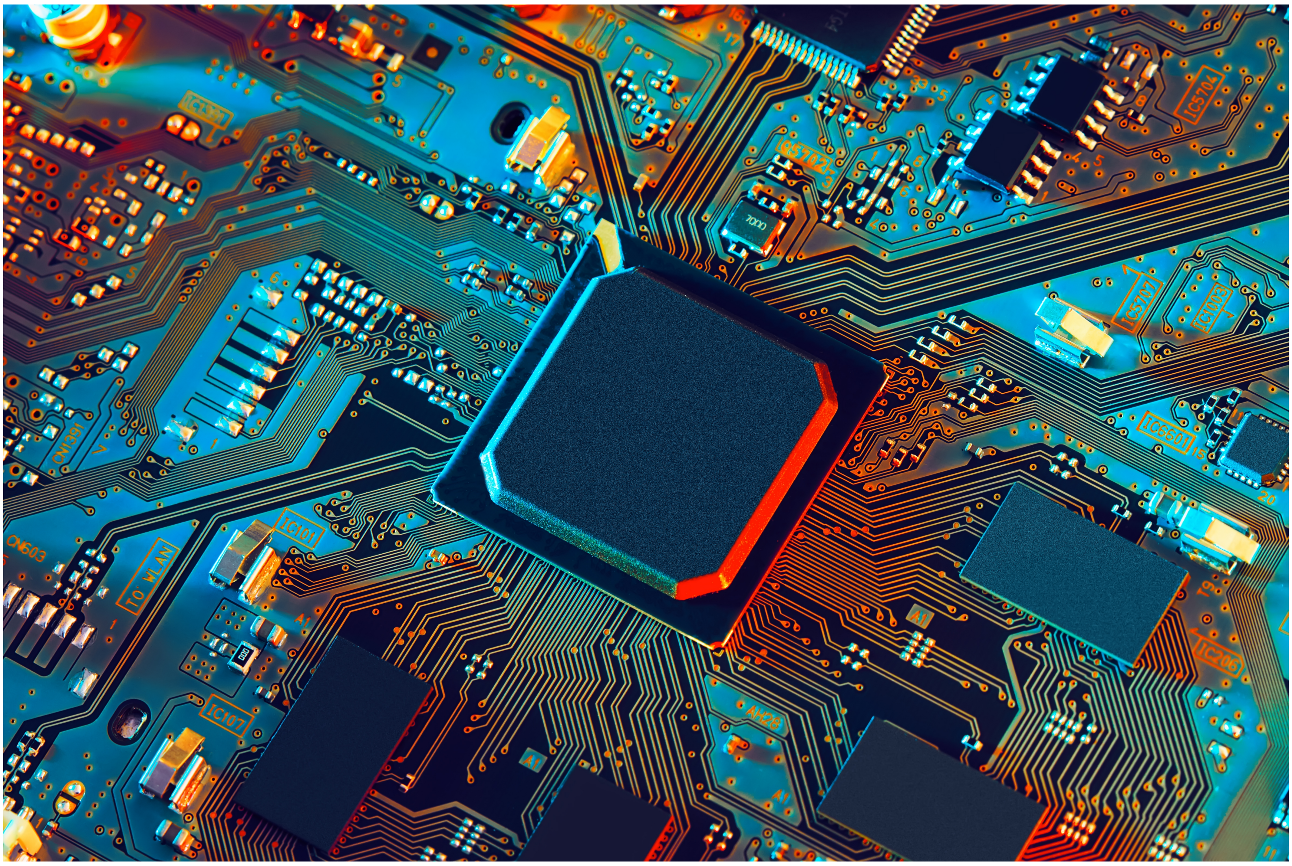
RSC INTEREST GROUP
ENVIRONMENTAL CHEMISTRY

January 2023
Environmental Chemistry Group
Bulletin



Electronics in the Environment. **Stephanie Powley** reports on our Distinguished Guest Lecture; **Steve Cottle** dives into fluorine greenhouse gases; Ian Williams reports on intergenerational e-waste activism and **Fiona Dear** introduces the Restart Project.

Articles. **John Collins** discusses the safety and toxicity of glyphosate, and **Laura Alcock** identifies precious prospects within e-waste.

Environmental Briefs. **Diana S. Moura** presents the effects of ageing in the adsorption of pharmaceuticals on micro plastics.

Meetings. We summarise our Circular Chemistry event; **Richard Hull** updates us on the chemicals that keep furniture from catching fire; **Rowena Fletcher-Wood** takes outreach to the nursery, and **Niall Marsay** leads volunteers to IF Oxford.

Upcoming meetings. #EnvChem2023 and Complex Matrices meetings are announced.

Also in this issue. **Symiah Barnett** tells us about her PhD monitoring microplastics; **Niall Marsay** shares our new *How To*: DIY air pollution sensors; and **Rowena Fletcher-Wood** summarises the year in the Chair's Report.

Contents

ECG *Bulletin*

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Environmental Chemistry Group

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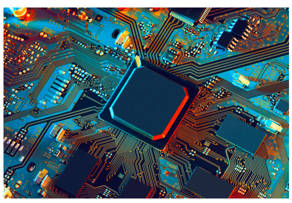


Front Cover- Shutterstock electronic circuit close up.

Report

Chair's Report for 2022

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

In 2022, the ECG saw the return to in-person events, although hybrid meetings and webinars continue, allowing us to reach a diverse audience. We now meet as a committee both in person and online, to lower our environmental impact and increase our geographic diversity.

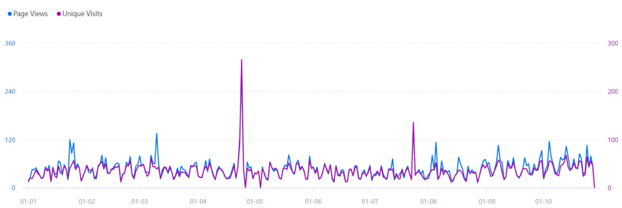
The ECG is pleased to welcome four new committee members: **Dr Kiri Rodgers** (University of the West of Scotland), whose interests lie in geochemistry, and has been contributing to our diversity initiatives; **Symiah Barnett** (Loughborough University), who works on plastics pollution, and has previously contributed to our outreach efforts (p.4); **Dr Sebastian Diez** (University of York) is an atmospheric chemist, and made a major contribution to the organisation of #EnvChem2022 this year; **Dr Helena Rapp Wright** (Imperial College London), studies drug analysis in water, and joins the committee after speaking at #EnvChem2021, and supporting #EnvChem2022. In addition, **Niall Marsay**, Cranfield University, has been **co-opted** onto the committee to act as Outreach Lead, representing us at IF Oxford 2022 (p. 13).

We say goodbye to our secretary, **Professor Steve Leharne** (University of Greenwich), who leaves after seven years, during which time he commissioned the *Bulletin Briefs* acted as an editor, organised numerous events, and acted as an extremely organised Secretary. **Professor Dominik Weiss** (Imperial College London), our *Bulletin* production editor and DGL co-convenor leaves after five years of service. **Laura Alcock** takes on the position of Secretary, **David Owen** *Briefs* co-ordinator, and **Caroline Gauchotte-Lindsay** production editor and Vice Chair. **Dr Roger Reeve**, after 16 years' service and a year-long handover, joins us for the last time in March. His contributions have included establishing event series such as Analysis of Complex Matrices and *Bulletin* editing.

In 2022, the committee organised five events, including our flagship events **#EnvChem2022** (hybrid) and the **Distinguished Guest Lecture** *Disposable Attitude: Electronics in the Environment* (in person, pp. 5-7, 22-29). We ran two webinars, **3B's in Circular Economy** (7th September) jointly with the Management Group, and **Plastics: Cradle to Grave and Resurrection III** (15th June) with RSC Toxicology, and Food Groups, and the Society of Chemical Industry, led by Innovate UK Knowledge Transfer Network – a recording is available. **Circular Chemistry; the enabler to help solve global challenges** (hybrid) ran joint with the Applied Materials Chemistry Group and DEFRA (30th November) (pp. 8-10), and the ECG attended three outreach events. Unfortunately, our popular event **State of the Art in the Analysis of Complex Environmental Matrices** was cancelled due to rail strikes, but is replaced by a series of seminars to take place in January and February 2023 (p. 32).

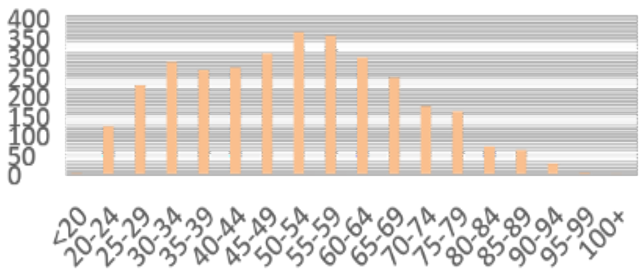
Overall events:

- ~250 attendees
- ~150 meaningful outreach engagements
- 51 oral presentations
- 2 round table discussions
- 23 posters



Our website has also seen nearly **11,000 unique visits** January-October 2022, including a spike of interest in April, which may be the result of a school project! Most (~93%) of viewers come through Google, and our most popular page is a 2007 article on climate change, methane and ozone, followed by *Environmental Briefs.*

A survey of our 2022 membership has shown that ECG has 3,248 members, representing all ages, including one member over 100(!). The gender breakdown is 69% male, 30% female, and 0.2% non-binary – in line with RSC general membership data (*1*). Results also show that members tend to maintain their commitment to the ECG for decades – two for between 76 and 80 years.



Members ages

References

1. Day, A. E., Corbett P. , Boyle J. (2020). Is there a gender gap in chemical sciences scholarly communication? *Chemical science,* **11,** 2277-2301. https://doi.org/10.1039/C9SC04090K

ECG Interview

The ECG Interview: Symiah Barnett

Symiah completed her undergraduate degree in Applied Chemistry at Aston university in June 2021. As of October 2021, Symiah is a Natural Environment Research Council (NERC) funded PhD student at Loughborough University. Her project is focussed on monitoring microplastics and nanoplastics in rivers and marine environments over long time periods to better understand their formation, transportation, and fate.

What inspired you to become a scientist?

As a child I had lots of questions and I remember my science classes providing a lot of the answers. Science appeared as a way of understanding the world around me. There is nothing that you can look at that you cannot explain or explore via science, and I have been able to learn a lot more about the world throughout the course of my chemistry degree.

Symiah Barnett

How did you come to specialise in plastic pollution? During my undergraduate degree, I completed a summer placement at the Archipelagos Institute of Marine Conservation in Greece. This is where I discovered that I wanted to tackle the environmental problem of microplastics in water. I loved the idea of continuing research in microplastic pollution; therefore, I started my research project at both Archipelagos Institute of Marine Conservation and Loughborough University, working on microplastics and nanoplastics in rivers and marine environments.

Could you describe your current job? My project is multi-disciplinary, which requires me to carry out a vast range of tasks such as analysing samples using a variety of techniques (e.g. FTIR, ICP-MS and GS-MS). There is kayaking, freediving and scuba-diving to collect samples. Or sitting in front of a computer screen searching for articles or data. No day or week is the same for me.

What advice would you give to anyone considering a career in environmental chemistry? Create and take every opportunity possible because you don't know where it will lead you. But more importantly, believe in yourself.

What are some of the challenges facing the environmental chemistry community?

Not enough listening amongst people. Whether that is the scientist not being listened to by governments and organisations, or local groups and communities not being heard by scientists. There is an overall lack of understanding and collaboration.

What is the most rewarding aspect of your career so far?

Whilst carrying out fieldwork in Samos (Greece), the local people came over to us and thanked us dearly. This had to be the most rewarding moment because it was at that moment I realised our work was making a difference to the local community.

If you weren't a scientist what would you do? I would be a Humanitarian aid worker because I really enjoy helping people and making a positive difference. Additionally, I love working around the world.

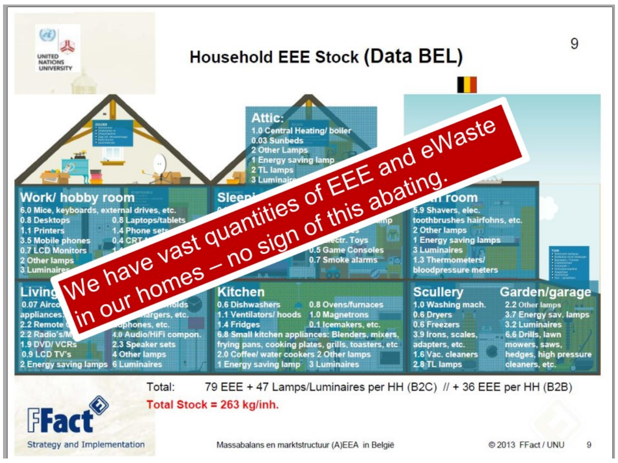
And what do you do when you are not working? When I am not working, I am traveling! Most of the time I have to travel locally. But when I have a lot of time off, I enjoy backpacking across countries. My aim is to visit every country in Europe and Southern and Central America. And if I am not travelling, I am sleeping!

