RSC INTEREST GROUP
ENVIRONMENTAL CHEMISTRY

January 2022

Environmental Chemistry Group
Bulletin

Articles. **Eliana Molina Ramirez** *et al.* dig up the biogeochemistry of mercury from artisanal mining; **Harrison Frost** explores microplastics as vectors for metals in the environment; and the Environment, Sustainability and Energy Division (ESED) Early Career Award winner, **Chiara Giorio**, looks at indoor air quality.

Environmental Briefs. **Borbála Szabó** revives the value of variance. **Hattie Brunning** assess pathways for polymers to enter the environment. **Celeste Felion** analyses rapid, low-cost biosensors. **Kate Fell** considers ultrasound in sample preparation.

Meeting reports. We report on five scientific webinars and one outreach event, covering topics from microplastics to wastewater-based epidemiology.

Upcoming meetings. We invite you to three meetings, two **on consecutive days** (in March): our 2022 Distinguished Guest Lecture, and ‘The Analysis of Complex Environmental Matrices’.

Also in this issue. Chair’s report with introductions to the new committee members; our first diversity statement; an interview with **John Collins** from the Environment Agency; an ESED report summary on critical raw materials.

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ECG *Bulletin*

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Environmental Chemistry Group

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Report

Chair's report for 2021

Rowena Fletcher-Wood (Freelance science communicator, rowena.fletcherwood@gmail.com)

In 2021, the Environmental Chemistry Group Committee celebrated its 200th committee meeting, 25 years of *Bulletins,* and published its first Diversity, Accessibility and Inclusivity statement. Due to the pandemic, and the subsequent move to online events, the committee is considering more hybrid events in future.

The ECG is pleased to welcome three new committee members: **Dr Pablo Campo-Moreno** (Cranfield University), who investigates the fate and transport of nutrients and contaminants of emerging concern in water, soils, and sediments; **Dr Stephanie Powley** (British American Tobacco), an analytical chemist with a background in marine environmental chemistry. She has an interest in outreach and is supporting the ECG website; **Irene O'Callaghan** (University College Cork) is a postgraduate researcher focusing on fates and impacts of emerging contaminants and trace metals on aquatic benthic macroinvertebrates – she is joining the ECG *Bulletin* editorial team.

In 2022, we will say goodbye to three current committee members: **Dr Laura Newsome**, whose invaluable contribution has included setting up, populating and maintaining the ECG website, and contributing to our 2019 Distinguished Guest Lecture on radioactive waste disposal. **Dr Roger Reeve** moves on after serving an incredible 15 years on the committee and contributing to numerous events, in particular, the Analysis of Complex Matrices series, and ongoing collaborations with the Water Science Forum and Separation Science Group. A longstanding editor, he has contributed to 27 *Bulletin* issues. **Dr Tom Sizmur** also leaves after 7 years. After serving as Chair, he is our Vice Chair and *Bulletin* commissioning editor, and has contributed to a wide scope of ECG events, including #EnvChem: Chemistry of the Whole Environment, and Early Careers Researchers meetings.

The committee attended various online events and engaged with the scientific literature to learn about citizen science, diversity, event evaluation, and specialist environmental chemistry topics, and disseminated our findings in Bulletin reports and book reviews.

Our virtual events included **#EnvChem2021: Chemistry of the Whole Environment** on 25th June, a forum for researchers working in environmental chemistry and ecotoxicology, featuring keynote speakers Dr Helena Gomes (University of Nottingham) and Dr Zhugen Yang (Cranfield University), who discussed resource recovery from waste materials and paper-based wastewater epidemiological diagnosis, respectively (see report p. 10). Our **Wastewater Based Epidemiology** Continuing Professional Development Webinar on 9th September hosted Professor Barbara Kasprzyk Hordern (University of Bath) and Dr Alwyn Hart (Environment Agency), who updated the membership on recent advances in these tools, using COVID-19 as a case study. On 17th September, we ran **Chemistry for the Environment**, a joint meeting with the RSC Biotechnology Group which focussed on effecting technological changes in the next ten years that will benefit the environment, and address the challenges scientists face (see report pp. 7-8). Our delayed 2021 **AGM** was hosted on 12th October, alongside a webinar on **Molecular biogeochemistry of soil organic matter: Analytical challenges, integrative approaches, and future perspectives** by Professor Myrna Simpson (University of Toronto). On the 9th June, we co-sponsored **Plastics, From Cradle to Grave – and Resurrection II**, an event led by the Society of Chemical Industry (SCI), which built on our event in 2019, discussing challenges in the sampling, analysis and future use of plastics (p. 9).

On 2nd March, we took part in the **#RSCPoster Twitter Conference**, an annual event that unites the scientific community through sharing research, networking, and debate. Featured poster contributors Juliana Vidal and Paul Kimani later contributed Early Career Briefs on nanostructures of exfoliated biochar and titanium dioxide microspheres (July 2021, pp. 7-10).

Our in-person events included IF Oxford: an outreach event where 6 volunteers ran 6 COVID-safe demonstrations over 2 days to 250-300 members of the public, mostly families (see p. 6). Our featured topics were ocean acidification, microplastic separation and analysis, and air quality monitoring, featuring a citizen science project with Abingdon schools.

Forthcoming events in 2022 include our postponed **Distinguished Guest Lecture** *Disposable Attitude: Electronics in the Environment* on 10th March at Burlington House with **Mr Steve Cottle** (Edwards EMS Ltd) as the Distinguished Guest lecturer.

The *ECG* Interview: John Collins

John Collins is Deputy Director of Evidence Assessment and Evaluation at the Environment Agency.

What inspired you to become a scientist? Science was what I was good at in school. The idea of being at the forefront of knowledge drew me in. I enjoyed watching my dad's favourite television programme, *Tomorrow's World*.

How did you come to specialise in science for the environment? After four years doing development and technical management in industry together with my chemistry background, I was ideally suited to the job of an Inspector of Pollution. Since then, having taken on a whole range of roles across the Environment Agency's remit in local operations and in head office, I am well placed to understand and provide many of the evidence needs for the organisation.

Could you describe your current job? I lead a team which provides the evidence that underpins many of the key decisions, messages, and policy advice for the Environment Agency. The work is very wide-ranging, covering air and land, but predominantly water issues. We publish state of the environment reports, evaluate the effectiveness of waste crime interventions, produce narratives on persistent pollutants, and design chemical indicators for Defra's 25 Year Environment Plan – and much more.

What advice would you give to anyone considering a career in environmental chemistry? Look at the range of possibilities. They are many and varied. They range from working in a lab and doing research to designing chemicals' policies in government and to helping industry understand the impacts of their emissions on the environment. There are many routes to using your skills.

What are some of the challenges facing the environmental chemistry community? For me, there are two world crises we need to address: climate change and biodiversity loss. As I write, we are still trying to get to grips with COVID-19, but we will learn to cope. Climate change and biodiversity loss are potentially existential issues and will need a cross-disciplinary effort to solve. Chemists, and particularly environmental chemists, will play important roles in finding solutions.

What is the most rewarding aspect of your career so far? The Environment Agency is very good at dealing with serious incidents. I spent a significant part of my career in operations management. I led our local Area in Herts and North London through the Buncefield fire. One of the many challenges related to the release, and potential impacts, of perfluorooctanesulfonic acid (PFOS) in fire-fighting foams, so it was useful to have a chemistry background. The incident involved applying science, but also many other activities, working across a wide range of subjects, and dealing with a diverse range of people including cabinet ministers, industrialists, emergency services, and other regulators, as well as looking after my own team. That said, I now get a great deal of satisfaction knowing that the work my team does enables the EA to make important decisions and speak influentially for the environment in many different forums.

If you weren't a scientist, what would you do? A very good question. As I said, I really enjoyed my time in operations management. Maybe there would be something in that. Otherwise, I think it would have to be something creative.

And what do you do when you are not working? One of my main roles is as a taxi driver for my children. When I am not doing that, I enjoy cycling around the forests where I live, sailing when I get the chance, and watching Liverpool FC play football.

Review

Critical Raw Materials: summary of the ESED report

David Owen (TreatChem Limited, david.owen@treatchem.co.uk)

The RSC's 20-page Environment, Sustainability and Energy Division (ESED) August 2021 report, ***Decarbonisation: materials and circularity challenges for clean technologies (The role of Critical Raw Materials in reaching net-zero emissions)***, examines what is needed to balance free will in markets whilst managing the resource base of critical raw materials.

The challenge is to reset our economic perspective, moving away from a linear economic model and towards a circular economic model. This may prove more difficult than anticipated because economic imperatives and international self-interest may be bigger obstacles than science-based solutions can address. It will require some lateral thinking about cooperation between government, industry, and the scientific community to introduce these changes.

A significant amount of research and development is dedicated to the design of recovery technologies such as novel chemistries, engineering, reimagining product life cycles, and the recovery of potentially valuable minor components lost by current waste management techniques.

This is all good, but without a coherent strategy to enable cooperation between competing companies to find the most viable way forward, the objectives are in danger of becoming unfulfilled because of vested self-interests or '*beggar thy neighbour'* policies and practice.

The power to resolve these challenges lies with international and local politicians. To ensure the system works for everyone, with little or no inequality between providers of services, they will need to ensure accurate and thorough information sharing takes place, and best practices are applied.

Figure 1. *ESED report: Decarbonisation: materials and circularity challenges for clean technologies.*

The report recommends that the competition between ideas about how best to recycle particular materials is best left between academia and industry. However, there needs to be a significant, legally enforceable framework to direct participants to best practices. This framework will ensure positive outcomes, not only in recovering materials of reusable quality, but also in ensuring planning permission is granted for the sites that will conduct the recycling and the disposal of by-product waste in an ecologically sound and economic fashion.

Reference

Decarbonisation: materials and circularity challenges for clean technologies (The role of Critical Raw Materials in reaching net-zero emissions), ESED, RSC, August 2021; available for free online.

Meeting report

Environmental Chemistry Group webinars

Tom Sizmur (University of Reading, t.sizmur@reading.ac.uk) and Caroline Gauchotte-Lindsay (University of Glasgow, caroline.gauchotte-lindsay@glasgow.ac.uk)

The Environmental Chemistry Group hosted two webinars in autumn 2021 on the topics of wastewater-based epidemiology and the molecular biogeochemistry of soil organic matter.

Wastewater-based epidemiology

The first of our webinars on 9th September saw **Professor Barbara Kasprzyk-Hordern** (University of Bath) and **Dr Glenn Watts**, **Dr Elena Armenise** and **Dr Kate Jackson** (Environment Agency) presented on wastewater-based epidemiology. As the current pandemic has clearly demonstrated, the ability to rapidly monitor the spread of infectious diseases is centrally important for prevention, intervention, and control. One proposed monitoring scheme that has emerged in recent years is wastewater-based epidemiology, which suggests that through analysis of population aggregated wastewater, infectious disease and the emergence of new disease outbreaks can be monitored comprehensively, and in real-time. The webinar provided an overview of the history and various uses of wastewater-based epidemiology and a detailed account of its rapid and necessary adoption by the Environment Agency during the COVID-19 pandemic.

Molecular biogeochemistry of soil organic matter

The second of our webinars on 12th October, coinciding with our 2021 Annual General Meeting, was provided by **Professor Myrna J. Simpson** (University of Toronto) on the use of nuclear magnetic resonance (NMR) spectroscopy and gas chromatography-mass spectrometry (GC-MS) to better understand how soil organic matter is impacted by warming, atmospheric nitrogen deposition, and changes in plant detrital inputs. Soil organic matter is also a major global carbon sink, but how changes in composition will impact overall ecosystem function in the long-term remain highly uncertain. The webinar introduced analytical challenges, integrative approaches, and future perspectives. Conclusions were based on a large body of data, collected over many years.

Meeting report

IF Oxford Science and Ideas Festival

Tom Sizmur (University of Reading, t.sizmur@reading.ac.uk)

On Saturday 9th and Sunday 10th October, Environmental Chemistry Group committee members and volunteers hosted a stand on the topic ‘Oceans and Air’ at the IF Oxford Science and Ideas Festival.

