consultation soon.

This presentation will review the key commitments of the Resources and Waste Strategy and its role to stimulate greater resource recovery from waste.

Speaker biography: Tom Murray is the Deputy Head of Resources and Waste Policy responsible for evidence and analysis at the Department for Environment, Food and Rural Affairs. An environmental economist by profession, Tom has experience estimating values for environmental goods and services as well as factoring environmental values into policy decisions. Tom is leading the evidence for the Government's Resources and Waste Strategy and the associated policy proposals it will announce.

Reflections on the RRfW Programme and the Future Funding Landscape

Ned Garnett, Associate Director (Research), Natural Environment Research Council (NERC)

- Reflecting on the delivery of the RRfW programme against the original NERC and ESRC investment.
- Highlighting the key messages from the programme that are beneficial to NERC.
- Commenting on future NERC strategy and investments in this space including UKRI collective funding opportunities.

Speaker biography: Ned Garnett is Associate Director for Research at the Natural Environment Research Council and is responsible for NERC's investments in strategic research programmes and discovery science. Prior to this he was Head of Atmospheric and Polar Sciences, commissioning and managing NERC's investments in this area, with a particular focus on climate change. He led on the NERC partnership with the UK Met Office and been responsible for setting up numerous collaborative programmes including with the Indian Ministry of Earth Sciences on the Changing Water Cycle, the South Asian Monsoon and Pollution in Delhi, and the National Science Foundation, China on Pollution and Health in Beijing.

Talk Session Chairs

Phil Purnell, Professor of Materials and Structures, University of Leeds

See speaker biography page 7.

Anne Velenturf, Impact Fellow, University of Leeds

Anne Velenturf is an impact fellow and the former programme lead of Resource Recovery from Waste. She has a PhD in industrial network development and governance for waste-to-resource innovation. Alongside her academic research and impact activities, Anne runs a consultancy and works as a practitioner on circular business model innovation. Her areas of expertise include circular economy, industrial ecology, governance, business models, and trans-disciplinary research and participation process management

Rachel Marshall, Knowledge Exchange Fellow, Lancaster University

Rachel is a researcher with interests in the sustainable resource use, agriculture and the environment. She works to facilitate knowledge exchange between researchers and stakeholders, including policy makers, industry and the third sector for the N8 AgriFood programme. She previously worked on the RRfW project AVAnD before taking the role as policy fellow for the RRfW programme with responsibilities for authoring policy notes and running events showcasing the policy relevant research emerging from the programme.

Panel session

The panel will discuss and prioritise future research and innovation challenges for resource recovery as part of the transition towards a circular economy. Some challenges already identified by the RRfW programme are presented on page 19.

Chair: Libby Peake, Senior policy adviser, Green Alliance

Libby Peake is a senior policy adviser on resource stewardship at Green Alliance, a UK based independent charity and think tank focused on achieving ambitious leadership for the environment. There, she works closely with other NGOs, academics and businesses to promote better use of resources throughout the economy. This includes managing the Circular Economy Task Force, a forum for policy, innovation and business thinking on efficient resource use in the UK. She is an expert and trusted commentator on resources and waste topics including: plastic, including marine plastic pollution; packaging; chemicals regulation; resource efficiency; and recycling. Before joining Green Alliance, Libby spent ten years at Resource Media, an environmental publishing house that promotes the use of waste as a resource.

Adam Read, External Affairs Director, SUEZ

Adam has been SUEZ's External Affairs Director for 18 months working with sector bodies on topical issues. He is supporting the ESA in developing a resource sector deal and led the SUEZ team assisting Defra during the preparation of their Resources & Waste Plan. He sits on numerous working groups, is a regular speaker and author, and a frequent blogger. He has been in the sector for almost 25 years specialising in municipal waste strategy, services, contracts and consultation.

Dr Andy Rees, Head of Waste Strategy, Welsh Government

Andy has 38 years' experience of working in the environmental field, including spending the last 22 years in the area of waste strategy. Andy has been Head of Waste Strategy at the Welsh Government for the last 18 years and is responsible for waste strategy policy and delivery. Andy was awarded an OBE in the Queen's New Year Honours List for 2019 for services to the environment and recycling in Wales. In addition, in 2017 he received the Material Recycling World magazine's 'Editor's Choice Award', and the Chartered Institution of Wastes Management's 'Waste and Resources Leader' of the year award, in recognition of Wales' success in recycling.

Jacqui Murray, Deputy Director - Faraday Battery Challenge, Innovate UK

A specialist in materials engineering, regulation and transformational change. Jacqui spent the early part of her career as a metallurgist in the Steel industry. Following her M.Eng. and MBA, she moved into industrial environmental regulation policy for the Environment Agency and Welsh Government. In August 2017, she stepped up as co-Interim Director for the £246 million Faraday Battery Challenge Programme, kicking off the programme to transform the UK world-leading in automotive battery technology by 2027. She continues as Deputy Director for Innovate UK, now part of UK Research and Innovation.