Meeting Report

Disposable attitude: Electronics in the environment

Stephanie Powley (ECG Committee, stephaniepowley@wildlifeonline.me.uk)

The first in-person Distinguished Guest Lecture (DGL) since 2019 was held on Friday 9th September 2022 at Burlington House. This one-day DGL and symposium explored the chemistry of electronics manufacture and disposal in the environment, the modern consumer attitude towards electronics and potential future sustainable methods for manufacture. The 2022 DGL was provided by Mr Steve Cottle of Edwards Ltd, supported by Professor Ian Williams (University of Southampton), Dr Catherine Ramsdale (PragmatIC Semiconductor), and Ms Fiona Dear (The Restart Project).



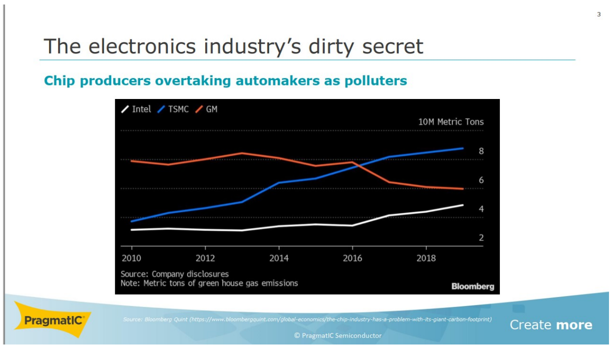
The symposium was opened by ECG chair, **Dr Rowena Fletcher-Wood**, who introduced the first speaker, **Professor Ian Williams** (University of Southampton) and his presentation entitled **Enabling recovery and recycling of materials used in electronics: The Trace Project** (pp. 24-27). Professor Williams began his talk with the background to the Waste Electrical and Electronic Equipment (WEEE) issue. WEEE or e-waste is defined as anything with a plug, electric cord or battery. Devices fitting this description are usually made up of a complex mixture of materials and can cause environmental and health problems if not handled correctly. To highlight the scale of the issue, a 2010 Belgian study found that the average home contains ~263 kg of electronic equipment per inhabitant. Professor Williams highlighted the difference in

technological evolution between radios and mobile phones, with the rapid increase in complexity of the latter leading to increases in e-waste. In 2019, 53.6 Mt of e-waste were generated globally, of which 82.6% had no documentation as to what happened to it.

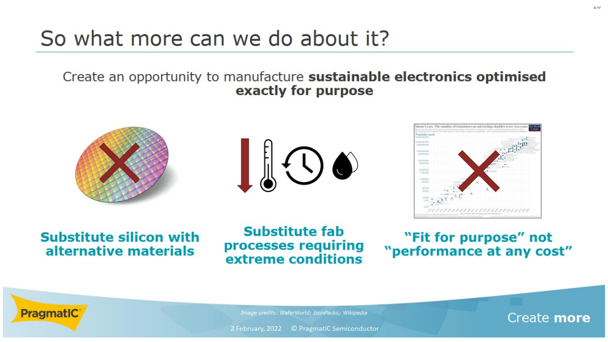
Some products that are classified as WEEE are commonly not treated by the public as such and, for example, vaping devices (e-cigarettes), batteries, and light bulbs are frequently disposed of inappropriately. Other hidden or less well known WEEE problems are "hibernating" devices – those that many of us keep as "back-ups" or devices in need of repair – and unwanted cables; the incredible statistic given was that unwanted cables in the UK alone could circle the Earth more than five times. Alongside the environmental issues related to the manufacture and disposal of electronics (including the pollution caused by mining raw materials), the impact of using these devices is also large. Irish data centres, for example, consume 14% of the total electricity used in Ireland and use huge quantities of fresh water for cooling.

Public awareness of the issues surrounding e-waste is low and the TRAnsitioning to a Circular Economy (TRACE) project was conceived to use art and music to help raise awareness and effect changes in behaviour and attitudes. One of the major concepts behind the TRACE project was the use of intergenerational influence – children discussing e-waste with their families and caregivers – and the creation of anthropomorphic personifications of objects by children to evoke emotional responses in their audience. After briefing the artists and musicians, Professor Williams and his PhD student, Alice Brock, led educational workshops in a local primary school which were complemented by musical workshops led by musicians. This culminated in two performances in early March 2020 during UK Science & Engineering Week and at an associated art exhibition. The pupils performed songs, poems, and raps that they composed themselves with support from the musicians Robin Browning and Ricky Tart. An art exhibition was also staged in March 2020, showcasing the work of artist Susannah Pal based on the briefing given to her by the scientists. The TRACE project successfully raised awareness of e-waste issues via collaboration between scientists and creative artists. This allowed the socioeconomic and technological challenges of managing e-waste and intergenerational influence to be explored. The project was so well received that it won a national recycling award.

The second speaker was **Dr Catherine Ramsdale** (PragmatIC Semiconductor), with a talk entitled **Flexible electronics: improving sustainability** Dr Ramsdale noted that the semiconductor industry is now overtaking the automobile industry as a leading source of greenhouse gases with the increase in use of electronics in day-to-day life. As semiconductors become smaller and more complex, their carbon footprint including use of volatile organic compounds (VOCs) and gases and use of energy increase. Around half of the energy consumption of wafer processing is from the actual manufacturing process, with the other half being accounted for by the support facilities and clean rooms.



Flexible electronics being developed by PragmatIC have a lower energy demand for manufacture, have fewer layers than silicon-based technology and are also more responsive with fewer errors. Flexible electronics fabrication can be smaller and lower cost than traditional facilities, allowing



manufacture to be more widely distributed to meet local demand, reducing transport requirements. Potential uses for flexible electronics could also help with other waste problems. For example, smart labels on plastic bottles could make deposit return schemes digital, and improve on the current rate of plastic recycling which is only 9% of all the plastic ever produced globally. The tracking of products through the waste stream, such as tyres, may reduce the levels of fly-tipping. Electronics in packaging to assess the safety of food could reduce the current global food waste of > 30% by reducing reliance on use-by dates. Questions from the audience investigated the potential effect of smart labels on recycling and the increase in WEEE from the addition of the electronics. Dr Ramsdale indicated that PragmatIC are taking these issues into account and expect that smart labels could be reused too. Their circular economy team are dedicated to ensuring that there is value in adding flexible electronics to products.

DGL convenor and ECG Secretary **Laura Alcock** introduced **Ms Fiona Dear** (Restart Project), who gave a presentation entitled **Reducing e-waste through repair: Better electronics, more access to repair and new behaviours** (pp. 28-29). Ms Dear opened her talk with the observation that we are stuck in the "use > throw > buy more" cycle, and noted that the UK is the second highest producer of e-waste per person in the world. For relatively energy efficient devices, such as laptops, the majority of their associated primary emissions come from the pre-use phase of their lifecycle; in the case of laptops, this can be approximately 88% in pre-use, 11% in use, and only 1% at end-of-life. Devices with a lower pre-use emission profile tend to be

Carbon dioxide equivalent and Global Warming Potential

Global Warming Potential (GWP) is the heat absorbed by any greenhouse gas in the atmosphere as a multiple of the heat that would be absorbed by the same mass of carbon dioxide (CO_2). GWP is defined as 1 for CO_2. For other gases, GWP depends on the gas and the time frame. See p 22 of this issue for some current GWP values.

Carbon dioxide equivalent (CO_2e or CO_2eq) is calculated from GWP. For any gas, CO_2e is the mass of CO_2 that would warm the earth as much as the mass of that gas. Thus it provides a common scale for measuring the climate effects of different gases. It is calculated as GWP times mass of the other gas.

CO_2e calculations depend on the time-scale chosen, typically 100 years or 20 years, since gases decay in the atmosphere or are absorbed naturally at different rates.

Source: 'Global Warming Potential', *Wikipedia* *https://en.wikipedia.org/w/index.php?title=Global_warming_potential&oldid=1124849235*

less efficient during use, such as toasters and kettles. It was estimated that the production of one laptop uses around 263 kg CO_2e, roughly equivalent to a flight from London to Berlin.

DGL Medal presented to Mr Steve Cottle

The use of devices for more than a decade is virtually unheard of and "sounds heroic", but to tackle the e-waste problem, this should become more common. In two studies, around 75% of people questioned support repair of items to allow longer lifetimes, but this is not reflected in public behaviour, where only 14% of devices are currently repaired or reused. Ms Dear outlined some of the major barriers that prevent the repair and reuse of items as follows:

How products are made: • Hard to open; parts often glued in; parts bundled; invalidation of warranties; availability of parts; software issues restricting parts and/or functionality.

Psychological obsolescence: • Must have the new model; focus on design over actual functionality; replace, do not repair; fewer repair options available.

Cost of repair: • Comparing one-off manual repair cost to mass production cost.

The Restart Project is focussed on driving for more Right to Repair legislation, as the current regulations are very limited, only applying to TVs and white goods and only available to professionals, leaving out local "repair café" type initiatives. The EU is increasing legislation around making batteries easier to replace and repair, eco design (right to repair on a larger scale), and France has a repair index which provides a scale of how repairable an item is; although these are currently EU only regulations, the requirement for manufacturers to comply with them is likely to have an impact globally. The Restart Project supports Restart parties and repair cafés to improve access to repair of devices, which allows data to be collected on how and where devices commonly break. Community initiatives also allow for young people to see and learn how to carry out some basic repairs. A question was raised about the safety of devices repaired by such enterprises; currently, community repairers are shadowed by more experienced colleagues before they are allowed to work independently. Design for repair will also improve safety.

The 2022 Distinguished Guest Lecture was given by **Mr Steve Cottle** (Edwards Ltd). Mr Cottle's lecture was entitled **Environmental management of exhaust gases associated with the manufacture of semiconductors** (pp. 22-23). 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 opened his lecture with a description of the environmental impact of semiconductor manufacture, from the 1 million gallons of water used daily by a typical US facility to the over 500,000 tonnes of CO_2e gas emissions per year per facility. The monitored emissions from semiconductor production account for 0.23% of the total emissions in the USA. Moore's law states that the number of transistors on an integrated circuit doubles every year, and over 8 billion transistors can now be found on a single mobile phone chip. It is estimated that 90% of the world's data have been generated in the last two years. Some of the most significant global warming impact comes from etch processes, but actions are being taken to reduce this, including moving away from the use of perfluorocarbons (PFCs) in favour of nitrogen trifluoride (NF_3). Recovery of PFCs is not economically viable as the purity of recovered gases is too low and inconsistent to be of use in subsequent semiconductor manufacture; abatement of emissions, therefore, is the main solution being employed.

Abatement takes the form of exhaust management, with sub-atmospheric plasmas being used to convert greenhouse gases to less harmful compounds. Emissions after abatement are in the region of 20,000 tonnes of CO_2e. Even after factoring in the approximately 25,000 tonnes of energy used in the exhaust management process this represents about a 90% reduction in net emissions from the 500,000 tonnes of CO_2e an unabated facility can produce annually. Over the past 25 years, Edwards have prevented the release of around 20 billion tonnes of CO_2e emissions.

The meeting concluded with the presentation of the 2022 Distinguished Guest Lecture medal to Mr Cottle.

The delegates left having enjoyed one of their first in-person meetings in over two years, and engaging in fascinating discussion on issues related to electronics and electronic waste.

Meeting Report

Circular Chemistry; the enabler to help solve global challenges

Rowena Fletcher-Wood (Freelance, rowena.fletcherwood@gmail.com), Helena Rapp Wright (Imperial College London, h.rapp-wright@imperial.ac.uk), and Laura Alcock (Edwards Ltd, laura.alcock@edwardsvacuum.com)

This event, jointly organised by the Environmental Chemistry Group and Applied Materials Chemistry Group (AMCG), and sponsored by the Department for Environment, Food, and Rural Affairs (DEFRA), attracted 30 delegates and ran as a hybrid event on Zoom and in Burlington House on 30th November.