The group has contributed to the event for several years, including in 2020, when the festival was organised online. This year, we provided demonstrations including an ocean acidification demonstration using universal indicator and dry ice, a novel method of separating plastics made from different polymer types based on density, the monitoring of air quality using an established sensor network, handheld monitors and homemade analogues, and the abatement of pollutants using a wet scrubber. We also featured a citizen science project with Abingdon schools, and saw 250-300 members of the public, mostly families, visit the stall and take away samplers for simple air monitoring activities at home.

Meeting report

Chemistry for the Environment

Laura Newsome (University of Exeter, l.newsome@exeter.ac.uk)

The Biotechnology and Environmental Chemistry Interest Groups of the Royal Society of Chemistry joined forces to host 'Chemistry for the Environment', an online event that took place on 17th September.

Increasing evidence suggests that the next ten years will be crucial for reversing the highly damaging effects our industrialised societies have had on our environment. It will certainly be the most important decade in history in terms of the impact of our decisions. The expectation is that scientists will find solutions, but the challenges go far beyond scaling up research. The next generation of scientists will need to break out of the lab and confidently address related issues of policy, funding, and public engagement. This event, targeted at scientists who want to do more for the environment, was organised with three main themes and two discussion panels.

Theme 1: Carbon capture

The event commenced with a talk by **Professor Colin Snape FRSE** (University of Nottingham) on "Adsorbents for CO_2 capture: the challenges and the pitfalls regarding scale-up". Although new CO_2 capture technologies with novel materials are demonstrated in laboratory conditions, many fail to deal with the challenges associated with scale-up, such as chemical and physical stability, minimising adsorbent replacement costs, and dealing with moisture co-adsorption. Any new materials that adsorb CO_2 need, as well as good sorption properties, to account for cost, durability, stability, and kinetics before they can move to pilot scale. The only large-scale demonstration to date has been at the Hadong power station in South Korea, using potassium carbonate-bicarbonate. This, however, requires high regeneration energy, limiting its potential for commercialisation. The talk explained how amine scrubbing is the most mature technology for separating CO_2, but the relatively high costs mean alternative technologies are being sought, such as silica-polyethylenimine, and activated carbons. Professor Snape found treating activated carbon with KOH can double the adsorption capacity. His team also synthesised a successful ultra-microporous CO_2 adsorbent from polyisocyanurate resins (but this has issues with moisture adsorption).

Following this, **Professor Christopher M. Rayner FRSC** (University of Leeds) talked about "Carbon dioxide capture chemistry – from laboratory to power station, and beyond". Here, he described C-Capture Ltd., a company spun out of the University of Leeds in 2009, which developed a new approach for separating CO_2 from large point source emitters. The company is unique in its focus on chemistry rather than engineering. C-Capture have been developing adsorbents based on amines, which present major challenges, particularly with respect to their own environmental impact. Steam use is important, and less is better when it comes to the amount required to regenerate the amines. Carbon capture technology has a 40% lower parasitic load, and lower energy penalty, as well as low corrosivity, minimal environmental impact, and very low degradation rates. This has been scaled up from the lab (~g CO_2/day) to a bioenergy demonstrator plant (~1 tonne CO_2/day), with C-Capture collaborating with Drax power station.

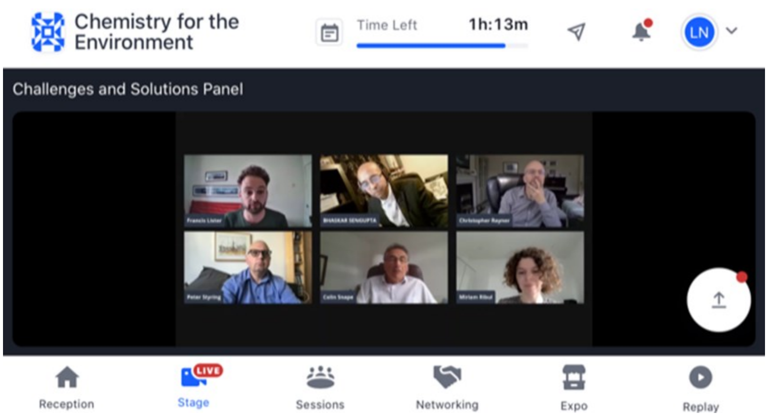
"CO_2 utilisation: driving a renaissance in the chemicals sector" was given by **Professor Peter Styring FRSC** (University of Sheffield). Whilst it is possible to capture CO_2 from large anthropogenic CO_2 point sources and convert it to useful products, this process is currently expensive. However, diminishing costs over time are expected to help us towards a circular economy. Products made from CO_2 are already available and include vodka, hand sanitiser, and synthetic petrol from flue gas (1-butan-ol). Another promising possibility is upgrading of biogas, where CO_2 is removed from the mix by precipitating it as $CaCO_3$, leaving a useful methane product.

Entrepreneurial and policy impact panel

The panel comprised **Kathy Page** (Environment, Science Policy Unit at Royal Society of Chemistry), **Dominic Falcão** (Deep Science Ventures), **Gael Gobaille-Shaw** (Chief Mission Zero Technologies and Supercritical Solutions) and **Sam Olof** (Science Creates Venture). The discussion covered entrepreneurial careers and the need for more electrochemical training. The panel agreed that the next ten years will be crucial for making significant changes to save our environment. Key tasks include sustainable aviation fuel, and energy storage. Due to an innovation gap to achieve the transition to net zero – something that policy makers are not necessarily aware of – we are not yet at the stage where scale-up of technologies is the only issue.

Theme 2: Circular economy

Dr Miriam Ribul (Royal College of Art) spoke on “Multi-stakeholder material systems: designing with materials in 2021”. Dr Ribul introduced life cycle analysis, and how it is ideal to obtain multiple reuses of an indivudal product. As such, new materials should be designed with recycling in mind, including downcycling, where the recycled material is of lower quality and functionality than the original, *e.g.* fabrics for insulation. Her research explores how to convert bio-based waste-derived feedstock into polymers to produce textiles for a circular economy. Dr Ribul and colleagues have produced novel, high-performance biocelluose composites, including a paper-like material from waste. Bio-based recycling complements physical and chemical techniques.



This was followed by “Engineering natural enzymes for the circular recycling of plastics” by **Professor John McGeehan FRSB FRSC** (University of Portsmouth). His team discovered an enzyme, PETase, that can digest PET polymers. Crucially, this enzyme can be engineered. To achieve this, samples from two natural environments were collected. The first sample consisted of gribble worms from Southend pier: these creatures produce enzymes that degrade the lignocellulose wood supports into organic acids. For the second, microbes were harvested from South East Asia mangrove root systems. Professor McGeehan’s team buried plastics in order to harvest bacteria. It was found that the PETase has similarities to another enzyme, cutinase, which breaks down waxy coatings on leaves, *e.g.* in mangroves. Professor McGeehan is now searching for more thermotolerant enzymes and working with GlaxoSmithKline to scale up production.

Theme 3: Metal pollution

The final session began with “Metal pollution from mining: challenges and opportunities” by **Professor Karen Hudson-Edwards** (University of Exeter). She explained how we need metals for green technologies (phones, bikes, electric cars, *etc.*). As, currently, not enough of these are recycled, we turn to mining to meet demand. Mining, in turn, produces wastes, metal pollution, and harms the environment through tailings dam failures. Ongoing research is looking at minerals in mine wastes, how plants adapt to metal pollution, new sustainable ways for recovering metals with green solvents, microorganisms, and how life cycle analysis can improve sustainability.

The final talk, given by **Professor Bhaskar Sen Gupta OBE** (Heriot-Watt University), was on “Solar powered, chemical, and waste-free arsenic removal system for community-level water treatment”. Arsenic contamination was first noticed in the 1970s, and was linked to the development of a hybrid rice variety that increased yield but demanded much more fertiliser and groundwater. The mitigation technology he developed is simple: it involves pumping water to the surface, mixing it with oxygen, then returning it to ground, where additional O_2 supports As(III)- and Fe(II)-oxidising bacteria to precipitate Fe(III) minerals that sorb aqueous As(V). These pumps are solar powered and have been used in Cambodia, Malaysia, Bangladesh, and Mexico.

Challenges and solutions panel

Finally, the speakers joined together to highlight challenges that are common to all environmental issues and to share best practices for overcoming them. Interacting with politicians was one of the items discussed – to do so successfully, the scientific message needs to be related in clear and simple language, and focused towards the main political interest (which is almost always economics). If working in other countries, it is also essential to have a local partner to understand the issues and the bigger picture (*e.g.* local conditions, byproducts available). In order to achieve success for the environment, we should work with a range of people from companies to environmental groups – and having an independent life cycle analysis really supports getting buy-in from a diverse range of parties.

Organising committee

Francis Lister, Mary K. Phillips-Jones, Klaus Rumple (RSC Biotechnology Group), Laura Newsome (RSC Environmental Chemistry Group) and Ben Reeve.

Meeting report

Plastics, from Cradle to Grave – and Resurrection II

Caroline Gauchotte-Lindsay (University of Glasgow, caroline.gauchotte-lindsay@glasgow.ac.uk)

This one-day conference was held virtually on 9th June 2021, hosted by the Society of Chemical Industry (SCI) (https://www.soci.org) and organised by the SCI Environment, Health, Safety and Food groups and the RSC's Environmental Chemistry, Toxicology, and Food Chemistry groups. The event was the second in a series started in June 2019. Aimed at the civil service, academia and industry, it seeks to address challenges around the current use of plastics, their toxicology and standardisation, the complex issues of sampling and analysis of plastic debris and the future of plastic usage.

The conference comprised three sessions with three talks of 15 to 20 minutes each and a 15-minute final discussion. The exciting principle behind this meeting is that it brings together all stakeholders along the life cycle of plastics.

The conference mainly focused on microplastics. Their presence in drinking water was discussed from both exposure and regulatory perspectives. **Dr Peter Marsden** (Drinking Water Inspectorate) illustrated the findings and recommendations of the 2019 WHO report on microplastics in drinking water. Then **Dr Pablo Campo-Moreno** (Cranfield University) focused on removal mechanisms of microplastics and their efficiency during the coagulation-flocculation of raw water, the first processing stage in a water treatment works. Current drinking water treatments successfully retain microplastics larger than 50 μm; the presence of smaller plastics (nanoplastics) and their impact on human health is still, however, unclear. **Dr Nathalie Welden** (University of Glasgow) discussed the potential impacts of exposure to plastics. Aside from drinking water, other routes of exposure for humans include food ingestion and airborne inhalation. Acute effects, however, have only been observed amongst people exposed to very high concentrations, such as those who wear prosthetics or work in plastic manufactures. These situations are not representative of environmental exposure. Dr Welden also discussed the impact of microplastics on environmental ecosystems. Microplastics can cause mortality and disrupt behaviour and reproduction; however, these effects vary greatly across different species. As for humans, accurate exposure is difficult to assess, model, and reproduce in laboratory experiments, leaving no clear way to assess the impact of microplastics on the environment and human health. Nevertheless, Dr Welden pointed out that we do not need to wait on filling data gaps to start making changes that would benefit both our health and the environment. **Professor Colin Moffat** (Marine Scotland) presented work carried out in Scottish waters to monitor and remove microplastics.

Removal of microplastics from the environment is the final link in a chain that starts at the production stage. The second topic of the day focused on mitigating pollution further up this chain. **Stuart Foster** (Recoup) provided a policy and politics update on plastics and packaging for 2021, while **Judy Proctor** (Environment Agency) closed the day, presenting the Agency's vision on reducing plastics in the environment. Examples of remedial actions were also discussed in more detail during the meeting. **Mike Simmonds** presented the plastic-free London project and the campaigning issues they have encountered, while **David Newman** (Bio-based and Biodegradable Industries Association) introduced the audience to compostable packaging and food waste management.

Public awareness on plastics pollution is growing; as such, policy agenda is likely to have positive environmental consequences. It is also important that we do not underplay the enabling role of plastics in our societies, particularly when it comes to public health. **Dr Anne Woolridge** (Independent Safety Services) gave a presentation on balancing benefits and risks of plastics in healthcare.

The conference was attended consistently throughout the day by an audience of 50 delegates across academia, industry, and the public sector. The organisers are already discussing the third edition to be conducted online in 2022.