Dr Jim Wharfe, Environmental Consultant

Jim is currently an independent environmental consultant following a career of more than 40 years with Government departments and environmental regulatory agencies. During this time he held executive management positions with the Environment Agency where his roles included the Head of the National Centre on Ecotoxicology and Hazardous Substances, and the Head of their Scientific Programmes. He has a long association with a number of the UK Research Councils, particularly the Natural Environmental Research Council, where he served on their Science and Innovation Strategy Board and is a long standing member of their peer review college. He currently sits on several of NERC's Programme Executive Boards and Advisory Groups, and has chaired a number of their moderating panels and Science Advisory Committees. More recently Jim has worked with the UK Water Partnership and serves on their Research and Innovation Group.

The Resource Recovery from Waste (RRfW) Programme

The £7M Resource Recovery from Waste programme addressed the strategic challenge of bringing the exploitation of renewable and non-renewable natural resources and the generation of wastes within the Earth's environmental limits. The programme delivered strategic science in support of a paradigm shift in the recovery of resources from waste landscape, driven by benefits to the environment and society rather than by economics alone.

Resource Recovery from Waste aspires to a circular economy in which waste and resource management contribute to clean growth, human well-being and a resilient environment. Achieving a circular economy will require radical changes in how resources are extracted, transformed through design, production and consumption, and treated, recovered and recycled when products reach their end-of-use.

Realising a circular economy requires transformative economic, social and environmental actions from people across society. Resource Recovery from Waste brought together a diverse set of six major and seven smaller projects on secondary mining, soil restoration, technologies to recover all materials from mixed waste flows and zero waste residue, and approaches for whole-system design and sustainability assessment. A community of researchers from engineering, environmental and social sciences, and business schools has emerged. Organisations from government, industry and third sector co-created responses and embedded them in policy and business activities. This has produced radical new visions, approaches, tools and technologies in response to the global challenge of resource management (see below, and presentations at the conference).

Further details on the RRfW programme, including its contributing projects (AVAnD, B3, CVORR, INSPIRE, MeteoRR, R3AW) and mini-projects, can be found on the RRfW website.

Radical ideas and exciting discoveries

Resource Recovery from Waste set out to contribute to radical change in waste and resource management. The highly diverse themes, people and projects brought together in the programme offered a fertile context within which the following radical ideas and exciting discoveries emerged.

There are thousands of valuable resource hubs in the UK alone. Our legacy of landfilled industrial, municipal, metallurgical and mining wastes are valuable resource hubs that contain important elements for clean growth, many of which are currently 100% imported into the UK.

Capitalising on the resource potential. Regulation should shift away from a primary focus on waste treatment to embrace the economic, social and environmental opportunities associated with resource recovery.

Integrated technologies for integrated resource flows. Many resource flows and products contain tightly-bound mixtures of biological and "technical" materials, and the concentration of materials targeted for recovery can be low. A new generation of technologies has been developed that enables the integrated recovery of minerals and

metals, biomass and/or aggregates while generating power, treating wastewater and/or restoring soils and land.

Extended carbon benefits of resource recovery. Resource efficiency is the single greatest potential contributor to decarbonisation of the UK economy. Moreover, bioelectrochemical technologies can turn CO_2 into chemical feedstock, while alkaline soils can become carbon sinks through resource recovery processes.

Low-impact, low-energy, low-cost. The integrated design of many RRfW processes optimises the use of waste materials, power, heat and even "waste-light", while external energy input and costs are reduced. The use of waste-based components in resource recovery systems helps to further limit costs and enhance technology effectiveness. Integrated systems require sponsors to overcome the 'silo' approach and be prepared to share both risks and benefits.

Extreme recovery. Technologies tested in the lab and/or field proved to be extremely effective with recovery rates of targeted materials of 95-99%. 'Second life' use of recovered materials into value products has been shown in case histories, removing some of the barriers to change.

Bio-related technology for targeted recovery. Technologies incorporated the selection and use of microbes that are naturally responsible for the mobilisation of resources such as precious- and base metals. Conversely, neo-nanoparticles with catalytic properties for resource recovery or green chemical synthesis can also be engineered with the help from microbes and integrated into systems for resource recovery.

Quality matters. Waste management should focus on enhancing the quality of resources recovered and reused rather than the mass or volume of material processed. Large volumes of waste are sometimes unavoidable, such as with acid mine drainage, but the majority of such waste streams can be valorised by focusing on the qualitative characteristics of all materials therein.

Multidimensional value: A major barrier to recovering materials is the lack of methods that can account for creation of value in social, environmental and technical domains, in addition to economic aspects; we have developed a framework that can address this.

There are multiple types of circular economies. There are different types of circular economy that can be realised, in which different positive (benefits) and negative (impacts) values are created. The economic, social, environmental and technical values that are created and destroyed in circular economy scenarios should be assessed and integrated into decision-making processes.