The meeting began with an introduction to the ECG, and **Dr Rowena Fletcher-Wood** chaired the opening session, introducing **Dr Chris Slootweg** (University of Amsterdam), with **'CHNOPS': from the origin of life to the origin of waste – the principles of circular chemistry**. These key elements, needed in large quantities to make living organisms, also form our key waste streams: whilst the 12 Green Chemistry guiding principles (*1*) are important, they optimise *linear processes*, not circular. With two students who gave the best responses to his challenge "define the principles for circular chemistry", Dr Slootweg published new principles (*2*). His approach focuses on circularity, functionality, and safety, leading to a more sustainable future. Sodium borohydride is under investigation as a potential source of hydrogen storage. The solid is relatively easy to transport, and on (catalytic) hydrolysis releases four mole hydrogen per mole sodium borohydride. The problem of recycling the hydrolysis products is an obstacle at present for its application. Inspired by Hennig Brand, discoverer of phosphorus from urine, Dr Slootweg is also exploring natural wastestreams as sources for phosphate and ammonia via the mineral struvite – an alternative to mining. Struvite ($NH_4MgPO_4{\cdot}6H_2O$) has shown promising results in removing and recovering metals such as Cu from wastewater effluents, reducing environmental risks.

Professor Matthew Jones (University of Bath) spoke next on **Catalytic Upgrading of Polymers – is Chemical Recycling the Answer?** Lightweight, durable, and flexible

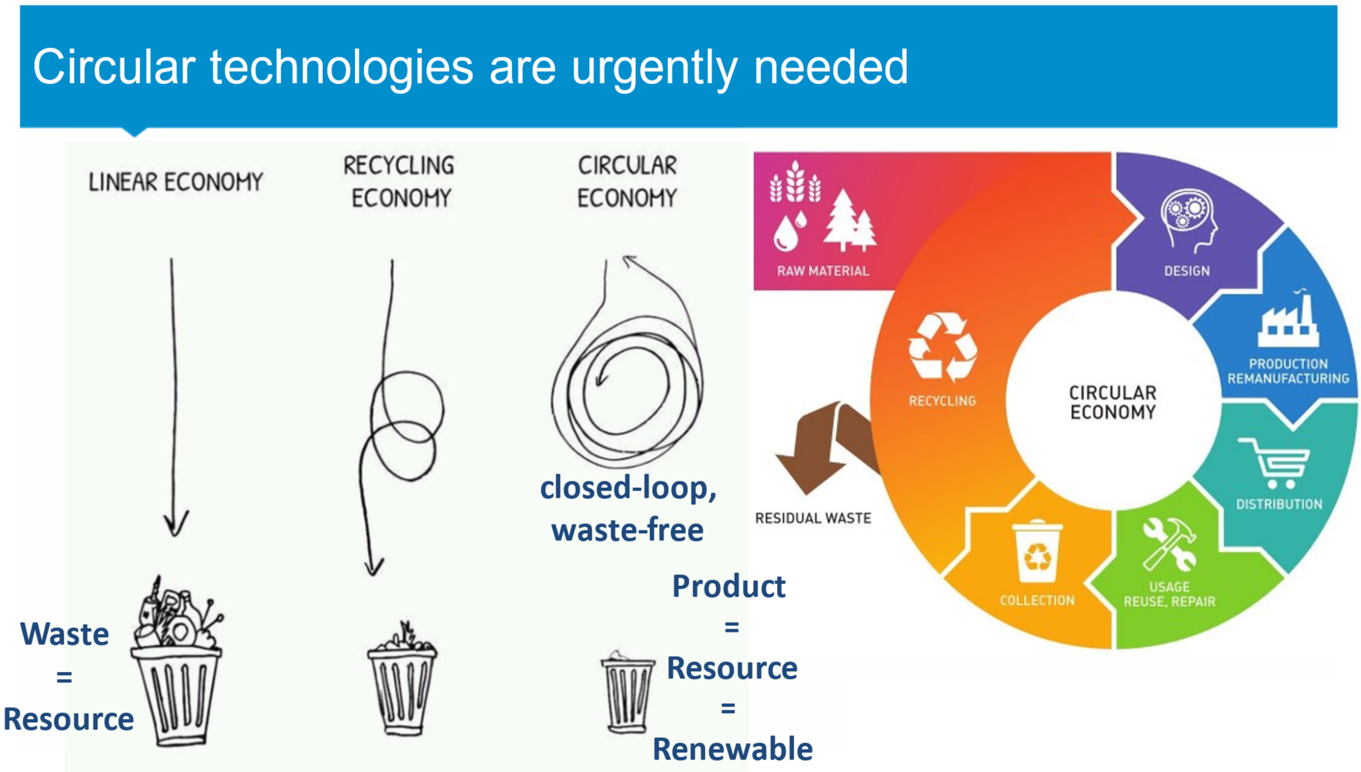


Figure. credit: Dr Slootweg

materials, plastics were originally hailed as an environmental solution – and they still can be, as a renewable feedstock. Professor Jones' work concentrates on keeping carbon in its highest value form (most reactive) to enable chemical recycling of polymers. This can take place through depolymerisation (into original monomers) or degradation (into other useful monomers such as the breakdown of PLA to lactate esters, rather than lactic acid). Professor Jones identified polycarbonates as a key area of opportunity for metal-based, sustainable solutions and plastics diversification (*3, 4*). Using simple ligands, he demonstrated the possibility of compostable, renewable and biocompatible polymers made from coke bottles, processed through aminolysis, glycolysis, and methanolysis. However, the need for smarter and simpler design, including preclusion of additives like plasticisers, fillers, and pigments, was also highlighted.

Inspired by geological timescales, **Professor Colin Hills** (University of Greenwich) next took us on a journey into **Using CO_2 as a raw material: CO_2 used in the treatment of contaminated soils and waste to produce building aggregates.** During the thermal maximum of the Cretaceous period, CO_2 was absorbed by the oceans, transformed into carbonate skeletons of microfauna and deposited as carbon ooze on the seabed, where it later underwent diagenesis to limestone. Professor Hills' work now aims to establish industrially-managed pathways to make similar carbonates on anthropogenic timescales. Using worldwide samples of industrial waste that naturally contain high amounts of Ca and Mg oxides, hydroxides and silicates that react with CO_2 to form carbonates, Professor Hills used two routes, wet and semi-dry (or thin film) to create construction aggregates. These additionally reduce pH and stabilise potentially problematic heavy metals including Zn, Pb, and Ni. Professor Hills highlighted that public perception of waste safety, incentives such as landfill tax and legal obligations, were essential for uptake of this technology.

Session 2, chaired by **Alan Armour** (AMCG) began with **Professor Alex Cowan** (University of Liverpool), presenting **Electrocatalytic reduction of carbon dioxide for a circular chemical economy.** He described the UKRI Interdisciplinary Centre for Circular Chemical Economy's aims to create a shift towards a fossil-independent climate-positive and environmentally friendly circular chemistry economy, considering not only the technical, but also policy, society, and finance aspects of enabling technologies. In particular, he focussed on advancements in CO_2 electrolysis, using the main waste product from fossil fuel combustion, and changing operating conditions from high pH (unsuitable for carbonate regeneration) to low pH, using the catalysts $Ni(cyclam)^{2+}$, $Mn(bpy)(CO)_3Br$ and derivatives (*5*). Whilst the 50% efficiencies achieved may not seem impressive, this is novel under these conditions. Professor Cowan also solved the problem of manganese catalyst poisoning by its products, a two-step process with reversible first step, initiated by rapid cycling. However, he did identify these conditions need to be carefully controlled to prevent dominance of hydrogen generation over hydrocarbons. Next, he is exploring impurity tolerance.

Professor Leon Black (University of Leeds/UKCRIC), presented **The use of industrial by-products (PFA and GGBS) in concrete**. Professor Black began his talk by highlighting the fact that concrete is the second most widely used resource in the world (only after water), and cement production is responsible for 6-8% of global CO_2 emissions. During the production of a single tonne of the material, 880 kg CO_2e is released.

There are several misconceptions around the hydration of cement, with few realising that a series of chemical reactions takes place as cement particles hydrate and dissolve. This is crucial because curing time, or prolonged hydration, affects microstructure. In his design of sustainable, low carbon concretes, and assessment of lifetime performance, Professor Black discovered that adding ground granulated blastfurnace slag (GGBS) to cement creates additional C-S-H bonds, improving durability. 35% calcined clay with 15% limestone, (both widely available), could reduce CO_2e by 250 million tonnes (whereas scale is limited by 350 million tonnes of worldwide available GGBS). Simultaneous thermal analysis showed that longer curing with ambient CO_2 provided more Portland-cement like material with intact microstructures. Construction is a conservative industry, and these findings highlighted the need for good site practice to ensure quality materials and achieve lower CO_2 emission targets. Working with Nigerian partners, Professor Black also identified the need to explore other curing temperatures in developing standards. At higher temperatures, high densification of hydrate was observed (greater porosity) – implying that standards of durability need to be local – British standards are not always relevant. **Professor Peter Edwards** (University of Oxford) described two projects: converting CO_2 into aviation fuel and the catalytic deconstruction of plastics into hydrogen and carbon nanotubes. Current catalysts are still being refined and optimised for sustainable aviation fuel, along with the separation of high value by-products including light alkanes, light olefins, water, and other liquid hydrocarbons. Professor Edwards shared a graphic which showed the human development index of various nations correlated with oil consumption per capita.

> **"If carbon dioxide were coloured, we might have dealt with this problem a long time ago." Professor Peter Edwards.**

The other project involved a change in paradigm: plastics have a high gravimetric density (weight %) of H_2. Using this, Professor Edwards proposed catalysed, microwave-driven plastic waste destruction, producing hydrogen fuel, and demonstrated that effective microwave penetration of materials provided rapid extraction: 20 s is sufficient time to decompose 0.3 g of wax, crude oil, or plastics, and release hydrogen. They are still exploring the mechanism.

Session 3, chaired by **Katie Hobson** (DEFRA), began with an introduction to DEFRA, and then **Sandra Averous-Monnery** (Knowledge and Risks Unit, UN Environment Programme, Switzerland) presented online, outlining the UNEP Framework Manual on Green and sustainable chemistry (*6*). This freely-available framework provides guidance in a variety of languages for a holistic, integrated approach to chemical innovation, including new molecules and compounds, but also opportunity for reducing resource use, conversion technologies, and some technical and policy aspects outlined in other talks today. The aim is to find a solution not just for pollution in general but to enhance the triple planetary crisis: climate action, nature action, and chemicals and pollution action. "Business as usual" is not an option with chemicals and waste. Ms Averous-Monnery outlined 10 ways to promote innovation and unveil the full potential for chemistry to support the implementation of the 2030 Sustainable Development agenda. The unit also facilitates conversation between chemists and the sustainable building and construction sector, encouraging research.

Designing for deconstructing (*e.g.* via modularity) (…) rather than demolishing at end of life, (is) crucial for adaptability.

Aptly, our next speaker, **Dr Katherine Adams** (Alliance for Sustainable Building Products), discussed **Circular economy in construction – what's it got to do with chemistry?** Her analysis of material opportunities for circularity in construction showed that although the UK performs well in terms of recycling, most material is downcycled, losing value. This is aggravated by a doubling global population – tripling materials extraction. Reuse could also be increased: in new building, embodied carbon content may be reduced using reused, recycled, and fewer materials, and replacing materials with lower carbon alternatives. New regulations have catalysed chemical analysis of materials by requiring demolition wastes to prove that they are not hazardous (otherwise they must be treated as hazardous), such as treated wood which will need to be incinerated. Other interesting findings have been the huge extent of microleakage from wear and tear of microplastic-loaded paints. Other factors, such as keeping buildings in use for as long as possible, since "the most efficient building is one that is already built", and designing for deconstructing (*e.g.* via modularity) rather than demolishing at end of life, are crucial for adaptability. Dr Adams highlighted some materials that are particularly problematic as demolition wastes: structural insulated panels (SIPs), introduced as an energy-saving, easy construction material, cannot be recycled, are incredibly difficult to separate, and the insulation material is often a hazardous waste. Carpet underlay is equally challenging, providing an interesting insight into how front-end work seldom accommodates back-end recovery of materials.