Find out more: https://www.soci.org/events/plastics-from-cradle-to-grave--and-resurrection-ii

Meeting report

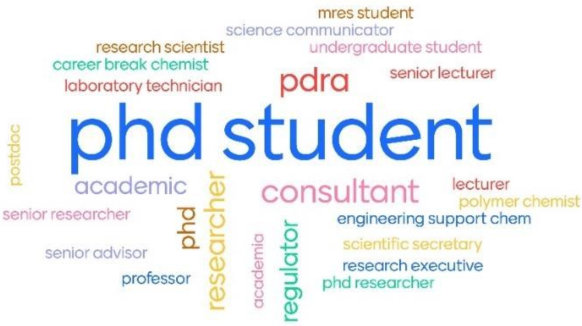
#EnvChem2021: Chemistry of the Whole Environment Research

Tom Sizmur (University of Reading, t.sizmur@reading.ac.uk) and Dominik Weiss (Imperial College London, d.weiss@imperial.ac.uk)

Now in its third year, #EnvChem is quickly becoming a destination for environmental chemists to showcase their latest findings. The delegates and speakers in 2021 were once again drawn from across the globe to join this conference, held online for the second year running. We received 67 abstracts and 244 registrations. A large portion of the audience comprised PhD students, with representative delegates from academia, industry, and regulatory agencies, as shown in the word cloud on the right. The presentations spanned the breadth of environmental chemistry, with the talks interspersed with three “creative display presentation” sessions akin to posters.

The first talk of the day was given by **Borbála Szabó**, who presented her work on inter-individual variance as a source of information in ecotoxicology (see pp. 23-24). While high variance is typically considered a nuisance, her work shows that valuable information can still be extracted from the data. Monitoring growth, reproduction and behaviour of *Folsomia candida* (Collembola) following exposure to sub-lethal doses of insecticide (Trebon 30 EC) showed consistent variance changes through generations in two parameters: clutch size and growth-reproduction trade-off. Next, **Wojciech Mrozik** presented on hazards from lithium-ion batteries, now found in many aspects of our lives, from portable electronic devices to electric vehicles. His investigations incorporated nail penetration experiments carried out at various stages of charge.

This was followed by the first creative display presentations in breakout rooms. **Aaron G. Schultz** presented his work on the developmental and cardiovascular toxicity of PVP-coated silver nanoparticles of different sizes (50nm and 5nm) and uncoated copper oxide nanoparticles on zebrafish (*Danio rerio*) embryos.



(Word cloud © H Gomes)

Benjamin Bálint described his studies to determine the effects of selenium on *F. candida* (*e.g.* mortality, reproduction, lipid peroxidation) and to verify if there is a difference between the effects of the two selenium oxidation states. **Friday Ojie Ehiguese** discussed the effects of exposure to polycyclic compounds galaxolide and tonalide on clams (*Ruditapes philippinarum*). A battery of biomarkers were measured in digestive glands related with xenobiotics detoxification, oxidative stress, and genotoxicity. **Harriet Sleight** described a study aimed to systematically review and analyse all of the existing empirical data for the uptake of pharmaceuticals in terrestrial crops. **Hattie Brunning** presented her work on identifying water-soluble polymers used in common UK household products and disposed down the drain, and on assessing the resulting environmental exposure and risk (see pp. 25-26). **Huan V. Doan** reported on the synthesis of a novel complex metal-organic framework from waste feedstock which exhibited excellent catalytic performance in the photodegradation of toxic pollutants (*e.g.* anionic azo dyes) in water. **Neha Mehta** explored the feasibility of biomethane for the decarbonisation of heat generation in Northern Ireland. **Alice Marshall** presented a high-resolution assessment of plant uptake and distribution of priority compounds *via* the novel application of single-cell mass spectrometry. **Jay C. Bullen** described a study on arsenic detection in contaminated groundwater in Mexico using a low-cost, commercial, open-source potentiostat based on Arduino technology. **Niall Marsay** reported on the development of a rapid non-invasive tool for assessing the presence and recovery of heavy metals and complex chemical mixtures from brownfield sites. The current surveying method involves collecting samples that are then sent to an accredited laboratory for ICP and GC-MS analysis. Portable visible-near infrared (Vis-NIR) and mid-infrared spectroscopy (MIR) show promise as a rapid, low-cost method to speed up the first stages of site surveying.

Back in the main room, and after a short break, **Marc Fadel** delivered a talk on his work on characterising the chemical composition and health risk of fine particulate matter ($PM_{2.5}$) from samples collected for a year in two urban sites under industrial influence in Lebanon. **Celeste Felion** described how trace analysis of organic micropollutants in environmental research and monitoring currently relies on chromatographic techniques, which can be expensive to implement and operate (see pp. 27-28). Her group developed a simple colorimetric assay based on gold nanoparticles using an available aptamer to monitor 17β-estradiol biodegradation.

The first keynote speaker, **Dr Helena Gomes** (University of Nottingham) then delivered a presentation on waste resource recovery, framing her talk on the transition from a linear to a circular economy and the obstacles to this process. She focused on a few key case studies, including vanadium, a critical raw material used in redox flow batteries that is also an emerging contaminant. Technologies for the recovery of vanadium from waste streams were introduced, such as microorganisms for increasing metal solubilisation for enhanced bioleaching from steel slag and municipal solid waste incineration residues. Dr Gomes' interactive talk employed the 'Mentimeter' app to collect audience opinions at key points.

After lunch, **Albern Tan** presented his work on the removal of phosphate dissolved in water. Phosphate is a key pollutant contributing to eutrophication, which in turn leads to algal blooms that harm ecosystems and impact water quality. Novel mineral-hydrogel composites of calcium alginate, calcium phosphate, and wollastonite, a naturally occurring calcium silicate mineral, were synthesised and tested to provide new sustainable ways to remove and control phosphate in water. Then, **Alexander Tait** described his work investigating the chemical speciation of mercury in a contaminated canal bed sediment from the River Weaver (Cheshire, UK) using a sequential extraction procedure in combination with ICP-MS and XAFS, with a view to establish the impact of iron nanoparticles and biostimulation.

This was followed by our second round of creative display presentations. **Theodora Nah** presented her research on the formation of light absorbing secondary organic aerosols (brown carbon) from the aqueous-phase nitrate-mediated photooxidation of phenolic compounds. **Megan Griffiths** reported on the acute toxicity and risk of individual plant-produced alkaloids to *Daphnia magna*, focusing on the longer term reproductive effects of a representative alkaloid, sparteine. **Shweta Gehlout** investigated two kinds of agriculturally-relevant iron oxide nanoparticles, biogenic and chemically synthesised, for their potential acute and sub-lethal effects on zebrafish (*Danio rerio*) embryos at increasing test concentrations. **Alexandra Richardson** described the development and application of a miniaturised 3D-printed passive sampler device for monitoring of emerging contaminants of concern in river water. **Astrid Solvåg Nesse** focused on developing a method for the quantitative determination of 16 antibiotics and steroid hormones and applied it to digestates from 14 Norwegian commercial biogas plants. **Kerry Sims** presented the recently developed Prioritisation and Early Warning System (PEWS) for chemicals of emerging concern in England. PEWS was created by assessing each substance in terms of its use, fate and ecotoxicology to ensure the appropriate regulatory focus on individual and groups of substances of emerging concern. **Ahmed Shalan** described his research on Ag-CdSe/GO nanocomposites in cellulose acetate (Ag-CdSe/GO@CA) and their characterisation in terms of structural, morphological, and photocatalytic properties, with the aim to use them to aid the photochemical degradation of malachite green in wastewater treatment. **Samantha Richardson** presented on the development of a simple paper-based microfluidic device for the detection of phosphates in freshwater systems, suitable for citizen-led real-world monitoring. **Celeste Magallanes** focused on the detection of Pb^{2+} in water by means of polyelectrolyte assemblies constructed by a drop casting technique on screen-printed electrodes. She used electrochemical impedance spectroscopy (EIS) for the final characterisation of the system after the interaction of Pb^{2+} with the polyelectrolyte assemblies. **Sophie Purser** introduced the use of Laser Dispersion Spectroscopy (LDS) for ambient emissions monitoring. LDS is capable of providing continuous measurements in real time across an area of ~ 1km^2 in almost all weather conditions with a precision below 5 ppb.

After the break, **Helena Rapp Wright** presented her results from a year-long study and risk assessment of contaminants of emerging concern at ng/L to μg/L concentrations in a range of aquatic matrices in Ireland.

Samples for surface waters and wastewater (both influent and effluent) were collected monthly for a year from a rural and an urban influenced area in Ireland.

This was followed by the third and final set of creative display presentations. **Luke Woodliffe** discussed the synthesis and characterisation of magnetic framework composites for carbon capture, focusing on porous and non-porous microspheres, their surface functionalisation and induction heating studies. **Alejandra Bouzas-Monroy** used global monitoring data to assess the ecotoxicological risks of pharmaceuticals in rivers. **Katie O'Rourke** assessed both acute and chronic effects of several pharmaceuticals (diclofenac, metformin, carbamazepine and gabapentin) and their mixtures on the physiology of *Daphnia magna*. **Mathavan Vickneswaran** reported on the best methods to extract targeted pesticide analytes from the soil samples, focusing in particular on comparing the QuEChERS and Dutch Mini-Luke extraction methods. **Melanie Egli** used rapid direct injection LC-MS/MS to investigate the contamination of the river Thames and five of its tributaries in 2019 and 2020, and to assess the environmental impact of the pandemic on detected levels of antidepressants, pain, and anti-inflammatory medications (NSAIDs), and pesticides in river water. **Narinj Taghiyeva** described the removal of pesticides from aqueous solution using a modified montmorillonite (MMT) clay. The potential of acid- and base-activated MMTs for removing benzofuranyl methyl carbamate was tested against non-activated MMT in batch experiments. **Ping-I Chou** investigated the effects of bicarbonate on arsenic mobilisation in managed aquifer recharge systems. The effects of different bicarbonate concentrations (0.01 mM, 0.1 mM, 1 mM, and 10 mM) on the dissolution of arsenopyrite and the formation of nanoscale iron-containing secondary minerals were assessed. **Rachel Little** presented laboratory experiments to determine the rate of aqueous photolytic degradation of metronidazole and its products. **Kate Fell** discussed the novel use of a sonotrode device, which applies indirect sonication without being directly submerged in the sample, for extraction of emerging pharmaceutical compounds in biosolid samples (see pp. 29-30). **Shuai Guo** investigated the distribution and retained amount of benzo[a]pyrene in mangrove leaf surfaces *in situ* using a novel confocal microscopic fluorescence spectral analysis (CMFSA) system, focusing on *Kandelia obovata*, *Aegiceras corniculatum* and *Avicennia marina* leaves.

To close the conference, **Dr Zhugen Yang** (Cranfield University) provided a keynote presentation on the use of paper-based devices for the rapid diagnosis of wastewater-based epidemiology. This timely talk covered sensitive, rapid, and low cost sensors that can operate with no tubing, no power, and work by lateral flow capillary forces, and are thus ideal for deployment in low resource settings. Dr Yang's research is at the forefront of innovative wastewater testing for SARS CoV-2. There are many advantages over standard techniques, which require samples to be collected and transported to labs prior to concentration, RNA extraction, molecular detection, and data analysis using sophisticated equipment. Dr Yang also provided a number of other applications for his devices, such as the detection of malaria or illicit drugs.

#EnvChem2022

Chemistry of the Whole Environment Research Meeting

A two-day meeting organised by the ECG of the RSC and the Society of Environmental Toxicology and Chemistry with a hybrid component.

Where: University of York **When:** 13th-15th July 2022

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Themes

- Environmental Processes in Soil, Water and Air
- Emerging Contaminants
- Novel techniques
- Atmospheric Chemistry
- Ecotoxicology

Key dates

Abstract submission deadline: 1st March 2022
Early bird registration deadline: 15th April 2022
Standard registration deadline: 13th June 2022

Registration

Fees incl. conference dinner. Non-member in brackets.

Early bird: £165 (£200)
Early bird student: £140
Standard: £215 (£240)
Online only: £65 (£80)

Article

Mercury: history, facts and concerns

Eliana K. Molina Ramirez, Laura Newsome, Karen Hudson-Edwards (Exeter University)

Scientists have been enthralled for centuries studying the profuse diversity of elements, compounds and reactions that shape the world we inhabit. In 1869, Dmitri Mendeleev created the chemistry masterpiece, a comprehensive compilation of all the different atoms in the universe: the Periodic Table. This organises elements according to their reactivity and electronic behaviour, enabling us to predict the properties of undiscovered elements. It was one of the most significant achievements of human thought. However, one element falls out of the box: despite being categorised as a metal, it could not be more different: mercury.