Circular economy is an engine for value redistribution. Monetary benefits generated through the preservation of technical value of materials and products should be used for the creation of net-environmental and social gains, and this is a stepping stone to the ideal situation in which the creation of social and environmental benefits through better resource use are rewarded economically.

Developing the policy environment

The RRfW programme has assessed the political and regulatory challenges to adopting new resource recovery technologies, processes and systems. Multiple industrial, commercial and governmental commentators expect resource recovery to deliver billions of pounds of financial savings for businesses and create tens of thousands of high-quality jobs. It also has the potential to improve the UK's resource security and reduce environmental impacts. Despite these clear benefits, the transition remains slow and the current policy landscape poses major challenges. RRfW makes the following overarching policy recommendations:

- **Integrate assessment of multi-dimensional costs and benefits into decision making:** Resource recovery business cases rest on the generation of social, environmental and technical costs and benefits, as well as those in the economic dimension. While in some cases these costs and benefits can be converted to economic values or 'monetised', in many cases they cannot and this should not preclude them from analysis: the model developed by the CVORR project allows just this. By incorporating values that account for social and environmental net gain into (economic) growth forecasting models the sustainability of policies can be better assessed.

- **Collect data on stocks and flows of material quantity and quality:** Poor data availability, quality and coherence are known issues in measuring resource flows, particularly for recovered materials. Better data must be collected for the express purpose of calculating the quantities and qualities of stocks and flows of primary and secondary resources within our economy. Material flows need to be measured from point of extraction/production, through fabrication, use and end-of-life options, so that a full life cycle overview is available for all products.

- **Launch Office for Resource Stewardship to coordinate government action:** Circular economy policy and regulations across the UK nations are diverse, currently driven by varying desires to comply with EU directives. An Office for Resource Stewardship could formalise collaboration between government structures such as Defra, BEIS, NIC and the EA. It should monitor stocks and flows of primary, secondary and critical resources, carry out multi-dimensional value assessments in priority sectors, and advise on cross-departmental interventions for circular economy. This implies a change in governance culture around circular economy, from a focus on health and environment at the 'end of pipe' stage to include economic and technical aspects throughout the supply chain.

- **Knowledge, skills and infrastructure for a circular economy:** A "Circular Economy Network" should be established to build a comprehensive programme of business support, disseminating essential circular economy knowledge and skills to companies throughout the UK. The Resources and Waste Strategy could catalyse the network, which also aligns with objectives in the Industrial and Clean Growth Strategies, delivering cross-departmental benefits. This would facilitate industries in developing resource efficient (e.g. zero waste) sustainable supply chains, waste minimisation, innovative circular business models, the uptake of clean technologies, and industrial symbiosis.

Two open-access technical policy notes have also been published by RRfW: *Making the most of industrial wastes: strengthening resource security of valuable metals for clean growth in the UK* (Marshall *et al*. 2018a) and *The organic waste gold rush: optimising resource recovery in the UK bioeconomy* (Marshall *et al*. 2018b).

Future research and innovation challenges

The Resource Recovery from Waste programme has made significant steps in supporting the radical change needed in waste and resource management landscape for a transition to a circular economy. But challenges still remain.

- A persistent challenge is managing the support of and collaboration between the stakeholders – materials processors, product designers, retailers, consumers, waste managers and secondary material processors – necessary to implement circular economy. Practical guidance for each is underdeveloped, especially with regard to accessing the benefits of a circular economy. Supply chains should be integrated to connect waste producers and users.
- Product design paradigms need to rank the ability to upgrade, repair, dismantle and recover materials equally with economic, aesthetic or technical performance. Wastes can be 'designed out' of the economy through improved durability and recyclability of products.
- Waste processing processes and technologies need further development, aimed at processing complete waste matrices, recovering all resources and leaving zero waste residue. Particular challenges remain for textiles, metals (faster acting leaching technologies), plastics (methods for separation, recognition and recycling), and construction wastes (recovery processes for bulk aggregates).
- Business models exist that contribute to solving global sustainability issues but need to be communicated and operationalised for firms along the supply chain. These can only be implemented with a better understanding of circular economy infrastructures and their relations to wider industry, via UK Research and Innovation.
- Data on the quantities, quality, and location in time and space of materials, resources and wastes needs to be coherently collected at local, regional and national scales. The use of digital and data technologies such as blockchain could make data collection, management and assessment more secure and reliable, and less costly and onerous.
- Better and consistent metrics, indicators and criteria need to be decided upon to measure environmental, social and economic values, to help integrate the creation of social and environmental benefits from resource efficiency into government and industrial policy. Consistent use of these metrics would also aid the development of strategies to implement international governance to preserve planetary boundaries (beyond climate change and carbon).
- Energy solutions: invent, scale up and industrialise processes using CO_2, more affordable low-carbon energy solutions; upgrade pyrolysis oil to enable wider use