Our final speaker, **Dr Richard Sheridan** (University of Birmingham), talked on **Recovery/Recycling of Critical Raw Materials.** Source minerals contain a mixture of rare earth materials. Many of these are desirable with applications such as making magnets for media storage. As we get more creative, more of the mineral is usable, but some of the more common rare earth materials cannot be used – and are stockpiled. It was highlighted that the primary applications of these materials is in renewable energy resources and electric vehicle components – particularly within wind turbines and traction motors, which use highly powerful magnets to generate electricity, either for the local infrastructure or the vehicle in which they are installed. Meanwhile, consumer demands such as higher power and faster cars drives the need for bigger and stronger magnets, and the creation of products such as mobile phones lock up critical raw materials that are challenging to recycle. One major sticking point is the presence of epoxy resins, which are found ubiquitously across devices containing critical raw materials. Dr Sheridan described his work using hydrogen for decrepitation and linking various stages of the processing route to reclaiming magnetic source materials. However, many challenges arise from rare earth magnets such as economy, and the small supply chain in the European Union. Overcoming corroded magnetic materials, and minimising the energy demands of the process are hurdles for scalability, and separation of magnets from traction motors and computer hard drives for recycling was particularly challenging. **Dr Andrew Dunster** (AMCG) provided the overview of the AMCG and closing remarks.

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Article

Revision of furniture flammability regulations

Richard Hull, RSC representative on the BSI FW/6 technical committee on flammability performance and fire tests for furniture (Professor of Chemistry and Fire Science, University of Central Lancashire, trhull@uclan.ac.uk)

Although the government's Office for Product Safety and Standards (OPSS) have not circulated their consultation on the review of the 1988 Furniture Flammability Regulations (FFRs), FW/6 has been meeting to discuss the development of new standards to demonstrate compliance with the revised regulations. The deliberations of standards committees are deemed confidential, and therefore this report outlines my thoughts on the current state of FFRs revision, an issue affecting the lives and health of UK residents.

The main task of this committee is to draft a new British Standard to support businesses to comply with the revised furniture flammability regulations (FFRs) - changes to the FFRs themselves are the remit of the government and OPSS. The proposed format of these revised regulations are generalised, outcome and performance-based Essential Safety Requirements (ESRs). A public consultation on the proposed ESRs is expected in 2023. BSI's standard will then define these performance requirements of new furniture in terms of flammability.

The composition of the committee includes a wide range of stakeholders, which has progressively changed to include those who are concerned about the unnecessary use of flame retardants, and their potential harm to people and the environment. Recently, I've perceived a shift in opinion away from the current, very stringent regulations. It appears that the manufacturers represented are mostly concerned with their obligations under the circular economy, because flame retardant additives add cost, and prevent effective recycling, whilst the test laboratories are dependent on income from furniture flammability testing. It remains to be seen whether the UK will modify its FFRs to align with less stringent Irish and European regulations.

The proposed changes seem likely to include:

1. Composite testing. Instead of testing fabric and filling separately, whole items of furniture are expected to meet the new ESRs. It seems likely that mock-ups made from the same materials will actually be tested for flammability. This should mean that fabric and filling manufacturers will minimise their flame retardant usage for each filling-fabric combination. However, they also want to minimise their product range while maximising market share, so if 20% of the market for a particular product requires flame retardant treatment, it may be cheaper to add a flame retardant to all of that product than to manufacture a separate one for the 20% who actually need it.
2. Foam component testing. Another ESR requires separate tests for foam fillings. If the new test is less severe than the current regulations require, it could allow a large reduction in flame retardant usage. Currently tris(chloropropyl) phosphate (TCPP) is the most widely used flame retardant in flexible polyurethane foams, although it is often used alongside melamine. Both TCPP and melamine are under investigation for potential toxicity by the European Chemical's Agency (ECHA). In mainland Europe, flexible polyurethane foam from used domestic furniture does not contain flame retardants, and is routinely recycled, yielding polyols (and potentially also isocyanates) for re-manufacture. In the UK, the presence flame retardants in foam prevents recycling.
3. Reduction in flame retardant use. The revised regulations also aim to bring about a reduction in reliance on chemical flame retardant (CFR) use to meet flammability standards. Current CFRs could be found to jeopardise the safety of the user or a third party. However, OPSS have said in discussion that until restricted under UK REACH, they can be legally used.
4. Technical File and Labelling. In addition, the proposed ESRs specify a technical file and labelling proposals, which provide information to consumers, trading standards and waste operatives on the use of flame retardants, traceability, and a technical file for enforcement of the regulations.
5. Justification for CFR use to follow a Flame Retardant Technology Hierarchy - in preferred order from: no need for CFR use; use of inherently fire-retardant materials; use of CFRs.

It remains to be seen what is, and what is not, included in the new FFRs once the review process has been completed, and where FW/6 propose the line should be drawn for achieving compliance in their new standard.

Meeting Report

Science outreach with new audiences

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

Science is for everyone, but not all the ECG outreach activities are appropriate for every audience: many require a good level of English, and an understanding of technical terms such as pH or acidity. Considering how to adapt activities to include more interested people led me to take three ECG outreach activities to a small class of pre-schoolers at **Little Pioneers Nursery,** Rose Hill, Oxford in October 2022.

The group of around 10 children were introduced to ocean acidification, making bee balls, and simple pH experiments.

The first experiment, **ocean acidification**, is a stunning visual demonstration where a universal indicator is added to slightly alkaline water, followed by dry ice. It is always popular, and children enjoy touching the "steam" coming off the top. An outline of this activity may be found in the **July 2019 *Bulletin***, p. 22 *(1)*. To make this safer for pre-school children, I confined the dry ice to a plastic box, sealed with tape, with holes smaller than the pellets pierced in it. After asking them what dry ice was, inviting them to touch the outside of the box and talk about what cold meant, the children guessed what would happen when I submerged the box in warm water – our 'ocean'. The most popular guess was that the solid would melt. This led on to a discussion of melting and boiling (the term 'sublimation' did not arise!). Flammable Universal Indicator and corrosive sodium hydroxide (to make the ocean alkaline) were excluded, but we did add some coloured juice to the water, to safely explore use of all your senses (seeing no colour change, smelling/tasting the orange carried by the vapour, touching the vapour and water, and hearing the bubbling).

The children guessed what would happen when I submerged the box in warm water. The most popular guess was that the solid would melt.

Whilst the environmental messages carried by this demonstration were clearly diluted, there remained plenty of opportunities for scientific engagement and honing observation skills.

Oppositely, the **bee balls** activity (**July 2022 Bulletin** p. 14 *(2)*) maintained its environmental message, but lost some of its finer details: measuring amounts had to be neglected: we took the activity outside and used a large table where all the components could be laid out and mixed. Some children took roughly even amounts, whilst others were more relaxed; however, all were keen to ensure they had included the soil, clay, seeds and water that make useful wildflower seed balls. Pouring water carefully was a challenge, and led to problem-solving to correct some very soggy results. The children and staff enjoyed talking about outdoor activities, plants and insects.

I was very impressed with the deductive thinking shown during our simple pH tests (which I called **marvellous medicines**). In order to show the three-year-olds pH changes safely, I used butterfly pea tea instead of Universal Indicator. Each had a little in a transparent plastic pot, and I offered lemon juice, white vinegar, orange squash and bicarbonate of soda with a spoon. First we looked at and smelt the samples to guess what they were, then we tested them. The children looked at the colours they each made and added more things with the aim of making their favourite colour. Green, blue, purple, pink and grey all arose. After one child mixed an acid and the bicarbonate of soda, the others keenly attempted to replicate this and paid good attention to detail. Some tried adding lots of the power either without acid or in excess, which helped us to show that both were needed to get more frothing.

The colours we made during pH experiments

You can watch all our activity videos and access *How Tos* and activity sheets at

https://www.envchemgroup.com/resources.html

Meeting Report

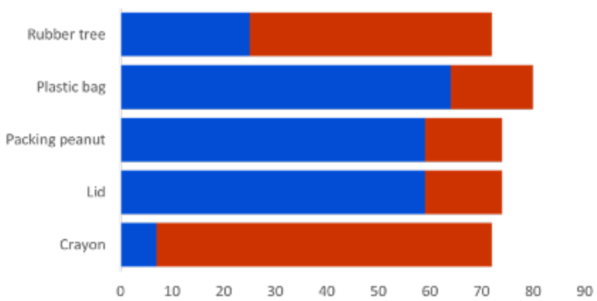
Science outreach – Oxford Science and Ideas Festival 2022

Niall Marsay (Cranfield University, n.h.marsay@cranfield.ac.uk)

What is science outreach? At Oxford Science and Ideas Festival (IF Oxford), it is captivating curious minds of all ages and backgrounds to access and shape new ideas. This year, the ECG was present in force to get people thinking about environmental pollution.

The tools of our trade

We ran four fantastic demos including a new activity inspired by recent headlines of sewage overflows in rivers: **testing riverwater samples** used a portable conductivity meter and various samples. Conductivity measurements establish the ability of water to pass electricity because of the presence of dissolved ions such as sodium, chloride, calcium, and magnesium. Water bodies tend to show a relatively stable conductivity, thus significant changes could indicate a pollution discharge into the aquatic environment. We discussed how clean our rivers were in rural and urban areas and how clean our drinking water is. Discovering that pool water has higher conductivity than river water surprised many, and led to thoughtful discussions about how we can use chemicals to keep environments healthy and unpolluted.



Sink of float? results: *Rubber tree and crayon sank (65% and 90% correct respectively), whilst plastic bag, packing*

Introduced earlier this year to the ECG outreach provision was **sink or float?**, a simple demo using several types of plastic which the public votes on – will it sink or float? This opened discussions about what plastics are made of, and allowed us to measure our **meaningful** engagements – this time, > 80.

Hunting for microplastics (**July 2018 Bulletin** p.22 (*1*)) – comprises of trays filled with soil contaminated with plastic pieces. While it does not sound fancy, kids love routing through the dirt with tweezers and a magnifying glass, and let our volunteers have deeper discussions about soil pollution with parents.

Our **ocean acidification** (**July 2019 *Bulletin*,** p. 22 (*2*)) demo has been a mainstay of ECG outreach and always draws the crowds. We start off with a slightly alkaline 'ocean' and get people thinking about acidity and alkalinity using the pH scale. To simulate increasing CO_2 in our atmosphere, we add dry ice. The "smoke" and bubbles get everyone excited – even the adults (and me!) – and makes the Universal Indicator in our ocean change colour from blue to green to yellow, sometimes even to red. This visualises drop in pH, and allows us to explain how ocean acidification causes coral bleaching. Finishing on a negative note, however, is not ideal, and although we have positive climate change stories, we are keen to develop a demonstration about fighting climate change – if you know one, please do get in touch.

Team*: Mark Powders, Rowena Fletcher Wood, Sophia Bahddo, Laura Alcock, Niall Marsay, Miles Folks.*

The show must go on.

A big thanks to the volunteer team. We will be doing more events like this in the future, and we always need volunteers so please do contact me at

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How to

DIY air pollution sensors

Niall Marsay (Cranfield University, n.h.marsay@cranfield.ac.uk)

Find out where the air pollution is hiding in your house with this simple DIY sensor.

We all live with air pollution daily, but did you know that research suggests there is 2 to 5 times more air pollution inside our homes than outdoors? Air pollution has been linked to higher chances of asthma and allergy and, in some cases, premature death. As environmental scientists, we work to understand where air pollution is and its sources.

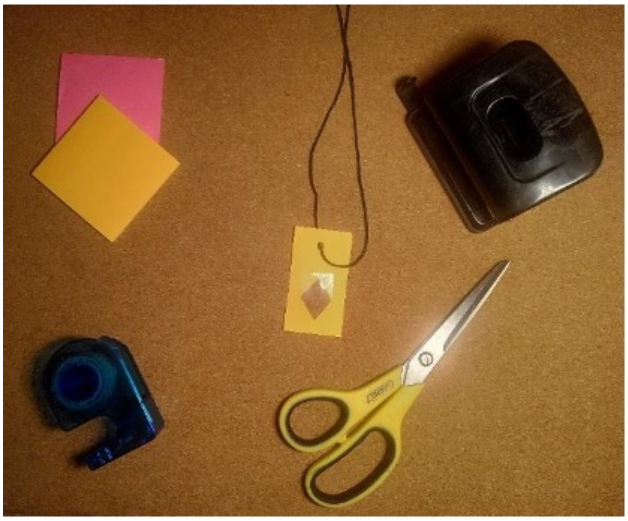
This *How To* shows you how to make a simple though effective air pollution sensor at home to monitor your environment.

Challenge

Dose the position of the sensors in each room make a difference? Can you think of or find any ways to reduce air pollution in your homes?

You'll need

- Paper/ card
- Sellotape
- Scissors
- A hole punch
- Magnifying glass or microscope



Instructions

1. Hole punch the top of the paper.
2. Fold the paper and cut a triangle in the fold.
3. Unfold and place Sellotape over the large hole be carful not to let the Sellotape in the opening touch any surfaces and become "contaminated".
4. Thread string through the hole to make a hanger.
5. Place a sensor in several rooms in the house and think about which room might have the most air pollution. Do not forget to label your sensors!
6. After a week, take down the sensors and examine them with a magnifier of some sort.
7. What did you find?