What is mercury?

Mercury is a unique and fascinating metallic element. Unlike other metals, it is a poor conductor, has a low melting point, and is liquid at standard temperature and pressure. This is due to its peculiar electronic configuration; electrons fill up as far as the 6s shell and are strongly influenced by relativistic atomic effects (*1*). The two 6*s* electrons move fast, and are tightly bound to the nucleus, increasing their relative mass, such that they do not contribute significantly to metal-metal bonds. The resulting weak bonding and reluctance to exchange electrons give mercury hints of noble gas behaviour, the best explanation for its liquid state. Mercury also has a high density, and metals like lead or copper float on it, while its high vapour pressure means that it slowly evaporates upon exposure to air. Mercury also has the highest surface tension of all liquids, which inhibits capillary action applied by absorbent materials, making it difficult to clean up spills.

Perhaps the most striking feature of mercury is its extreme toxicity. When it enters a living organism, it can substitute for cofactors in enzymatic reactions, interfering with biochemical transformations and metabolism (*2*). Protein function and ATP production are affected, and cellular activity eventually becomes damaged. This disruption can occur in cells from different organs, but it particularly affects the brain neurons (*3*). Consequently, people suffering from mercury poisoning typically suffer neurological symptoms such as speech difficulties, lack of coordination, vision loss, sensory conflicts, and tremors, among many others. Prolonged exposure to high concentrations of mercury compounds can ultimately lead to death. While all forms of mercury are toxic, organo-mercury compounds such as methylmercury ($MeHg^+$, CH_3Hg^+) are particularly problematic because they accumulate through the food chain, causing concentrations to magnify in higher organisms.

Historical uses

Mercury is a scarce element in the Earth's crust, yet there is evidence of widespread use in ancient cultures. It is most commonly found as cinnabar (mercury sulphide, HgS), a bright red mineral and quintessential ore whose oldest known use is as a pigment. Cinnabar pigments have been found in pictograms of Egyptian tombs, American amulets and ceramics, Greek ointments, Roman cosmetics, and Chinese burials. It is a historical paradox that such a toxic element is used in such a diverse array of applications in medicine. From the 17th to 19th century, mercurous chloride was a popular syphilis treatment in Europe. Other mercury compounds served as dermal antiseptics to treat injuries. Mercury-containing amalgams became prevalent for dental fillings, and the preservative thiomersal (an organomercury derivative) has been used in vaccine manufacturing. Its diverse properties also made mercury popular for many other uses including batteries, switches, thermometers, manometers, light bulbs, household products, fungicides, and even explosives.

European alchemists thought mercury transcended physical boundaries, that it was the main ingredient in all metals, and could undergo transmutation into gold (*4*). Despite this belief, the ancients did discover mercury's amalgamation properties, setting the foundations for its most application today – in artisanal gold mining.

Use in artisanal gold mining

The use of mercury amalgamation to extract precious metals dates back to the Romans, around 50 AD (*5*). Amalgamation is the formation of a mercury alloy with another metal, such as gold. This preferential bonding extracts the precious metal from the ore by generating an amalgam that can be manually separated and burned to isolate the gold – the principal procedure utilised in artisanal and small-scale gold mining (**Figure 1**). This single activity introduced 1220 tonnes of mercury into terrestrial and freshwater environments in 2015 (*6*).

Although mercury's environmental and health effects are now well known, artisanal miners have practised amalgamation for centuries, making it an entrenched tradition that is hard to change. Mercury toxicity has been contested because poisoning becomes evident only after long-term exposure, and this viewpoint interferes with efforts to introduce alternative gold mining techniques, *e.g.* borax extraction (*7*). Consequently, to overcome mercury amalgamation's extensive use, it is necessary to use societal approaches to encourage the appropriation of safer procedures among ancestral mining communities

The biogeochemical cycle

Mercury exists in three oxidation states: Hg^0 (metallic), Hg^+ (mercurous) and Hg^{2+} (mercuric, ionic) mercury. The latter forms a variety of inorganic as well as organometallic compounds (*8*). The speciation of Hg affects its behaviour in the environment and its toxicity.

Metallic mercury vapour is emitted to the atmosphere by natural degassing of the Earth's surface, forest fires, or volcanic activity (**Figure 2**). However, most emissions and releases derive from anthropogenic sources, increasing total atmospheric concentrations to ~450% above natural levels (*6*). In the gaseous phase, mercury is transported by wind over long distances for up to a year before precipitating in aquatic and terrestrial ecosystems as oxidised Hg^{2+} (*9*). For example, in the polar regions, springtime mercury depletion events refer to low concentrations of gaseous elemental mercury due to its active oxidation and deposition onto ice and snow (*10,11*). Such favourable conditions for mercury accumulation pose high risks to humans and wildlife.

After deposition, mercury may undergo transformation. In aerobic conditions, Hg^0 is scarce in soils due to its high volatility and susceptibility to oxidise and, therefore, Hg^{2+} is the most common form (*12*). Hg^{2+} sorbs to soil constituents such as clay particles and organic matter. This process is influenced by several factors including the presence of chloride, dissolved organic carbon, and pH (*13*). After stabilisation, storage may last for decades (*14*).

Figure 1. Artisanal scale gold mining in Colombia located in (A) Pueblo Nuevo, Cauca (B) Buenos Aires, Cauca (C) Mallama, Nariño (Photographs © Pure Earth). (23)

Microorganisms are able to survive in environments with high concentrations of toxic metals and can perform mercury speciation through their metabolism. Many prokaryotes have *mer* genes which confer resistance to mercury (*15*). Certain microorganisms can sequester, reduce, or oxidise mercury. Some microorganisms transform mercury between inorganic and organometallic compounds, producing methylmercury (Figure 2) and demethylating $MeHg^+$ to produce Hg^{2+}. Although many mercury transformation reactions can occur abiotically, methylation is strongly mediated by microbial activity. Genes associated with mercury methylation have been found across a range of redox conditions, including within sulphate-reducing bacteria found in anoxic conditions (*16*). In reduced sulfidic environments, considerable amounts of methylmercury become available for biomagnification up the trophic chain (*15*). This is significant in aquatic systems; biomagnification of $MeHg^+$ in shellfish and fish was discovered to have caused a mass poisoning in Minamata, Japan in the 1950s. Bacteria can also reduce Hg^{2+} back to Hg^0, leading to an increased probability of volatilisation (**Figure 3**).

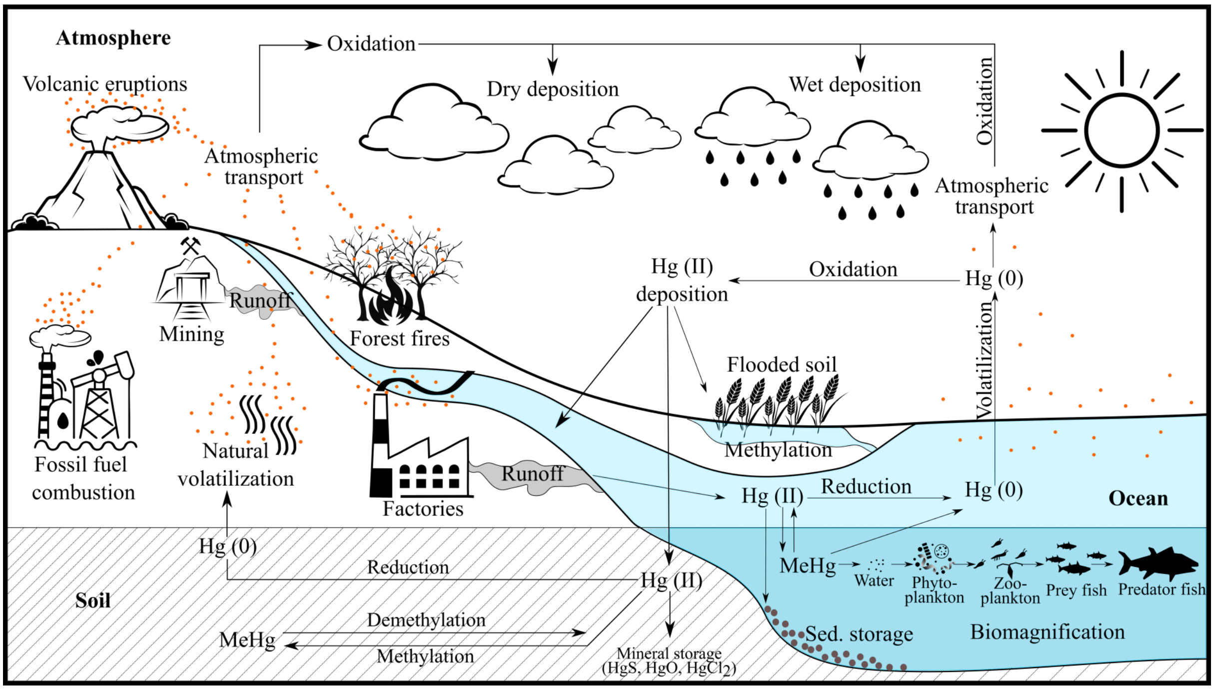

Figure 2. The biogeochemical cycle of mercury (© E. Molina).

Environmental challenges

Mercury pollution is a critical worldwide issue. Its toxic and non-degradable nature cause severe damage to air, water, and soil quality. The recent exclusion of mercury from most industrial applications is a step forward, yet many challenges lay ahead. The last UN Global Mercury Assessment states that the majority of emissions in 2015 occurred in Asia (49%), South America (18%), and Sub-Saharan Africa (16%). Artisanal gold mining accounts for almost 38% of the total anthropogenic global mercury emissions, and fossil fuel combustion for 24% (primarily from coal-burning (21%), as well as other fossil fuels (3%)) (*6*). Implementing control measures for these two biggest contributors is the only effective solution to solving the issue of global mercury pollution.

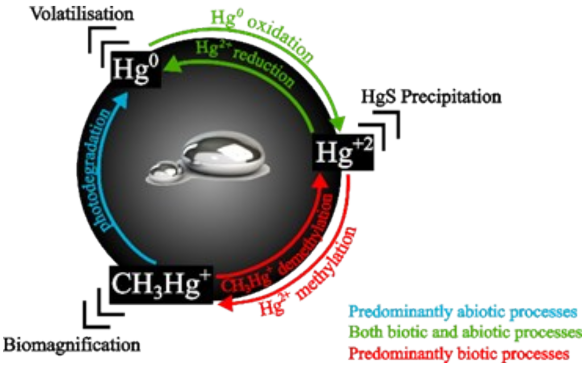

Figure 3. Simplified biogeochemical cycle of mercury showing the role of microorganisms (© E. Molina).

Of course, mercury emissions will inevitably decrease as climate change mitigation measures grow and the use of fossil fuels diminishes with the transition to greener technologies and consequent reduction in carbon combustion. However, the artisanal gold mining sector demands further consideration. Even though the use of mercury in mining is commonly illegal, it still takes place in countries where regulatory oversight and law enforcement is difficult. Overcoming hurdles to reduce or eliminate mercury emissions from the energy and mining sectors will require considerable financial, political, and social efforts.

Further, humanity must address the massive levels of mercury pollution already present in the environment. Scientific research has provided many ideas for how mercury pollution can be remediated. Activated carbon membranes have been used to filter atmospheric mercury, along with similar barrier systems and nanomaterials for water treatment (*17-20*). Teng *et al.* provide an excellent review of physical, chemical, and biological processes for removing or immobilising mercury in soils (*21*):

- replacement of polluted soil for clean soil
- soil vapour extraction (*via* reducing the vapour pressure of soil pores)
- thermal desorption to vaporise and trap mercury by heating

- electrokinetic remediation by establishing an electric field gradient using electrodes
- soil washing to extract and separate contaminants by eluent
- chemical stabilisation using immobilising reagents
- phytoremediation
- microbial remediation for binding, immobilisation, oxidation, transformation, and volatilisation

Some technologies are unaffordable, while others have secondary adverse effects or require further study to reach the point of viable commercialisation. Mercury fixation and uptake by phytoremediation is promising because of the considerable scale of application and minor waste generation it allows (*22*). Future research endeavours for mercury remediation should attempt to be simple, economical, and consider both waste disposal and any adverse environmental effects.

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Article

Sorption of metals onto microplastics

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Microplastics are ubiquitous, persistent environmental contaminants of concern, and may act as vectors for metals in the environment. The sorption of metals onto microplastics is influenced by the physicochemical properties of the microplastics, the chemical properties of the metal, and the chemistry of the environmental medium. Higher distribution coefficients are seen for lead, copper and cadmium. As microplastics undergo weathering, the subsequent formation of new oxygen-containing functional groups and fragmentation will increase sorption capacity. The implications for metal bioavailability to organisms are largely unknown.

Microplastics are synthetic, typically organic polymer (plastic) fragments, 5 mm or smaller along their longest axis. Primary microplastics are specifically manufactured at this size for industrial uses, such as in plastics manufacturing or cleaning abrasives. Secondary microplastics are formed as larger plastic litter undergoes fragmentation over time, due to mechanical, photochemical and, to a lesser extent, biological degradation processes. Microplastics have been found in oceans, rivers, lakes, sediment, soil, sewage sludge, and agricultural soils. Both marine and terrestrial organisms have been observed to ingest microplastics, with mounting evidence of negative health consequences. Their relatively high resistance to chemical and biological degradation means that microplastics might remain in the environment for long time periods, and are expected to accumulate in agricultural soils, river and lake sediments, and oceans. Microplastics, unlike most other environmental pollutants, are heterogenous in shape, size, and chemical composition, possibly containing thousands of additives such as flame retardants, plasticisers, and dyes.

Microplastics as sorbents

Common polymers used to make plastics, such as polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), and polystyrene (PS), were not considered important sorbents of environmental pollutants until recently. However, current research has shown that the microplastics may accumulate chemical pollutants on their surfaces through physical and chemical sorption processes. Most research thus far has focussed on the sorption of organic pollutants such as pharmaceuticals; however, a few key studies have demonstrated that microplastics can sorb metals (*1-5*). This research, although in its infancy, is essential to understanding both the influence of microplastics on the environmental fate of inorganic pollutants, and of the potential impacts of metal-loaded microplastics on organisms.

Metal sorption

In the experimental metal-microplastic systems shown in **Table 1**, the distribution coefficient (K_D) quantifies the partitioning of the metal between aqueous and microplastic-sorbed or solid phases, with a higher K_D value indicating a higher proportion of sorbed metal relative to dissolved metal at equilibrium.

Table 1. *Mean distribution coefficients (K_D; $mL\ g^{-1}$) quantifying sorption of various metals onto microplastics. Values are from available literature data (1-5). Me = metal, PP = polypropylene, PE = polyethylene, HDPE = high-density polyethylene, LDPE = low-density polyethylene, PVC = polyvinyl chloride, PS = polystyrene.*

Me	PP	PE virgin	PE beached	HDPE	LDPE	PVC	PS
Ag		1.2	96.3				
Cd	53.9	0.8	7.9	493	85	322	
Co		0.6	4.0				
Cr	28.5	6.3	112.8				
Cu	44.8	24.3	53.1	340	64.0	796.7	393
Hg		5.8	31.8				
Ni		1.0	8.9				
Pb	270	3.0	183.0	240	324	1841	
Zn	0.2					113.5	234

Experimentally determined K_D values vary greatly both within and between microplastic types. Microplastic composition and metal type account for some, but not all, of the variation. Sorption is a complicated process, and is influenced by a) the physicochemical properties of the microplastics (specific surface area, functional groups, degree of surface photo-oxidation, zeta potential at experimental pH), b) the chemical properties of the metal (concentration, oxidation state, ionic potential), c) the chemistry of the experimental medium (pH, ionic strength, presence of humic substances), and d) the physical conditions of the experiment (contact time, solid-to-liquid ratio, temperature) (*5-8*). Key factors are summarised in **Figure 1**.

Although current research has not been systematic, and data gaps exist, some tentative conclusions about metal sorption onto microplastics may be drawn. The composition of microplastics influences their capacity to sorb metals. PVC contains regularly distributed C-Cl bonds, which are polar due to the high electronegativity of chlorine. Chlorine atoms on the polymer surface create localised centres of partial negative charge, resulting in stronger electrostatic interactions between the microplastic surface and cationic metals (*5*). The relative order of metal sorption is different for each plastic type, however, meaning that functional groups are not the only control. Microplastics with a high specific surface area (SSA) provide a greater number of potential sorption sites relative to mass (*8*). As plastics degrade into smaller fragments over time, their specific surface area, and consequently sorption capacity for pollutants, increases.

Under exposure to ultra-violet radiation, photo-oxidative microplastic weathering takes place. This increases the surface density of oxygen-containing functional groups, which are thought to increase the relative strength of physical sorbent-sorbate interactions, due to the electronegativity of oxygen-creating localised centres (**Figure 1**) (*9*). Biofilm formation on the surfaces of microplastics is also thought to influence sorption capacity over time. Colonising bacteria secrete extracellular polymeric substances, such as polysaccharides, forming a biofilm on the microplastic surface. Biofilms change the surface properties of the microplastics, for example by introducing new hydroxyl, amine, and carboxylic acid groups (*10*).

High initial metal concentrations result in a steep concentration gradient between aqueous and sorbed metal phases, since successful collisions between metal ions and sorption sites are more likely. Microplastics present in highly contaminated environments are therefore predicted to accumulate higher concentrations of metals. Data on the sorption of metals with variable oxidation states, such as chromium and vanadium, onto microplastics are lacking. Cr(VI) and Cr(III) sorption onto microplastics has not yet been compared but are vastly different on the mineral struvite (*11*). For Cr(III), $Cr(OH)^{2+}$ predominates at circumneutral pH, whereas for Cr(VI), CrO^{4-} is the dominant species (*11*). The effect of oxidation state on speciation is expected to alter the relative strength of electrostatic attractions between the metal ions and microplastic surfaces (**Figure 1**).

Ionic potential (the ratio of ionic charge to radius) also influences metal sorption. High ionic potential elements have relatively small ionic radii and high charges. This facilitates stronger electrostatic attractions between sorbate and sorbent (*5*). For beached PE and PVC (**Table 1**), the KD values follow the order Cd < Cu < Pb, which correlates with the ionic potential of the metals. Data for other microplastic types are inconsistent, however.

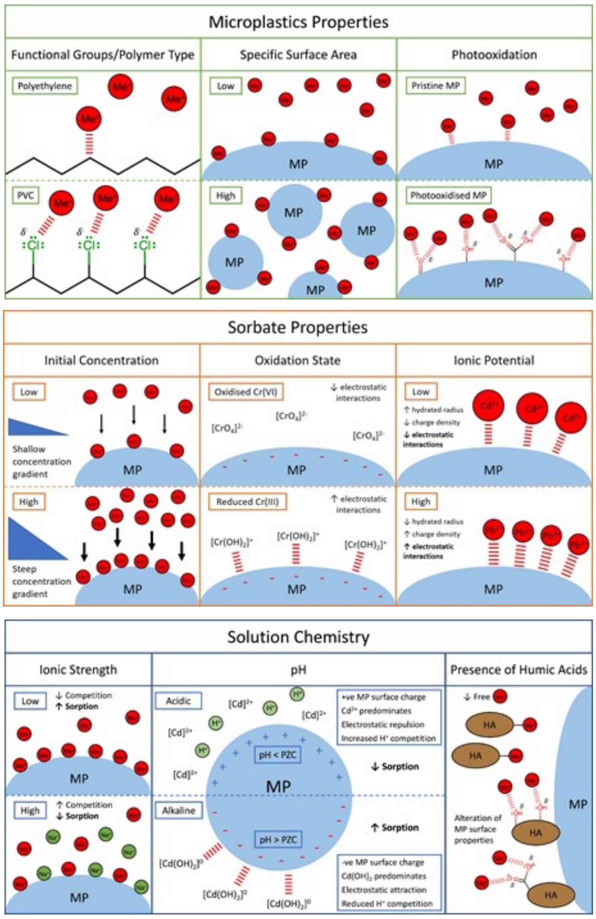

Figure 1. *Schematics of microplastic properties, sorbate properties and solution chemistry (see text for details).*

Solution chemistry can alter both microplastic surface properties and the speciation of the metal, with pH perhaps the most influential factor (*5-9*). Under strongly acidic conditions, there is increased competition between cationic metal ions and hydronium (H_3O^+) ions for sorption sites on the microplastics. The zeta potential of the microplastic surfaces depends on solution pH. The net surface charge of the microplastics becomes increasingly negative as pH increases and, below the point of zero charge (PZC), increasingly positive as pH decreases. **Figure 1** shows the example of Cd, which exists in solution almost entirely as divalent Cd^{2+} ions at $pH < 6$. As pH increases, $CdOH^+$ (pH 6-7) and $Cd(OH)_2$ ($pH > 8$) ions predominate. Where solution pH is below the PZC of the microplastics, electrostatic repulsion between the positively charged microplastic surface and the cationic Cd^{2+} ions are high. Highly ionic solutions, such as seawater, contain high concentrations of competitor ions, such as sodium (Na^+), which can also sorb to the microplastics, occupying sorption sites and decreasing the sorption capacity for metals. The presence of humic acids (HAs) may increase or decrease metal sorption to microplastics. HAs are high molecular weight organic macromolecules with heterogeneous branching structures and oxygen-containing functional groups. HAs may sequester aqueous metals, reducing free metal ion concentration, and consequently decreasing sorption (*7*). Contrarily, HAs may themselves sorb onto microplastics, altering their surface properties by introducing new oxygen-containing functional groups (*6*).

Environmental Implications

Potentially toxic metals, including lead (Pb) and cadmium (Cd), show limited potential to sorb onto pristine microplastic surfaces. However, current evidence suggests that the sorption capacity of microplastics for pollutants increases over time, due to fragmentation, photo-oxidation, and biofilm formation, and it is therefore a multifaceted environmental phenomenon that requires careful, systematic study. Microplastics may act as vectors to transport metals into new environmental spheres or into organisms.

During wastewater treatment, microplastics are removed from the wastewater with a very high efficiency (88-94%). However, the vast majority subsist in sewage sludge (*12*), which is commonly applied to agricultural land as a fertiliser, presenting a pathway for metal-loaded microplastics to be transported into soils. Upon ingestion, the acidic conditions in the digestive tracts of organisms may facilitate the desorption of bound metals, potentially increasing their bioavailability. In soils, plants acidify the rhizosphere, and release root exudates during nutrient uptake. Implications for the mobility and bioavailability of microplastic-bound phytonutrients, especially micronutrients, and phytotoxins, present an important knowledge gap. As plastic production continues to increase year-on-year with no sign of slowing down, microplastics are predicted to continue to accumulate in terrestrial and aquatic environments.

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Article

Energy efficiency *vs* indoor air quality conundrum and possible solutions

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With increased energy demand and the need to improve energy efficiency to limit human-caused climate change, new buildings and renovation of old buildings will need to comply with increasingly strict national standards and guidelines. Given that most of the population spend about 90% of their time indoors, actions to improve energy efficiency should not come at the expense of indoor air quality and comfort.

A large part of the population, especially in urban areas, is exposed to air that does not meet European standards nor World Health Organisation Air Quality Guidelines, with consequences in increased morbidity and mortality mainly due to cardiovascular and pulmonary diseases (*1*). Air pollution kills more than malaria and HIV combined (*1*) or the novel coronavirus disease (COVID-19) on a global scale, and represents the largest environmental risk factor behind premature deaths (*2*). Mounting evidence indicates that COVID-19 might leave a significant proportion of the population with permanent lung damage, making them even more susceptible to the detrimental effects of air pollution (*3*).