Extension

If you are feeling particularly scientific, try to count the number of particles on each sensor, and estimate the particle density (e.g. how many per square cm). You can then compare quantitatively as well as qualitatively between sensors.

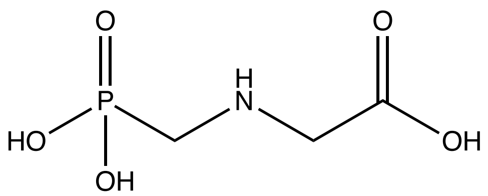
Article

Glyphosate – An effective but controversial weedkiller

Dr John Collins (Environment Agency john.collins@environment-agency.gov.uk)

Marketed under trade names including Roundup, glyphosate is a widely used herbicide. Recently, glyphosate usage has prompted a vigorous debate about its safety and toxicity.

Glyphosate, or *N*-(phosphonomethyl)glycine, is an organophosphorus compound analogue of the amino acid glycine. Under the tradename Roundup, glyphosate was sold worldwide, originally by the Monsanto Company, now part of the German multinational Bayer AG; many other weedkiller products now also contain glyphosate. Its chemical structure is as follows (*1*):



Nowadays, commercial manufacture of glyphosate follows either the " alkyl ester " route by reacting glycine with phosphorous acid and formaldehyde or the "iminodiacetic acid (IDA) " route, which replaces glycine with IDA (*2*).

Glyphosate is widely regarded as an effective weedkiller, which explains its long and widespread use. When applied, glyphosate enters the plant via the leaves. Once absorbed, glyphosate migrates to the growth parts of the plant. Then, by disrupting a synthase (enzyme), glyphosate stops the shikimate pathway, which regulates the synthesis of proteins, causing plant mortality. Glyphosate is commonly apply to soybeans, field corn, pasture, and hay production (*3*). Varieties of plants including soy and corn have been adapted to glyphosate, allowing selective action against non-crop weeds

Concerns about glyphosate have been heightened by studies which reported that the chemical is almost ubiquitous

Animal and human exposure routes mainly include inhalation, ingestion, and dermal contact. Studies involving rats and mice exposed to high doses of glyphosate showed growth delays, kidney damage, liver enlargement and gastric disease (*4*). In 2015, the World Health Organisation (WHO) reclassified glyphosate as "probably carcinogenic to humans". In a 2018 court case, Dewayne Johnson, a Californian groundsman who had developed non-Hodgkin's Lymphoma, won damages from Monsanto of $226m, later reduced to $78m (*5*). Subsequent studies, however, have failed to provide conclusive evidence substantiating the WHO classification. Andreotti and colleagues (2018) studied glyphosate's cancer incidence within a cohort of American pesticide applicators under the Agricultural Health Study (*6*). The cohort comprised 54,251 applicators of whom 44,932 used glyphosate. While 5,779 cancer cases were reported amongst glyphosate users, no correlation with glyphosate use was found. An increasing risk of developing acute myeloid leukaemia was reported amongst the highest use quartile. Nevertheless, no significant correlation was established.

Concerns have been heightened by studies reporting that glyphosate is almost ubiquitous in humans. According to the Heinrich Böll Foundation (*7*), traces of glyphosate were consistently detected in the urine samples across Germany (99.6% of the population); the highest concentrations were found in children and young people who had worked in the agricultural sector. In 2013, another German study comprising 182 samples of urine collected in 18 European countries showed that 45% of the samples contained glyphosate (*8*). While stakeholders received with alarm these results, the German Federal Institute for Risk Assessment described them as "expected" and "less than one hundredth of the acceptable daily intake" (*9*); the Institute also criticised the scientific quality of the Heinrich Böll's Study.

In 2017, the European Chemical Agency's Committee on Risk Assessment concluded that glyphosate should be classified as a substance causing serious eye damage and exerting toxicity on aquatic life with chronic effects. The available scientific evidence, however, did not meet the criteria to classify glyphosate for specific target organ toxicity, or as a carcinogenic, mutagenic, or reprotoxic substance. A following 2022 review concluded the 2017 classifications for glyphosate should be maintained. Again, no sufficient evidence was found to classify glyphosate as having other health or environmentally hazardous properties (*10*).

Safety data sheets consider glyphosate toxic to aquatic life, causing long-lasting effects, and recommend it must not be

dispersed in the environment. Glyphosate shows toxicity to aquatic plants by disrupting photosynthesis, respiration, and amino acid synthesis (*4*).

In soils, glyphosate is reported to break down, in a relatively quick reaction, into (aminomethyl)phosphonic acid(or AMPA). Degradation rates vary with temperature, soil type, and water availability. A strong chelating agent, glyphosate binds to minerals in the soil environment; this reduces its activity (*11*).

Because of intensive usage in agriculture, Van Bruggen and colleagues suggested a potential link between the proliferation of bacteria recalcitrant to glyphosate and the development of antimicrobial resistance in the environment (*12*). The authors speculated that both glyphosate and antibiotic resistance results from common mechanisms. Hence, changes in microbial populations driven by glyphosate exposure could translate into thriving antibiotic resistance strains with the potential harm to biota and humans.

A meta-analysis of 34 different studies linked an increase in bee mortality with exposure to glyphosate. When dosed at the manufacturer's recommend concentrations, glyphosate seems to impact bee survival, development, and behaviour (*13*). Furthermore, researchers from the University of Texas at Austin (*14*) reported that glyphosate affects gut bacteria in honeybees, specially those strains using the shikimate pathway; altered gut microbiota can result in more bees prone to stressors (*e.g.* malnutrition and pathogens).

The controversy surrounding glyphosate's health and environmental impacts continues.

The controversy surrounding glyphosate's health and environmental impacts continues. The European Food Safety Authority is currently assessing the food safety implications of the European Chemicals Agency's risk assessment decision (*10*). In the United States, the courts are starting to play an increasingly prominent role. In January 2020, the US Environmental Protection Agency (EPA) issued an interim decision claiming that, as long as revised mitigation measures were followed, glyphosate was safe to use from both a human health and an environmental perspective. The Agency also reiterated glyphosate's non-carcinogenic nature. Such decision was challenged in a federal appeals court by a group of food, agricultural, and environmental stakeholders. The court noted EPA's limited evaluation of the health and environmental risks associated with glyphosate, and ordered a thorough review of current evidence (*15*); citing insufficient time to address the court's requirements, EPA withdrew its interim decision.

Disputes around glyphosate and the uncertainty about its toxicity are perhaps summed up by the wording that California's Office of Environmental Health Hazard Assessment proposed for the labels of glyphosate-containing products in the state: "CALIFORNIA PROPOSITION 65 WARNING: Using this product can expose you to glyphosate". The International Agency for Research on Cancer classified glyphosate as probably carcinogenic to humans. US EPA has determined that glyphosate is not likely to be carcinogenic to humans; other authorities have made similar determinations. A wide variety of factors affect your potential risk, including the level and duration of exposure to the chemical. For more information, including ways to reduce your exposure, go to http://www.P65Warnings.ca.gov/glyphosate.

In summary, while being an effective weed killer, glyphosate is widely regarded as toxic in the environment. Evidence about its toxicity to humans remains a point of debate.

View expressed in this article are those of the author and do not represent those of the Environment Agency.

Native Irish Honey Bee- Photograph by Cindy Smith

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Article

Materials recovery: The precious prospects within e-waste

Laura Alcock (Edwards Ltd, laura.alcock@edwardsvacuum.com)

This year, the Royal Mint unveiled plans to extract gold from e-waste using a room temperature process, recently developed by the Canadian company Excir (1). For the 2020 Olympic Games in Tokyo, enough gold, silver, and bronze was extracted from two years' national e-waste to produce all 5000 Olympic medals (2). Could these two separate ventures sufficiently demonstrate the value of e-waste to encourage better rates of recycling?

Currently, 50 million tonnes of electronic waste (e-waste) are produced globally every year. Presently, less than 20% of this waste is recycled appropriately, the remainder being incinerated or sent to landfill. The total mass of e-waste production is expected to reach 74 million tonnes by 2030. Unless recycling and reuse rates increase, this will mean more than 59 million tonnes of material wasted, equating to billions of dollars of value (*1*).

Apart from the "rare" earth elements utilised in the manufacture of electronic devices, particularly batteries, significant quantities of precious metals are present within the circuit boards. All these elements contribute to electronic devices having a high monetary value at the time of disposal. Additionally, the decreasing availability of materials in the earth's crust and their low concentrations where they are available (average concentrations in ore: copper 50 ppm, silver 0.07 ppm, and gold 0.005 ppm) (*3*), the ability to extract these materials from end-of-life electronics, where their presence can be measured as a percentage, is becoming increasingly more attractive.

With this consideration, the organisers of the 2020 Tokyo Olympic Games (*2*) and the British Royal Mint (*1, 4*), respectively, have made efforts to extract the precious metals from e-waste, whilst the Urban Mining Innovation Centre at the University of British Columbia are looking to develop processes to make mobile phones 100% recyclable.

Extraction from gold ores, as well as secondary sources, typically involves the use of cyanide.

2020 Tokyo Olympic medals

The Rio de Janeiro 2016 Olympic medals utilised recycled silver, obtained from sources such as mirrors, car parts and x-ray plates and copper (for the bronze medals) came from mint waste (*2*). This was a significant step for the global sporting celebration towards a sustainable model. This step was not only equalled, but far exceeded by the 2020 Tokyo Olympic Games organisers, who sought to achieve production of the required 5,000 medals from entirely recycled e-waste materials.

In April 2017, the Tokyo Olympic Committee initiated a two-year campaign to collect and recycle sufficient e-waste to recover the materials for the manufacture of the medals for the Games. At the beginning of the campaign, 600 municipalities were involved, this number growing to exceed 1,600 by the end of the project in March 2019 (*2*). Sites opened across the nation to allow people to donate their electronic devices locally to their homes. The result of the campaign was a staggering 80 tonnes of small electronics such as mobile phones and laptops. However, this is an incredibly small portion of the estimated 2 million tonnes of e-waste produced by Japan annually – suggesting that only 0.002% of Japan's annual e-waste contributed to the Tokyo Medals Project, but this was a marked increase in recycling of the devices.

Around 250 mobile phones needed to be processed in order to obtain the 6 g (out of 500 g) of gold for each gold medal. In total, around 32 kg of gold, almost 3,500 kg of silver, and around 2,200 kg of bronze (95% copper, 5% zinc) were recovered from the donated waste small electronic devices (*2, 5*) (**Figure 1**).

Whilst this was acknowledged as a significant step in the right direction, Professor Maria Holuszko (of the Urban Mining Innovation Centre at the University of British Columbia) expressed concern that this is insufficient (*6*). Whilst the metals within e-waste is the valuable portion and simpler to recover, the remaining portion of the device can present significant environmental risk if simply sent to landfill or shredded and incinerated, particularly as this represents the majority portion of the device.

Royal Mint e-Waste recycling plant

In March 2022, the British Royal Mint announced that they were constructing a plant within their secure site for the extraction of gold and other precious metals from e-waste (*4*). The facility will use a process developed by Excir which achieves over 99% recovery of the precious metals at room temperature. The site is expected to be fully operational in 2023.

Figure 1. *Composition of 2020 Tokyo Olympic Medals. Credit: Andy Brunning, Compound Interest, 2021 (5).*

The average annual gold mining output is over 2,500 tonnes, whilst annual global recovery is approximately 900 tonnes. This includes anode slime, jewellery, dentistry, and electronics scraps, and other material sources. The extraction from gold ores, as well as secondary sources, typically involves the use of cyanide, making the process potentially toxic, to form the water-soluble complex gold cyanide, *e.g.* $K[Au(CN)_2]$ or $Na[Au(CN)_2]$. When present in solutions at a pH less than 11, 99% of the cyanide exists as hydrogen cyanide gas (*3*). Over a period of 5 hours, this process typically recovers < 5% of the gold in the source material (*3*).

Thiosulphate has been the most commonly studied alternative to cyanide for gold leaching from ores and other sources (*3*). Benefits of its use include faster leaching kinetics, lower toxicity and a higher rate of gold recovery in the case of some refractory gold ores. However, the chemistry is complex and requires the use of ammonia, meaning that the process is still toxic, involving high thiosulphate consumption. Thiourea is another well-studied gold leaching agent (*3*). However, the technique using it requires high consumption of thiourea and, presently, no techniques have been developed to recover the gold leached from solution, following this process.