Air pollution epidemiology has so far primarily relied on fixed outdoor air quality monitoring stations and static populations which cannot capture the high heterogeneity of personal exposure, as individuals move between different microenvironments, spending as much as 90% of their time indoors (*4*) at home and school/work. Indoor air (gases and particulate matter) contains a complex mixture of abiotic and biotic components that may be generated by indoor sources or may come from outdoor pollution. Indoor generated pollutants include volatile organic compounds (VOCs) as well as aerosols (primarily- and secondarily-sourced) emitted by consumer products (*e.g.* cleaning products, personal care products, furniture, electronics), building materials and wall painting, people-related emissions (*e.g.* exhaled volatile compounds, cigarette smoke including thirdhand exposure), activity-related emissions (*e.g.* cooking) ,and a variety of natural organic particles including living (microbes such as bacteria and fungi) and non-living matter (*e.g.* hairs and fragments of biological tissues).

According to a recent Eurobarometer survey, most European citizens are concerned about air quality with more than two-thirds of respondents (71%) saying they think the EU should propose additional measures to address air quality-related problems in Europe. The European Green Deal has recently introduced the ambitious commitment to a ‘zero-pollution action plan for air, water, and soil’ to protect humans and the environment. Within the same framework, the European Commission adopted a package of proposals for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels, to turn Europe into the first climate-neutral continent by 2050. The UK government has recently announced the target to reduce UK's emissions by at least 68% by 2030 compared to 1990 levels.

Owing to climate change concerns, improving the energy efficiency of homes, public and private buildings is of paramount importance. With new “nearly zero energy” buildings, and retrofits to improve the energy efficiency of old buildings, it may be tempting to increase airtightness. The EU directive 2010/31/EU leaves flexibility in the implementation plan and the choice of how to balance the different factors such as energy consumption, indoor air quality, and comfort levels so each country has its own standards and regulations (*5*). This leads to the so-called “energy efficiency/indoor air quality dilemma” (*6*).

The ventilation rate of a building, usually defined as the rate at which external air flows inside (*5*), is very important in controlling air quality in the indoor environment. The ventilation rate determines the rate at which outdoor pollutants can enter a building but also the rate at which indoor generated pollutants can be dispersed out of a building. Ventilation is also important to reduce the transmission of airborne viruses and bacteria (*7*). With an increase in airtightness, occupants of a building may experience the "sick building syndrome" (*8*), which is characterised by nonspecific symptoms such as headache, eye or nasal irritation, skin rash or itch, malaise, or difficulty concentrating (*9*). As an example, in schools, a satisfactory indoor environment in terms of airflows, temperatures, and air quality is important for children's well-being and their performance in the classroom (*10*, *11*). Ventilation guidelines recommend that CO_2 in indoor spaces should be maintained below 1000 ppm. At these levels, CO_2 is not viewed as a pollutant of concern (even if it is, especially above 2500 ppm), but rather as an indicator of how well both people-related and activity-related indoor pollutants are controlled (*9*, *10*).

To make sure that we do not pursue energy efficiency at the expense of indoor air quality, actions need to be taken to improve both. The use of consumer products labelled as "low emissions", coupled with behaviour changes to reduce emissions related to indoor activities such as cooking, may not be enough to mitigate people-related indoor air emissions (*e.g.* exhaled CO_2 and VOCs). A recent review by Frisk *et al.* (*12*) reported that green retrofits in old residential buildings in Europe and the US that added ventilation and improved temperature comfort led to improved asthma symptoms amongst both adults and children. Introducing mechanical ventilation (*e.g.* a network of ducts powered by fans), with either outdoor air or purified outdoor air for buildings in areas characterised by elevated outdoor pollution, may be the way to go (*13*). While this may increase energy consumption, the trade-off may be in the order of 1-2% decreased energy efficiency (*14*) compared to the situation where there is no mechanical ventilation. A passive and lower-energy alternative would be to manage/control natural ventilation, for example, through air vents and/or dynamic insulation. In the latter case, building envelopes could be made of porous material in which airflow is achieved by pressure differential and heat is transmitted by conductance through the material to the air. With sufficiently small airspeed, the temperature gradient at the external surface may be reduced virtually to zero, and the heat loss would be only that of the ventilation (*5*). There are also instances in which ventilation may promote energy efficiency. As an example, ventilation, either natural or mechanical, may be exploited in the warm seasons for thermal storage/night cooling purposes in which high ventilation rates at night would remove heat from the building envelope that has been stored during the day, so that in the following day the building envelope would absorb heat from the internal air to provide passive cooling (*5*).

Finding a trade-off between energy efficiency and indoor air quality does not seem impossible given the aforementioned solutions and new solutions that may arise with further interdisciplinary research involving — among others — architects, engineers, material scientists, and atmospheric scientists.

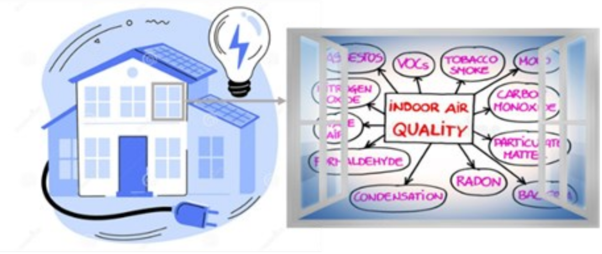

Figure 1. *This infographic depicts the importance of indoor air quality in energy efficient buildings.*

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For other technologies that address problems raised by this author, see https://www.cse.org.uk/advice/advice-and-support/mechanical-ventilation-with-heat-recovery

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Diversity statement

Diversity, Access and Inclusivity Best Practice

The Royal Society of Chemistry Environmental Chemistry Group

June 2021

The **Environmental Chemistry Group** is a voluntary member-led interest group of the **Royal Society of Chemistry**. Our focus is the promotion of interests and expertise of members across all areas of environmental chemistry, including water, soil and atmospheric, natural, anthropogenic, biogenic or geochemical territories, and between peoples of all demographics, including all ethnicities, cultures, genders, sexualities, geographies, abilities, and career stages.

We are dedicated to supporting and increasing inclusion, access and diversity in environmental chemistry. We believe that for the chemical sciences to prosper, they must attract, develop and retain a diverse range of talented people.

This statement and the following strategy are based upon those of the Royal Society of Chemistry: https://www.rsc.org/globalassets/22-new-perspectives/talent/inclusion-and-diversity/strategy/rsc-inclusion-diversity-strategy-2025.pdf

The ECG Approach

The remit of the Environmental Chemistry Group involves the organisation and delivery of scientific meetings, outreach, and the publication of scientific texts in our biannual *Bulletin*. We offer bursaries and support for some events, such as supporting access for early career researchers and retired members. We also represent expertise on committees and recognise the achievements of those in the field of environmental chemistry, such as by the award of our annual Distinguished Guest Lecture medal. As such, our efforts are directed towards:

- Promoting inclusive language, such as avoidance of ableist terms, and sensitivity towards use of pronouns
- Working from a diverse committee of individuals and backgrounds
- Creating events and publishing works that showcase and support a diverse community of speakers and authors

Some of the specific steps that we are integrating into our practices are summarised in the the RSC publication *Quick guide to running an inclusive event*:

v18_co_member-networks-conference_inclusive-event_a5_4pp_web.pdf (rsc.org)

Update: November 2021

In November 2021, the RSC Networks team ran a diversity forum to update members on changes that had been made following the previous consultation, and how these changes would affect committees and members.

In particular, committee member election was touched upon: previously, this had moved from committee to member selected, via email vote. However, committees had complained this narrowed rather than broadened their diversity, including subject expertise diversity, because members were inclined to vote for "people like me". The new recommendations were to include an overview of the existing committee and outline of the expertise gaps (you will have noticed this appearing already on ECG calls for new committee members). The Networks team are also offering to proofread call outs and responses for "buzzwords" that make applicants stand out and, in particular, their absence, especially from overseas applicants, who may promote themselves differently. Voting now takes place through anonymised individualised links that can only be used once.

The Networks team are still keen to encourage hybrid events that mix virtual and physical meeting attendance. The hurdle of learning how to use hardware, and which hardware, remains on the agenda. The purchase of such kit for committee use now needs to be recorded as a committee asset, a new initiative detailed in this handbook: https://rsc.li/member-networks-handbook

ECG Environmental Brief No. 29 **ECGEB No. 29**

Variance between individuals can provide additional information for ecotoxicologists besides the mean

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In dose-response studies, the standard method is to compare the means of the tested parameters of the treated groups to the control. The variance is usually considered as background noise. Our example demonstrates how variance is not just a confounding factor, but can be a source of meaningful information. We measured fifteen parameters to identify which ones show differences in variance related to concentration.

Ecotoxicologists usually think about variance as a nuisance

Ecotoxicologists usually consider variance (the distribution of data around the mean) as a nuisance. It causes several setbacks, like simple statistical tests cannot be used, our estimates become imprecise, and differences from the control group become hard to find. However, in the 1980s and 1990s, discussion emerged around the use of variance as a meaningful parameter (*1,2*) which could even be more sensitive than the "golden" mean (*3*).

An experiment was performed to assess the effect of increasing insecticide concentrations on the springtail (*Folsomia candida*). Our model animal was the "white-rat" springtail, a soil living animal microorganism, which is asexual and very common in organic matter rich soil. Several standard tests (*e.g.* OECD, ISO) were developed using them. Springtails have a role in the litter decomposition and regulation of soil microbes, such as mycorrhiza.

One of the main reasons behind changes in variance may be selection; selection may cause the genetic variance to decrease. On the other hand, with basic high genetic variance, toxic material could induce different reactions in different genotypes. Asexual species show little genetic variability; however, epigenetic variation can provide the raw material for selection in their populations. Epigenetic modifications change the DNA expression without altering DNA itself.

The experiment about variance

A multigeneration experiment was performed with the springtail. The animals were treated with increasing concentrations of an insecticide Trebon 30 EC (*4*). Three growth, eight reproduction, and two behavioural parameters, and the food consumption were measured, and the growth-reproduction trade-off calculated (*5,6*). Measurements were repeated on the three subsequent generations in two ways: (i) the offspring got the same treatment as the parents (multigenerational treatment) and (ii) the offspring were not treated (transgenerational treatment). Only the effects of the parental, grandparental, grand-grandparental treatment were visible in the subsequent generations (see **Figure 1**). Variance differences from the control were then statistically tested.

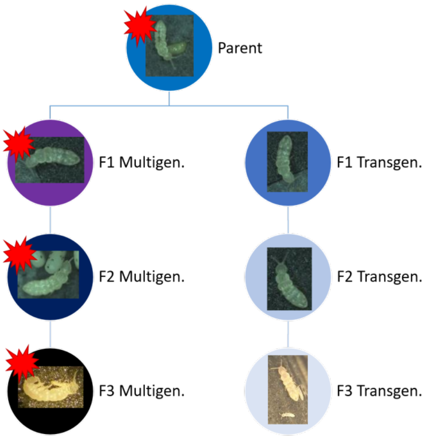

Figure 1. *Experimental design. The darkening colour symbolises the strengthening effect of the insecticide and the fading colour the weakening effect. The red spark shows the insecticide treated groups*

Variance reveals different selection types

In one-third of the parameters, we found a significant change in variance (decrease, or increase), compared to the control. In the following, we present the results for the first clutch size (an important life-history parameter), and explain the possible reasons behind the observed variance changes.

In the first generation, the variance increased in the treated groups compared to the control, which can have several causes. Trait-flexibility could be one reason, but if that were true, then we would not see an effect in the transgenerational group, which was not treated; only maternal effects would be present. More variable offspring have a better chance to survive in a stressful and changing environment, because at least some of them will survive the new circumstances. In addition, selection can support not only one but more strategies simultaneously; this is called disruptive selection. As a theoretical example, there are two strategies found in case of springtails. Those who lay few eggs during the first reproduction (*e.g.* 20) and detoxify more; or those who lay a lots of eggs during their first reproduction (*e.g.* 60) and detoxify less, compared to an intermediate strategy, where the mean is stable at 40 eggs and has a low variance (*e.g.* 10). Thus, for the whole population the mean number of eggs is still 40, but because half of the population tends to a mean of 20 and the other to 60, the variation becomes 30, which is much higher than the original 10.

In our experiment, the two possible successful strategies are (i) individuals invest energy into the first clutch, but not much into detoxification, and (ii) individuals invest energy into detoxification and their own survival, but not into the size of the first clutch. Both strategies may be successful in the long-term for the survival of the population. This energy trade-off was observed with fruit-flies and mosquitos (*7,8*). However, disruptive selection is a low probability explanation, while it acts in the long-term and the next generations show a different pattern, the increasing variance may indicate maternal effects. In addition, it is known that the next generation embryonically may be affected in the body of the adult animal.

In the later generations, the variance of the first clutch size decreased because of the treatment, while the mean of the parameter did not change. This pattern is the marker of stabilising selection when the mean of the given trait is near the current best possibility, and that is why individuals farther from the mean are selected out. Another possibility is that producing variable offspring for the stressful environment is costly for the animals, so it will not be worth keeping up the process if the stress is not too high. The third option is that because one reaction is the best in a particular stress situation, the phenotypic variance, so the variance of the appearance of trait is channelled into a narrow range. In the case of water fleas, it has been found that high concentration treatment with crude oil could decrease the variance compared to the control (*9*).

As such, we conclude that variance can give information about the stress state of animals, even when the measured mean does not react; as such, variance may provide early warning of problems. In addition, testing variance differences does not require extra laboratory work or measurements, only further calculations on existing data.

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ECG Environmental Brief No. 30 **ECGEB No. 30**

Potential environmental risks of water-soluble polymers

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The potential environmental risks of plastics and microplastics have been widely studied, yet research into the impacts of other polymer types including water-soluble polymers remains scarce. Given their widespread usage in household products, wastewater treatment, and agriculture, and thus multiple pathways of emission, it is likely water-soluble polymers are present in the environment; however, their potential environmental risk is uncertain. Research into tools and techniques for risk assessment of these polymers, as well as efforts to address data gaps, are essential to characterise environmental risk.

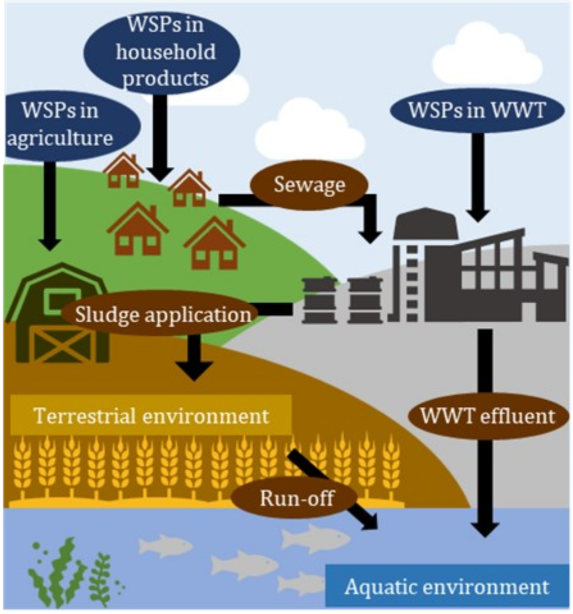

Figure 1. *Routes of environmental emission of water-soluble polymers (WSPs) used in household products, wastewater treatment (WWT), and agriculture.*

Polymers are high molecular weight molecules with widespread usage in a number of sectors, including as packaging materials, and in vehicles and construction, electrical and electronic materials, wastewater treatment and agriculture, and household products. In particular, plastic polymers have gained significant attention due to their ubiquitous presence in the environment and poor biodegradability, with both large-scale plastic debris and plastic particles such as microplastics being the focus of environmental research efforts. However, other types of polymers such as water-soluble polymers (WSPs) have received comparatively little attention (*1*). Given the previous lack of regulation of polymers due to the assumption that their high molecular weights indicate minimal ecological hazard, there is a need to determine the potential extent of environmental exposure and the hazards of WSPs.

> **“A number of applications of water-soluble polymers involve direct pathways of emissions into the environment”**

Usage and emission pathways

WSPs are widely used in a number of sectors, with annual production of WSPs in Europe estimated in the range of millions of tonnes (*2*). A number of applications of WSPs involve direct pathways of emission into the environment, including in wastewater treatment as flocculants, in agriculture as soil conditioners, or in pesticide and fertiliser formulations, and in household products such as detergents, cleaning products, and personal care products, which may be released down-the-drain (*2*). Common polymer types used in household products include polycarboxylates (used as ‘builders’ and anti-redeposition agents in detergents), polyquaterniums (anti-static and film-forming agents in personal care products), and polyethers (often bonded to hydrophobic groups to act as surfactants). WSPs released down the drain which are not degraded during wastewater treatment have the potential to be released in effluent waters or applied to agricultural soils if in the sludge.

Presence in the environment

Thus far, there have been relatively few studies focussed on measurement of environmental WSPs originating from household and personal care products released down the drain. Polyether polymers and oligomers have been most frequently studied, with alcohol ethoxylates, alcohol ethoxysulfates, and polyethylene glycol measured in surface waters in the range of ngL^{-1} to µgL^{-1} (*3-6*). Polydimethylsiloxane has also been monitored in surface waters, but found to be below the limit of detection (< 5 µg L^{-1}) in most cases (*7*). However, measured environmental concentrations for other types of WSPs remain scarce. A lack of specific and sufficiently sensitive analytical methods for detection of WSPs is a key issue, with the potential complexity of polymer mixtures requiring additional considerations for analysis (*2*).

Modelling approaches are key in predicting environmental concentrations of potential environmental contaminants where measured data are not available. Predicted environmental concentrations have been calculated for several alcohol ethoxylates and alcohol ethoxysulfates, a select number of polycarboxylates, and polyquaterniums (*8,9*); however, these data cover only a small number of WSPs in current use. In addition, a lack of publicly available data on usage and production volumes of polymers hinders many typical modelling approaches, with a lack of data on environmental fate of water-soluble polymers, preventing the use of higher tier models for more in-depth exposure predictions. Given the widespread usage and direct emission pathways of WSPs, it is likely that several WSP types are present in the environment; however, there remains uncertainty around actual environmental concentrations and potential risk.

Potential environmental risk

Environmental risk assessments (ERAs) of most WSPs in current use are scarce. Whilst most polymers, in general, have been previously assumed to pose little ecological hazard due to their high molecular weights (and thus low solubility/environmental mobility), some polymer classes are considered to be a potential cause for concern. For example, polyquaterniums (characterised by cationic quaternary ammonium groups along the polymer chain) have been recognised as having potential aquatic toxicity (*10*). In addition, the widespread usage of other polymer types indicates a need for risk assessment regardless of prior assumptions of low toxicity. ERAs of alcohol ethoxylates, alcohol ethoxysulfates, and polycarboxylates used in household cleaning products have been previously performed, with no environmental risk identified as likely, since they biodegrade in sediments (*8*). However, these risk assessments again cover only a small selection of the WSPs that are in current use, with a number of WSPs used in household products being shown to have insufficient data available to conduct an ERA (*11*).

Conclusions

Given the widespread usage of WSPs, with many applications resulting in the potential for direct emissions to the environment, there is a clear need to characterise their potential environmental risks. Addressing knowledge gaps in both exposure and potential hazard of WSPs in the environment is key, with a need to develop analytical methods for sensitive and specific WSP characterisation as well as modelling approaches which account for the specific and complex nature of polymers. The previous regulatory exemptions of polymers have resulted in the need to confirm a lack of environmental risk moving forward.

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ECG Environmental Brief No. 31 ECGEB No. 31

Nanobiosensors in monitoring biodegradation of micropollutants

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Biodegradation is a promising, low-cost treatment for removing organic micropollutants from wastewater. However, biodegradation processes are largely viewed as a “black box”, whereby the underlying mechanisms of removal are not fully understood. The ability to quantify chemical pollutants accurately and selectively at low concentrations in complex biological matrices is essential for biodegradation. However, analytical techniques used in biodegradation research utilise expensive instrumentation with high consumable and running costs. Nanomaterials-based biosensors are an emerging technology that have the potential to become a rapid, low-cost alternative to conventional trace analysis methods.

Micropollutants are environmental contaminants present at very low (sub parts-per-billion) concentrations which have the potential to cause adverse effects (*1*). Many organic micropollutants are everyday chemicals, which have been discharged into the environment for decades by municipal and agricultural wastewater treatment systems. These micropollutants include pharmaceuticals and personal care products, hormones, pesticides, disinfectants, and other household chemicals. Biodegradation, or the use of microorganisms to transform chemical contaminants to less harmful products, is one of the most cost-effective approaches towards removing micropollutants (*2*). Biodegradation occurs in a variety of water treatment processes, including activated sludge, membrane and moving bed bioreactors, and sand filtration (*2*). However, engineering biological waste treatment systems for enhanced micropollutant removal has significant challenges. Some of these challenges include identifying microorganisms with the metabolic capacity to degrade pollutants, and optimising treatment facility operating conditions (*2*,*3*).

Trace analysis in biodegradation

Analytical chemistry plays an important role in measuring micropollutant removal rates and efficiency. The standard workflow for measuring organic micropollutants from environmental matrices consists of sample extraction and pre-concentration followed by instrumental analysis (*4*). Solid phase extraction and other sorptive extraction techniques are most commonly used, as these can process larger sample volumes with less solvent consumption than liquid-liquid extraction. Traditionally, hyphenated techniques utilising liquid or gas chromatography (LC or GC) have been employed to quantify organic micropollutants (*4*). When combined with mass spectrometry (MS), organic micropollutants can be analysed at nanogram per litre (ng/L) concentrations.

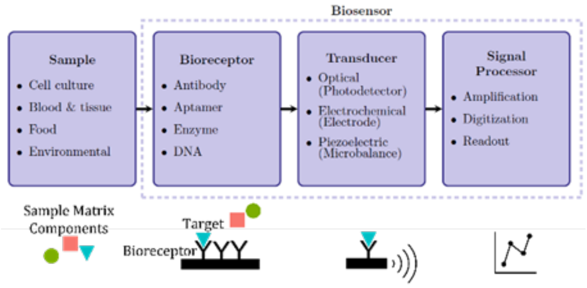

Figure 1. *Schematic showing the components of a biosensor.*

Nanomaterials-based biosensors

Biosensors are devices used to measure chemical or biological targets via a biological recognition element (**Figure 1**) (*5*). The biological recognition element is a biomolecule which is capable of binding to the target with a high degree of affinity and specificity, such as an antibody, a nucleic acid aptamer, an enzyme, or complementary DNA. In a biosensor, a target-bioreceptor binding event yields a physical or chemical change, which is detected by a transducer, such as a photodetector, electrode, and piezoelectric balance. The transducer then converts the physical or chemical response into an electronic signal, which is processed, converted into a digital form, and printed as an output.

Nanomaterials – or structures which are less than 100 nm in at least one dimension – have been used extensively in biosensors (*5*,*6*). Nanomaterials may be composed of organic or inorganic materials and can be synthesised in different geometries, such as nanoparticles, nanowires, nanosheets, and more complex structures. In addition to the high surface area-to-volume ratio which provides efficient bioreceptor immobilisation, nanomaterials possess unique physicochemical properties which are sensitive to changes in their environment, such as the interaction of the bioreceptor with the target. Thus, the nanomaterials in nanobiosensors are used to produce or enhance a measurable signal following target detection.

Nanobiosensors for micropollutants

Environmental monitoring is a rapidly emerging application for nanobiosensors (*5*,*6*). Nanobiosensors hold key advantages over conventional trace analysis of micropollutants, including minimal or no sample preparation, and the potential to be scaled down for portability and in-field monitoring (*7*). Nanobiosensors have been designed for numerous environmental contaminants, including seven substances listed under the European Union's Watch List (**Table 1**) (*8*). Electrochemical and optical sensors are the most common transducing mechanisms for organic micropollutants.

Table 1. *Examples of nanobiosensors for micropollutants listed under the EU Watch List (8).*

Substances	Nanobiosensor Type
17-Alpha-ethinylestradiol	Electrochemical immunosensor, silica nanoparticles (*9*)
17-Beta-estradiol, Estrone	Colorimetric aptasensor, gold nanoparticles (*10*)
Macrolide Antibiotics	Colorimetric immunosensor, gold nanoparticles (*11*)
Methiocarb	Colorimetric immunosensor, carbon nanoparticles (*12*)
Neonicotinoids	Fluorometric aptasensor, gold nanoparticles (*13*)
Amoxicillin	Electrochemical aptasensor, TiO_2-g-C_3N_4@gold nanoparticle composites (*14*)
Ciprofloxacin	Electrochemical aptasensor, carbon nanotubes (*15*)

Considerations for applications in monitoring biodegradation

Although numerous nanobiosensors have been designed for measuring micropollutants in various samples, these techniques have not yet been widely adopted. Biodegradation of micropollutants, particularly lab-based studies, has the potential to be a springboard application for demonstrating the utility of nanobiosensors in environmental research. The selective bioreceptor allows for micropollutant detection in a complex biological matrix, while the controlled nature of the inoculum and medium allows for reproducibility across laboratories in ways that field sampling is limited. In addition, this application could benefit from simpler and more cost-effective analytical methods for micropollutant quantification where multi-target analysis is unnecessary.