The Excir method's novelty lies in its use of water-miscible and partially water-miscible organic solvents for the dissolution of gold from ores and secondary sources, whilst saving energy and material (*3*). The method allows recovery of gold, platinum and palladium from compounds and mixtures using a combination, under appropriate conditions, of an acid, an oxidising agent, and a water-miscible or partially water-miscible organic solvent. Their research found that mixtures of hydrochloric acid and hydrogen peroxide or calcium hypochlorite in ethyl acetate or acetonitrile leached greater than 99% of the available gold from a mixed or compound source within a short period of time, at room temperature.

A benefit of this process is that, whilst impurities can be reduced during the gold reduction process, the gold precipitate can be purified by solvent extraction. The solvent can then be evaporated from the leached precious metals and condensed for reuse, reducing the consumption of materials and energy overall. The patent outlines that the process can use a wide range of purification, precipitation, and filtration methods to achieve the desired purity of precious metal product. Additionally, the method allows use of any of a number of compatible acids, oxidising agents, and water-miscible or partially water-miscible solvents.

The Excir process has greater efficiency than cyanide-based processes. This is achieved by the simultaneous leaching and solvent extraction of the precious metals from the source material, whilst the cyanide-based processes achieve these as separate steps. The solvent can also be recovered and reused from the process as developed by Excir, reducing material consumption, combined with reduced time requirements and the ability to complete the process at temperatures between 10°C and 80°C, the energy and material requirements are drastically reduced. The process also provides the fastest known dissolution rate for gold in organic or aqueous systems (6020 $gm^{-2}h^{-1}$ at room temperature and 9000 $gm^{-2}h^{-1}$ at 60°C). Less water consumption and safer materials mean that the environmental benefits of this process are not only based in the resourcing of precious metals from secondary sources, rather than mining, but also the reduced impact of the process compared with other methods of leaching gold.

During incineration of printed circuit boards containing BFRs, hydrogen bromide forms in the fly ash.

This method will be utilised at the Royal Mint's new plant from 2023 onwards to process an expected 90 tonnes of e-waste per year, producing hundreds of kilograms of gold from this waste (*4*). The UK produces the second highest quantity of e-waste within Europe, after Norway. Less than 20% of e-waste is currently recycled and, of this, only a small portion is reused. With a current global production of 50 million tonnes of e-waste per year, forecast to rise to 74 million tonnes per year, this process, along with the efforts of the Urban Mining Innovation Centre, could make the proper recycling and material recovery from e-waste more attractive to many industries, resulting in a potential improvement in the rate of these activities.

In the meantime, the Royal Mint's new facility will support around 40 new jobs and begin to make use of the $57 billion dollars of precious metals contained within e-waste every year.

Urban Mining Innovation Centre

Professor Maria Holuszko, of the University of British Columbia (UBC), founded the Urban Mining Innovation Centre within the university. The goal of this centre is to develop techniques and processes which allow recycling and recovery of the entire material make-up of a mobile phone (*6*).

Professor Holuszko has also collaborated with Professor Clara Satato, of Polytechnic Montreal, in training engineering professionals in Sustainable Electronics and Eco-Design (SEED). This includes training design, manufacture and recycling of electronics. It is also hoped that these engineering professionals will become educated in urban mining and go on to develop economically, environmentally beneficial, safe methods of recovering and repurposing the materials from e-waste, whilst minimising both loss of material and impact to the environment (*7*).

The team at UBC also made advances toward their goal of 100% recyclability of mobile phones, in 2018, when Professor Holuszko and Amit Kumar developed a process for the separation of fiberglass and resin. This is a massive step towards reducing the waste portion of mobile phones and other electronic devices utilising printed circuit boards – which comprise a much more significant proportion of the device's mass than precious metals (*7*).

There exist several issues with these components and materials which mean that they are not recycled. Firstly, they are more complex to recover, in that they cannot simply be leached or dissolved and therefore extracted. These materials also have a lower monetary value, and they are more abundant, which means that there is much lower incentive to recover them from end-of-life products (*8*). Their impact to the environment, however, and the general public's improving awareness and sensitivity, are key reasons to pursue advances, such as those made by Professor Holuszko and Mr Kumar to, not only develop the processes, but also to scale them up and apply them to real-world waste streams.

Apart from the fiberglass being recovered, this process will limit the addition of brominated flame-retardants (BFRs) into the environment through the disposal of printed circuit boards. BFRs are used to ensure that the circuit boards can operate within a range of temperatures without damaging the components and to reduce the risk of fire within the devices (*9*).

During incineration of printed circuit boards containing BFRs, hydrogen bromide forms in the fly ash produced, as well as polybrominated dibenzodioxins and dibenzofurans being released to air (*10*). These present hazards to the environment and, potentially to human health. Hydrogen bromide is harmful, as a gas, at concentrations of 2 ppm and acutely toxic to humans at only 30 ppm. Polybrominated dibenzodioxins and dibenzofurans can also enter food sources for ecosystems and studies have revealed them to be highly toxic, causing death in rats within 30 days or potentially bioaccumulating through the food chain (*11*).

In landfill, BFRs can be leached from the printed circuit boards and volatilisation occurs, meaning easy and rapid uptake into ecosystems, which can be very damaging. These compounds, which are also toxic, have been found in ecosystems, including terrestrial and water-based systems, far from the landfill sites where they originate. These compounds are persistent and bioaccumulate, presenting greater risks at higher levels of the food chain. The distance that these compounds are able to travel is also astonishing, with studies revealing the presence of BFRs in the Arctic. Investigations have revealed that plants and wildlife throughout the natural and cultivated food chains, as well as human tissues, contain BFRs at varying concentrations. Evidence also indicates their potential for various methods of toxicity and endocrine disruption, though little study has been made into their environmental fate and biodegradability.

The method developed by Professor Holuszko and Amit Kumar utilises the different densities of the glass fibres and the resin to achieve gravity separation of the two materials. The separated fiberglass can be used for construction and insulation materials. There is also the potential for its reuse in circuit board fibreglass. However, the reports on the study do not indicate that the resin can be reused, nor its fate following the separation from the fiberglass.

Conclusion

There are many directives driving improvements in the reuse and recycling of waste electronics and electrical equipment. Among these are the Waste Electronic and Electrical Equipment Directive (WEEE, 2012), Restriction of the use of certain Hazardous Substances Directive (RoHS 2011/65/EU), Energy Related Products Directive (ErP 2009/125/EC) and the Energy-using Products Eco-Design Directive (EuP). These place the onus and cost of recycling and disposal of waste electronics on the original manufacturer. Furthermore, they require improvements in the energy efficiency and useable lifetime of consumer electronics, in order to reduce the rate of waste (8).

However, whilst these directives have driven improvements, the primary incentives have come from consumer pressure, increasing scarcity of materials, and increasing value of materials that can be recovered. As a result, the direction of manufacturers has been to recover the precious and "rare" earth metals which have high sourcing costs and, therefore, high value. These make up an incredibly small portion of electronic devices, meaning that recovery of the bulk of material comprising the devices must be developed by those whose primary interest is in protecting the environment and limited resources that it has to offer.

Whilst the Tokyo Medals Project and the Royal Mint's new plant are significant steps in the right direction, they are still only a few paces on a very long route towards sustainable electronics and sufficient recovery of the materials at the time of disposal. This route relies not only on the manufacturers' attitudes towards design and material sourcing, but also on consumer and retailer attitudes evolving and becoming more responsible and sustainable to compliment these new techniques. The concern around this is that potentially the largest obstacle to a sustainable electronics economy lies in retailers. Electronics retailers have no legal nor financial responsibility for safe and sustainable manufacture, use or disposal, however, they stand to make the greatest profit from rapid product turnover and replacement.

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Article

Environmental management of exhaust gases associated with the manufacture of semiconductors

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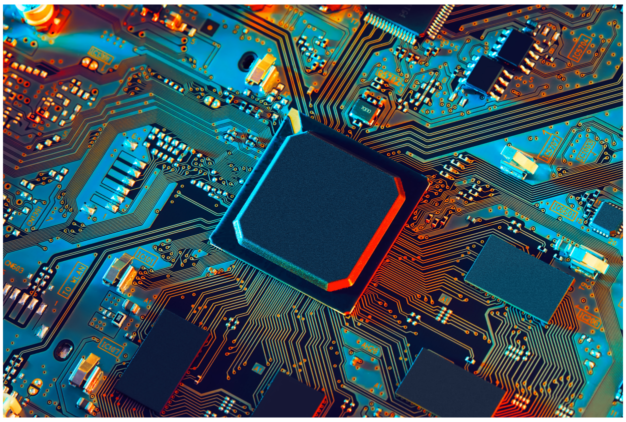


Ever considered the environmental impact of a computer? A phone? Or even just the silicon chips inside them? The semiconductor industry is a $375 billion (*1*) business, and the manufacturing of silicon chips creates a great deal of waste. One key set of chemicals used in the processes are Fluorinated Greenhouse Gases (F-GHGs). Here we will explore the F-GHG usage and the carbon dioxide equivalent (CO_2e) footprint of the factories that make them.

Semiconductors are devices that when an increasing voltage is applied to them, will begin to conduct electricity. Usually made from silicon, by varying the electrical properties, transistors (an electrical switch) can be manufactured. Over the past 40 years Moore's law, named after Gordon Moore the co-founder and CEO of Intel, has meant that the number of transistors in an integrated circuit has doubled every two years. This has been achieved by continual process development to shrink the size of transistors, such that the most modern chips now have a density of over 100 million transistors per square millimetre and that a processor such as the Apple A16, which is used in the latest iPhone 14 Pro, has more than 16 billion transistors (*2*).

The density of transistor on a modern chip is now over 100 million per mm². This means that for an Apple A16 chip there are more than 16 billion transistors.

Table 1. *Global Warming Potentials (3).*

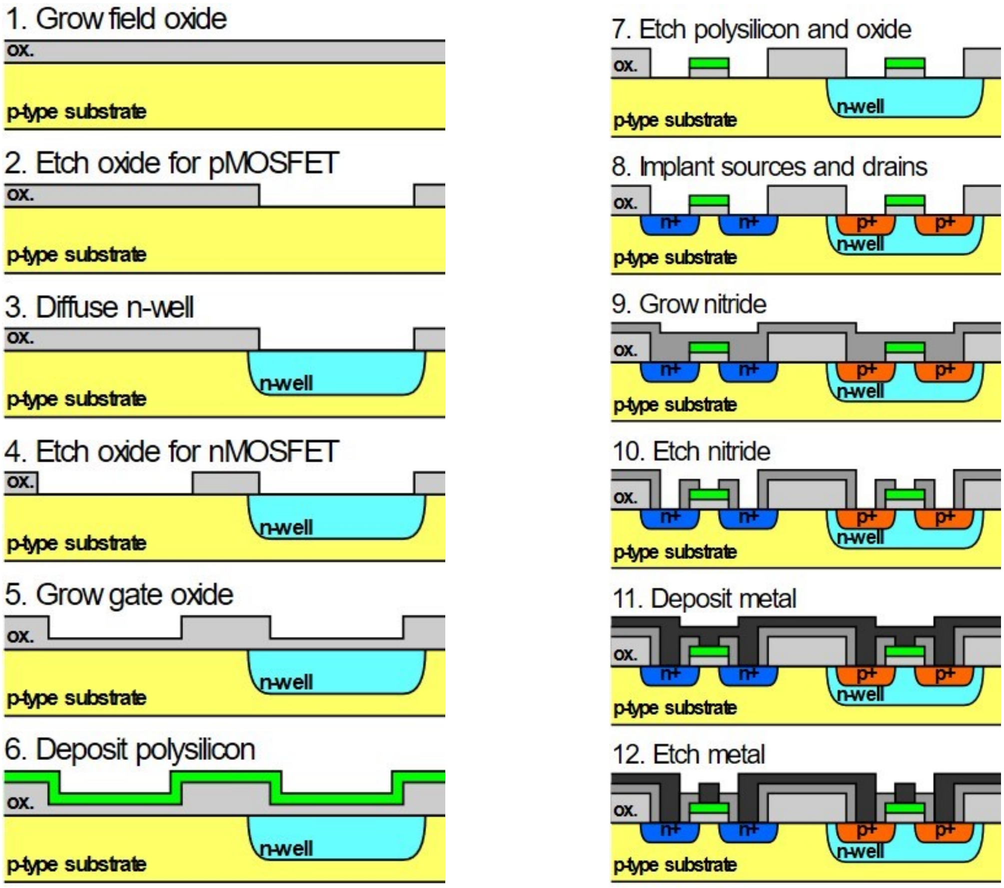
Gas	Atmospheric lifetime years	100 year GWP
Carbon dioxide (CO_2)	50-200	1
Nitrous oxide (N_2O)	109	273
HFC-23 (CHF_3)	228	14,600
HFC-32 (CH_2F_2)	5.4	771
HFC-41 (CH_3F)	2.8	135
CF_4	50,000	7,380
c-C_4F_8	3,200	10,200
SF_6	3,200	25,200
NF_3	569	17,400

The other major use for semiconductors is memory and the amount of memory required is increasing exponentially. According to Forbes, 90% of the world's data was generated in the last two years with 2.5 million terabytes data being created each day. In 2014 less than 0.1 zettabytes (1021 bytes) had been generated whereas the forecast for 2024 is that over 90 zettabytes of data will be generated.