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ECG Environmental Brief No. 32 **ECGEB No. 32**

Using ultrasound for environmental sample preparation: what's the buzz?

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The application of ultrasound in sample preparation has been shown to facilitate and accelerate each stage, reducing overall sample preparation time. In addition, ultrasound assisted techniques reduce energy and solvent consumption, reducing the overall cost of analysis. The ultrasound process aligns with numerous Green Chemistry principles, which is an advantage for environmental chemists.

Ultrasound is used in a variety of applications, including sonograms in healthcare and SONAR (sound navigation and ranging) systems in naval ships. When applied to chemical applications, it is known as 'sonochemistry' or, more generally, as 'sonication' (*1*). It has been applied to sample preparation at many stages, including extraction, precipitation, and derivatisation. Ultrasound assisted techniques are becoming more utilised by analytical chemists due to the versatility, flexibility, and ease of use of the techniques, combined with the advantages of reduced energy consumption and cost (*2*).

Cavitation

Ultrasonic waves alternate between expansion and compression cycles, generating bubbles in the liquid medium. The formation, growth and implosion of these bubbles is known as cavitation (**Figure 1**). The process results in extreme changes in local temperatures and pressures which help to facilitate chemical reactions (*1*), driving the extraction and derivatisation processes. The cavitation process depends highly on the intensity and frequency of the ultrasound (*3*), the time and temperature of the reaction, and the properties (viscosity, volatility *etc.*) of the solvent (*1*).

Direct vs indirect sonication

In most studies, a sonication probe (direct sonication) or sonication bath (indirect sonication) are used to implement the ultrasound to the sample. Although direct sonication is more intense, there is increased possibility of cross contamination (*4*), as the probe is submerged in the sample. Indirect sonication, using a bath, allows for the ultrasound to be applied to multiple samples at once; however, a lack of uniformity in ultrasound transmission is a potential limitation (*5*)

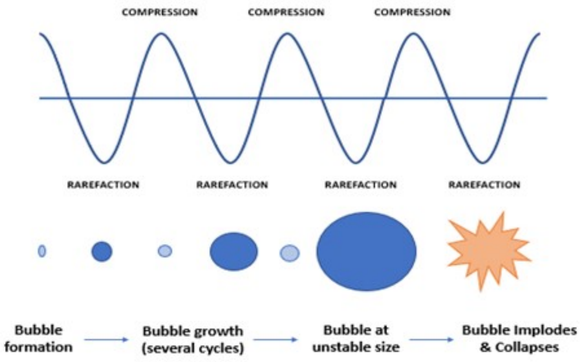

Figure 1. *Schematic of cavitation process in ultrasonication. Adapted from (6).*

The novel method of a sonotrode (*7*) (**Figure 2**) offers similarities to both the ultrasonic bath and the sonication probe by applying intense indirect sonication – the ultrasonic waves cross the walls of the sample vial – without possibility of sample loss or contamination. The sonotrode is suitable for use with smaller solvent volumes (µl-ml), making it ideal for both extraction and derivatisation, with the added benefit of reduced solvent waste. The sonotrode offers control over operating parameters, including amplitude, ultrasound application (continuous or pulsed), and time, and thus optimisation of the extraction or derivatisation methods.

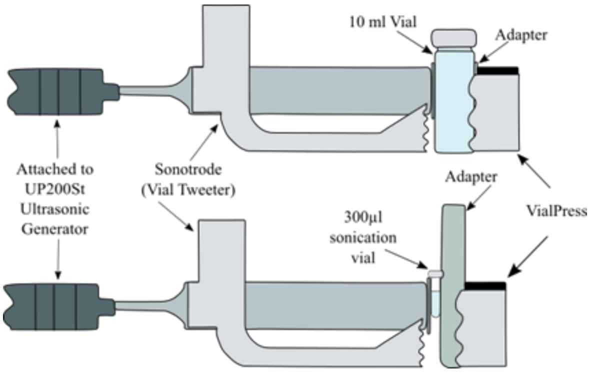

Figure 2. *Schematic of sonotrode set-up for a) extraction, 10 ml glass crimp seal vial with fine plastic adapter b) derivatisation set-up, 300 µl glass crimp seal vial with large plastic adapter. Adapted from (7).*

Ultrasound assisted extraction

Solid environmental samples including soil, sediment, sludge, and biosolid pellets, often require lengthy extraction and sample preparation steps prior to analysis. Ultrasonic assisted extraction (UAE) is an alternative to traditional extraction methods such as solid liquid extraction (SLE) and newer techniques, *e.g.* microwave assisted extraction (MAE) for analyte removal from solid matrices (*2*). The technique has seen a rise in application over the last 10 years, especially pharmaceutical and personal care product (PPCP) analysis in sewage sludge (*3*). Extractions with UAE can be completed in minutes, with reduced solvent consumption and energy use, higher reproducibility, and reduced costs compared to older techniques like Soxhlet (*2*).

Ultrasound assisted derivatisation

Ultrasonic assisted derivatisation (UAD) is a fairly new technique which is applied to accelerate silylation derivatisation (*8*) when gas chromatography (GC) is used as the analysis technique. Conventional derivatisation generally requires heating to around 60°C for upwards of 30 mins (*9*), whereas UAD has been undertaken in as little as 1 min (*5*). Ultrasound application provides intense mixing of the sample, which will influence the number of collisions (*10*) between the analyte compound and derivatisation reagent, facilitating the reaction. Reaction times have been reduced by ~90%, with increased yields and similar LODs to conventional heating methods (*11*).

Green Chemistry

There are 12 principles of Green Chemistry (*12*), as shown in **Table 1**, based on the fundamental concept of making chemistry ‘benign by design’ (*13*). Sonochemistry and ‘Green Chemistry’ share objectives of energy efficiency and waste reduction (*1*). This is because of the intent that sonication facilitates the reaction, be it extraction or derivatisation, which will reduce the sample preparation time vastly. The energy savings attributed to the reduced sample preparation time and the reduction in heating align with principle 6 – design for energy efficiency. Sonication also is shown to reduce solvent use, in comparison to more traditional techniques, and thus a reduction in waste is achieved (*2*).

Combining UAE and UAD with GC methods could also further reduce the solvent consumption in comparison to liquid chromatography (LC) methods. GC is not as susceptible to matrix effects, does not require analysis in positive and negative ion mode, and has a gaseous mobile phase – all contributing to reduced solvent consumption.

Table 1. *Anastas and Warner’s 12 principles of Green Chemistry* (12)

	Twelve Principles of Green Chemistry
1.	Prevention
2.	Atom economy
3.	Less hazardous chemical synthesis
4.	Designing safer chemicals
5.	Safer solvents and auxiliaries
6.	Design for energy efficiency
7.	Use of renewable feedstocks
8.	Reduce derivatives
9.	Catalysis
10.	Design for degradation
11.	Real-time analysis for pollution prevention
12.	Inherently safer chemistry for accident prevention

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Upcoming meeting: 2022 ECG Distinguished Guest Lecture and Symposium

Disposable Attitude: Electronics in the Environment

A one-day symposium organised by the Environmental Chemistry Group exploring the environmental implications and defences, material scarcity and modern attitude associated with electronics manufacture and disposal.

Where: The Royal Society of Chemistry, Burlington House, London, W1J 0BA

When: Thursday 10th March 2022

The ECG Distinguished Guest Lecture (DGL) and Symposium is our annual flagship event, and focuses on a specific contemporary environmental chemistry topic. Previous DGLs have included antimicrobial resistance, fuel emissions, and nanomaterials. The Distinguished Guest Lecturer is a scientist who is recognised to have made a significant contribution to the field, and is awarded our ECG medal.

Speakers:

Professor Ian Williams (University of Southampton)

Professor Williams is a Professor of Applied Environmental Science and Associate Dean within Engineering and Physical Sciences at the University of Southampton. He has an established track record in the field of environmental pollution and waste management. Professor Williams will speak on the recovery and recycling of materials used in electronics.

Professor Tim Cooper (Nottingham Trent University)

Professor Cooper is leading research in the fields of sustainable design and consumption and he is member of the Product Design academic team at Nottingham Trent University. Professor Cooper will speak on sustainable design and consumption and product lifespans.

TBC (Restart Project)

Following unexpected circumstances, Ms Janet Gunther will no longer be able to speak as a representative of the Restart Project, a London-based charity established to combat the "throwaway consumerist model of electronics" that has established in the 21st century. A representative of the Restart Project will speak on the disposable attitude associated with modern electronics and alternatives to recycling.

2022 Distinguished Guest Lecturer: Mr Steve Cottle (Edwards EMS Ltd)

Mr Cottle is a Senior Applications Manager at Edwards Vacuum. During his 25-year tenure at Edwards, he has worked in multiple technical roles leading advanced development of customer specific solutions for Exhaust Management. He is an industry recognised expert in exhaust management and knowledgeable in all technical aspects of exhaust management. He holds a BSc in Chemistry from Bristol University. Mr Cottle will speak on the management and pollution of exhaust gases associated with the manufacture of electronics.

Registration

To register, visit the RSC events page: https://www.rsc.org/events/detail/72946/disposable-attitude-electronics-in-the-environment., or visit: https://rsc.li/3lp1G6M

EARLY BIRD is available before **1st February 2022**.

Early Bird Members: £40 (free to join as an RSC member)
Early Bird Non-members: £55
Members: £55 (free to join as an RSC member)
Non-members: £70

Upcoming meeting

State-of-the-art in the analysis of complex environmental matrices

A one-day meeting for environmental analytical chemists organised by the Royal Society of Chemistry Environmental Chemistry Group, Separation Science Group, and Water Science Forum.

Where: The Royal Society of Chemistry, Burlington House, London, W1J 0BA

When: Friday 11th March 2022, 9:30-16:30

The 5th meeting in this biannual series on the analysis of complex environmental matrices brings together analytical chemists from across the environmental sciences and covers the range of contemporary chromatographic, spectroscopic, and mass spectrometric techniques. The day consists of nine invited talks with ample time for community-building and an exchange of ideas.

Conference aim
The aim of the conference is to showcase state-of-the-art work in the analysis of complex environmental matrices in the UK.

This meeting is aimed at:

- Academic researchers
- Professional environmental analytical chemists
- Environmental practitioners

Registration

Non-members £120
RSC members £90
BMSS/Chromatographic Society Members £90 with discount code

Student non-members £35
Student RSC members £25
Retired/unwaged members £25 with discount code

Registration includes:

- Attendance at the sessions
- Refreshments throughout the meeting
- Lunch

Confirmed speakers

Leon Barron, Imperial College London
Rapid monitoring and risk assessment of chemicals of emerging concern at scale

Barbara Kasprzyk-Hordern,University of Bath
Wastewater based epidemiology and One Health

Nicholle Bell, The University of Edinburgh
Using NMR and FT-ICR-MS to tackle natural and man-made mixtures in our changing environment. A journey from peatlands to drinking water

David Scurr, University of Nottingham
Reducing combustion engine emissions with secondary ion mass spectrometry

Jacqui Hamilton, University of York
Are emissions from green spaces important for urban air quality? Using high resolution methods to understand the interactions of biogenic emissions with air pollution in cities

Brett Sallach, University of York
Increasing our understanding of xenobiotic uptake and fate in plants using single cell mass spectrometry

Caroline Gauchotte-Lindsay, University of Glasgow
Non-targeted analysis for the evaluation, monitoring and prediction of environmental engineering processes

Mark Perkins, Anatune
Rapid analysis of soils and water using selected ion flow tube mass spectrometry (SIFT-MS)

Richard Cross, CEH
Monitoring microplastics in the environment – experiences in detection and interpretation of microplastic contamination in increasingly complex media