Semiconductor Manufacturing

The simplistic view of semiconductors manufacturing is a cycle of depositing material onto silicon, patterning (lithography) and, then etching.

The deposition process uses some F-GHGs in order to maintain the cleanliness of the processing chamber as deposited material can contaminate the next wafer. The etch processes use a great deal of different F-GHGs to create the fine structures for circuitry. These F-GHGs can have high Global Warming Potentials (GWP) and long lifetimes in the atmosphere as seen in **Table 1**. An example is CF_4, which has a 100 year GWP of 7,380 compared to 1 from CO_2.



CMOS fabrication process. Credit: Creative Commons Attribution-Share Alike 3.0 Unported license.

According to US Environmental Protection Agency's Facilities Level Information on Greenhouse gases Tool (FLIGHT) (*4*), the emission of the F-GHGs for a modern semiconductor fabrication plant can be in excess of 500,000 tons CO_2e. However, the semiconductor industry has long recognised the potential impact of F-GHGs and has, over the last 25 years, strived to reduce the emissions of these gases. An example was The World Semiconductor Council, which agreed in 1999 to reduce emissions by 10% by 2010 (*5*). They have employed strategies such as optimization of processes, substitution of non- (or low-) GWP gases and particularly abatement, where the destruction of some of these gases can be particularly challenging. This means that emissions can be reduced by 90%. So, what does that mean for our environmental footprint of phones? The iPhone 14 Pro has a lifecycle carbon footprint of 63 kg CO_2e of which 81% is from the production process (*6*). Increasing the memory from 128 GB to 512 GB increases the footprint to 84 kg CO_2e; however, increasing to 1TB and it becomes 116 kg CO_2e. Thus, the importance of reduction of F-GHGs in the semiconductor manufacturing process is paramount.

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Article

Combining art and science for effective public communication

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Scientists struggle to convey scientific findings and concepts to the public. The Transitioning to a Circular Economy with creative artists project (TRACE) was a novel and ground-breaking collaboration between scientists, creative artists, and primary school children to communicate and raise awareness about electronic waste (e-waste) and accelerate the circular economy. TRACE aimed to demonstrate the capability of intergenerational and creative projects to raise awareness of, and influence public attitudes towards, e-waste. The project was a resounding success as 99% of audiences reporting a rise in awareness, 70% indicated an intention to change their e-waste disposal and 65% intended to change their reuse/ repair behaviour.

Enabling effective resource management requires active public engagement, which pose huge challenges. Many political, environmental, social, technological, legal and economic approaches have been trialled, but little progress has been achieved because scientists frequently experience considerable difficulties communicating findings to the public. The TRACE project aimed to address this problem for e-waste by developing, trialling and testing a new public communication method. The campaign combined two rarely used methods: intergenerational influence and creative arts.

> **Scientists frequently experience difficulties communicating findings to the public.**

Communication methods

Traditional methods of public communication about waste include consultation papers and requests for comments; community information (posters, leaflets, doorstepping, focus groups); meetings (private or public); citizens' juries and parliaments; workshops and seminars; advisory panels, committees and fora; stalls at fairs events; and media campaigns (radio / TV / the Internet). These channels tend to have limited, mainly short-term impacts. Even very high-profile campaigns in the UK – popular children's TV characters The Wombles highlighting the problem of littering (*1*) and the Waste and Resources Action Programme's highly acclaimed "Love Food Hate Waste" campaign (*2*) – failed to stop litter and food waste from growing. This is because these methods tended to assume that the divergence between scientific and public views are caused by incomplete/flawed public knowledge and, so communication efforts focused on public education and raising awareness.

Musician Robin Browning with the children of Otterbourne Primary School, Hampshire.

Recent studies have highlighted that ideology, not knowledge, best predicts environment-related attitudes and behaviour (*3*). Thus, researchers have moved away from investigating cognitive bias towards understanding the effectiveness of emotion-based approaches (*4*). The problem is particularly notable in environmental science due to the immediacy of the issues at stake. Whilst the public may be aware of general environmental problems, they may be oblivious to new and emerging issues along with the collective positive outcomes effected by a change in their behaviour (*5*).

Awareness is significant, because i) citizen support is essential for implementation of ambitious environmental policies and ii) populism and its rhetoric are currently burgeoning, which often pushes the public away from policies based on science-based evidence (*6*). Hence, to communicate scientific findings in a way that is more accessible to the public, new methods must be explored.

A rarely used method that has previously shown success in the field of waste management is intergenerational influence (*7*), where one generation has a positive influence

Environmental scientists Ian Williams and Alice Brock teaching children about e-waste.

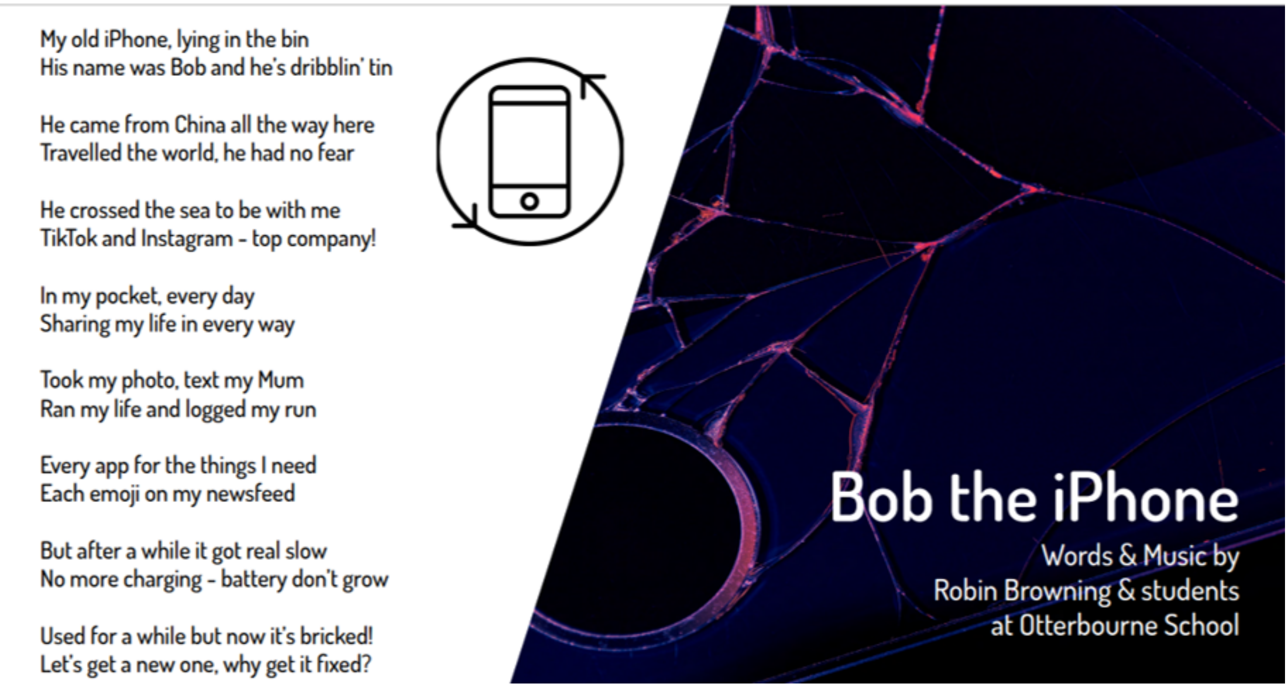
on the behaviour of another. Intergenerational influence is an underutilised communication pathway and can leverage and energise youth-initiated movements (*8*). To develop curiosity and enhance the wider skills of under- and post-graduate students, I have, for over 30 years, encouraged them to reach out to primary and secondary school children. The purpose of this approach is to actively demonstrate how the thinking characteristics, skills and attributes of student scientists and engineers can be integrated and further developed to engage the next generation. With (now defunct) environmental charity Wastewatch, I worked on the "Taking Home Action on Waste" (THAW) project, which was among the first attempts to measure the intergenerational influence of an education programme on (recycling) behaviour at home (*7*). Focusing on primary-age children, the project showed that the school-based education programme led to increasing household participation in recycling as well as declining levels of waste generation. The work inspired American researchers to show that teaching in this way significantly increased parents' concern over domestic refuse (*9*).

Another method for raising awareness of an issue is through art. There is a long history of art being used to communicate problems within society. Artists have an ability to convey issues in a highly emotional way, which could raise awareness, promote reflection and encourage behavioural change. Claude Monet's conceptual art, especially his London Series paintings at the turn of the 20th century, was important in terms of exploring humanity's relations to nature. Nevertheless, the environmental art movement only emerged in the 1960s, when individuals such as Jean-Max Albert and Piotr Kowalski laid the foundations for this form of art expression followed by many others. However, most artwork created to communicate an environmental message was not done so with an exact goal in mind. Thus, whilst nature and the environment have long been an inspiration for artists, the value and outcomes of making environmental scientific content visible via art have not really been tested (*10*).

Music has long been used for the purposes of environmental activism and protest, with a timeline that stretches from Woody Guthrie's "This Land is Your Land" (1945) to Billie Eilish's "All the Good Girls Go to Hell" (2019). The interrelation between music and the environment is demonstrated by the recent emergence of "ecomusicology", defined by Allen (*11*) as "the study of music, culture, and nature in all the complexities of those terms", as a field of study. In particular, musical expressions of environmental activism have potential to animate environmentalist causes for children and can act as a method for coming to terms with existential threats (*12*). However, this powerful tool has been largely neglected by scientific communities seeking to educate and influence the public about environmental issues or the need for behavioural change (*13*).

A musical approach has been used for many years by two of my musician friends (Robin Browning and Anca Campagnie) during their work as educators and performers, and this assisted us to work together.

Artist Susannah Pal and her exhibition of e-waste inspired art (Hartley Library, University of Southampton).



Example of lyrics about e-waste created by the children of Otterbourne Primary School, Hampshire.

The TRACE Project

Evaluating the potential of communicating environmental information and research through the arts is an emerging area. Few research projects have used the arts as a scientific communication method and, indeed, the few research papers on this topic tend to be reflective rather than systematic studies. Hence the TRACE Project was conceived, managed and led to trial and critically review the capability of intergenerational and creative projects to communicate to the public about e-waste to stimulate behavioural change towards circular economy principles. The project's objectives were to: i) raise public awareness of the need for sustainable waste management using intergenerational education, ii) use art and music to portray the socio-economic technical challenges of e-waste management and the potential solutions to this crisis generated by research, and iii) change attitudes and behaviour towards e-waste

Rehearsal at the University of Southampton just before two public performances

management in the public, the artists involved, the school children and their caregivers.

An artist, musicians and 85 schoolchildren from Otterbourne Primary School in Hampshire participated in TRACE over several months in 2019-2020. The artist, Susannah Pal, was engaged to translate academic research on e-waste into artwork that provoked emotional responses and discussion to inspire action. The artwork invited the viewers to empathise with their discarded waste through anthropomorphising and imbuing it with an organic feel. The SÓN orchestra collaborated with schoolchildren to develop and produce original musical performances focusing on e-waste. All involved were guided by scientists to further their own understanding about e-waste and solutions to this problem. TRACE culminated in two musical performances by the SÓN orchestra and children with an attached art exhibition at the University of Southampton. Changes in awareness and attitudes to e-waste were critically analysed, by using the ABC Model framework.

The project concluded in March 2020 at the University of Southampton's Highfield campus, just before COVID-19 lockdown was implemented, the children put on musical performances and took part in art exhibitions. The artist created a blog reflecting on her experience of the project and showcasing some of the work produced.

The musical performances art exhibitions, and an overall video of the project can be seen at the website:

https://ewaste.thesonproject.com/ and https://www.youtube.com/watch?v=duDdWoq8BZE.

Susannah Pal's blog can be read at the following link: http://www.susannahpal.com/blog/2020/3/26/reflectionewaste.

Findings

Conveying the gravity and adverse impacts of e-waste to the public effectively is a huge challenge. The TRACE project has shown that a communication method applying intergenerational influence combined with emotional responses to music and art can help to promote pro-environmental attitudes and behaviours. TRACE was successful in developing a new way to communicate to the public about e-waste through combining creative art and music, intergenerational influence and science. Independent, expert recognition of the project has been provided via receipt of a prestigious (communication) award at the 2021 UK National Recycling Awards.

Anthropomorphism of e-waste and creating empathy was effective in stimulating emotional responses in participants. Intergenerational influence contributed to raising awareness in caregivers. In households where children had frequently discussed the project or were speakers or soloists, caregivers were more likely to report higher levels of awareness. The degree to which awareness was raised, and its intensity, demonstrates the viability of the use of intergenerational influence and the creative arts as tools to communicate environmental issues effectively.

Response of school staff to the children's performances

The evidence from the TRACE project suggests that the audiences seem to have grasped the importance and impacts of e-waste generation. This response was probably because: i) the public judged that the scientific evidence provided was trustworthy and authoritative and ii) the emotional messages from the art and musical performances worked well, i.e. hope exceeded fear, resulting in a desire to change behaviour in a pro-environmental direction. The TRACE method could therefore be applied to generate public support for pro-environmental policies based upon independently peer-reviewed, widely supported, and trusted scientific evidence. This is a significant finding because citizen support is essential for implementation of ambitious environmental policies. Scientists and researchers are encouraged to develop partnerships with creative artists to accelerate uptake of their research findings.

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Article

Reducing e-waste through repair: Slowing the electronics replacement cycle

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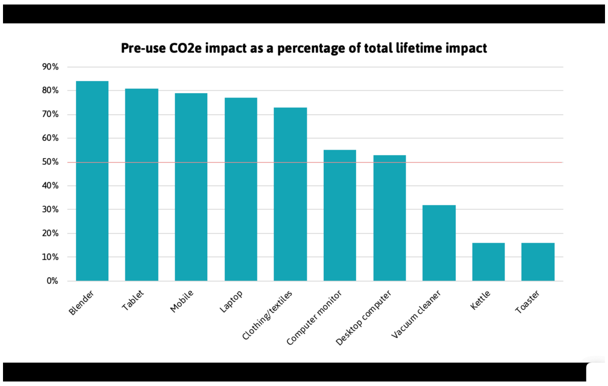
The Restart Project works to keep electronics in use for longer. This aim is principally achieved through encouraging and supporting repair. The bread and butter has always been 'Restart Parties': community events where people teach each other how to repair their broken and slow devices. The project team also campaigns for electronics to be more fixable and encourages people to choose repair. But, why does Restart think electronics should last longer?

The first answer to that question is because of the rampant problem of electronic waste (e-waste). According to the last estimate conducted by the Global E-waste Monitor around 53 million tonnes of e-waste were produced in 2019 worldwide (*1*). Such amount outweighs the Great Wall of China and expands each year. E-waste is the fastest-growing waste stream, yet less than 20% of it is recycled globally. We need to get better at recycling e-waste but, more importantly, we simply must throw fewer electronics away.

A second and less recognised answer to keep electronics in use for longer is the resources and energy utilised during their production. Last year, the Restart Project looked into the carbon footprint of small electronics from cradle to grave. We reviewed publicly available life cycle assessments conducted by manufacturers, academics, consultancy firms, and public bodies. Information was hard to find. In total we collected data on 1406 products. From these, CO_2 equivalent data were extracted on 491 products (*2*). We found that, for many of the products, most of the global warming impact occurred before we even opened the box; the actual use of our products generates as little as 20% of the carbon emissions produced in their whole lifetimes. This means the best thing we can do to cut the climate impact of electronics is to keep those that we own for as long as possible – and buy fewer new products.

Even repairing a toaster, all environmental indicators considered, scores better than replacing it with a newer, more efficient product. This is considering all common breakdowns until the toaster reaches its expected lifespan of 8 years (*3*). Whether avoiding waste or reducing emissions, we must slow our replacement cycle, repair more, and use or reuse for longer. The good news is that

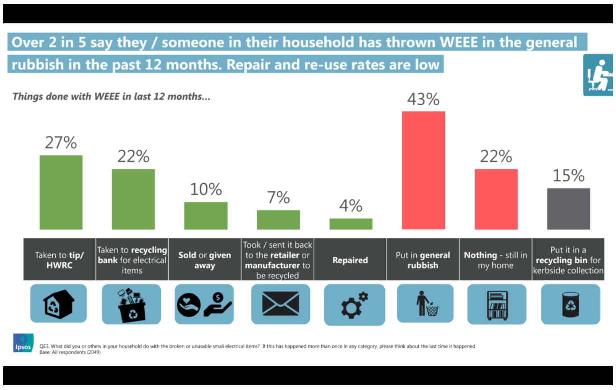


Pre-use CO_2e impact as a percentage of total lifetime impact for various products.

people like repair: almost 80% of participants across Europe (84% in the UK) said manufacturers should make it easier to repair digital devices (*4*). Conversely, this opinion does not always translate to behaviour: E-Spares found 75% of people surveyed were more likely to discard broken appliances than attempt to fix them (or is this a product of expectations of the challenges?) (*5*); Material Focus found that only 4% of people had repaired small electronics, far more kept them at home (22%), recycled them (27%), or put them in general rubbish (43%) (*6*).

So why do more people not repair electronics?

Cost is consistently quoted as a barrier to repair for more than half of people surveyed (*7*). Spare parts and labour are expensive when compared with cheaper mass produced new products. Professional repair options are harder to find, whilst there are multiple barriers for home repair. Whether intentional or otherwise, electronics are rarely designed for repair. Hardware includes glued components, hidden screws and often requires unique tools for different models. Parts are bundled together so that minor faults require changing several parts. Official repair manuals are hard to source, as are spare parts. Software is also increasingly used to hinder repairs. Most connected products are not supported with security updates for long enough and are increasingly rendered prematurely obsolete. Part pairing is used to tie specific parts to software, ensuring that spare parts can only be sourced from the manufacturer, and must be individually paired to the device by that company. These software barriers to repair are becoming ever more commonplace, not to mention warranties voided, if repairs are carried out by independent shops.



A Material Focus Study asking what people have done with electrical and electronic waste in the last 12 months.

These built-in barriers mean people are less likely to attempt fixing their own devices; barriers also push up the repair costs for reaching professional service. Hence the vicious cycle of people choosing to replace rather than repair, and repairers going out of business, alongside constant marketing of the newest must-have model.

What can we do to bring back repair?

To bring back repair, we must first increase the repair options available to people. The Restart Project's core work is supporting a network of groups that organises Restart Parties. Based loosely on the repair cafe model, these events provide a space in which people can bring broken and slow devices, and a volunteer repairer will help fix them. But this approach is not simply a free repair service: by involving owners, they overcome the fear of opening electronics and empower people to value the devices they have worked to keep alive.

In 2022, we opened two Fixing Factories in London, and started signposting people. Our Londonrepairs.org directory enables users to find reliable London repair services, and our laptop donation directory points people towards local groups that refurbish devices for donation to those without digital access. Restart is part of a growing ecosystem of people and groups championing repair, but there is much more to do changing perspectives. To really create changes, we need to look upstream at what manufacturers are (or are not) doing to support repair.

A growing movement is calling for a Right to Repair: a right to fix our things without barriers put in place by manufacturers. In 2021, the United Kingdom brought in the first Right to Repair law, which mandated manufacturers to provide spare parts to professional repairers during at least 7 to 10 years for white goods and TVs as well as instruction manuals. But what about all the other electrical products, and community repairers?

There is more progress in the EU Ecodesign legislation, which is where UK Right to Repair law originated pre-Brexit. Initially, regulations covered smartphones and tablets, adding laptops, vacuum cleaners, and printers later. By the end of 2024, a recent law will require all phones and tablets sold in the European Union to use the same charger, shrinking the spaghetti of wires and chargers we all have in our homes. Battery legislation is in progress, but movement remains slow and piecemeal. Expected EU consumer rights legislation that would have introduced more Right to Repair provisions across more products has recently been delayed. If we continue to introduce legislation product by product at this rate, we cannot fix the problem. There are good examples of national pro-repair policies in other countries: a French repair index, which prominently displays a repair score for all electronics at point of sale, introduced in 2021, is already shifting how consumers buy, and thus impacted manufacturers' repair offers. An Austrian repair voucher scheme offers 50% off repair costs up to €200. Starting at city and regional level, in 2022, it was rolled out across Austria supported by EU COVID-19 recovery funding. In the United States, appliances with an energy rating may soon require including repair instructions to ship.

The challenge is huge, but we have solutions. With infrastructure and public support for repairs growing, manufacturers and governments are being pushed to remove barriers. Let's look to a future where repair comes first, and e-waste mountains become a thing of the past.

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Aged microplastics enhance adsorption of pharmaceuticals

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Plastic pollution is an increasing environmental concern with increasing understanding of the nature and extent of the issue (*1*). Microplastics (< 5 mm in all dimensions (*2*)) often co-exist with aquatic pollutants, including pharmaceuticals. Pharmaceutical ecotoxicity and the adsorption potential of microplastics is worrisome from an environmental and human health perspective, particularly relating to the potential of particles entering the food chain.

The mismanagement of solid wastes contributes to plastic contamination. In 2018, only 32% of post-consumer plastic waste was recycled, and 25% was sent to landfill (*3*). Plastic particles can enter freshwater systems in a wide range of sizes. In the aquatic environment, plastic debris is exposed to continuous photo-oxidation and/or mechanical abrasion that can lead plastics to be broken-down into smaller particles (*4*).

Microplastics are divided into two different types, primary and secondary microplastics. Primary microplastics are plastic particles, including pre-production pellets, manufactured to microplastic size; despite recent regulations prohibiting their use, they are still commonly found in legacy personal care products (*5*). The most abundant microplastics in the environment (*6*) are secondary microplastics, produced by physical, chemical, and/or biological degradation of larger plastic materials (*2*).

Artificially aged microplastics

Microparticles of polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polyamide (PA), polystyrene (PS), and polyvinyl chloride (PVC) are widely detected in freshwater environments (*7*). Two sizes of these polymers were investigated, described as 'small' (median size < 33 μm) and 'large' (median size 95-157 μm). Virgin microplastics were artificially aged in the laboratory by subjecting them to light and heat to evaluate how the photo and thermal oxidation processes affect microplastic interactions with pharmaceuticals.

Pharmaceuticals as the adsorbate

Pharmaceuticals are widely reported in freshwater environments, especially those with high prescription rates

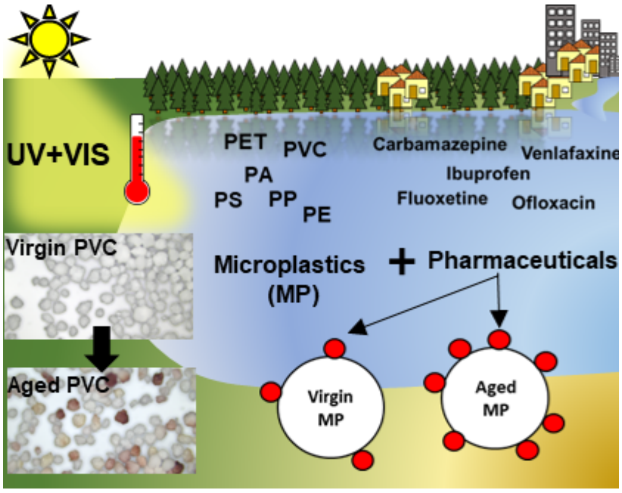

Figure 1. *Environmental interaction due to the co-occurrence of micropollutants, such as microplastics and pharmaceuticals in the aquatic environment.*

and/or low biodegradability (8, 9). Ibuprofen, carbamazepine, fluoxetine, ofloxacin, and venlafaxine were selected for this study due to their environmental relevance. The chemical parameters considered were toxicity to aquatic organisms (i.e. the water flea, *Daphnia magna*), prescription rate, and persistence in freshwater. Those selected cover a range of hydrophobicities.

Recent adsorption studies focused on the adsorption of organic compounds onto virgin plastic particles, which have been reported to adsorb a range of aquatic contaminants, from natural toxins (*10*) to toxic metals (*11*). However, in the environment, microplastics are exposed to a variety of degradation processes that can impact the adsorption behaviour of the microplastics (**Figure 1**). This study investigated how ageing microplastics affects the adsorption potential of water contaminants. Results demonstrated a significant increase of the concentration of pharmaceuticals adsorbed by aged microplastics when compared to virgin microplastics (**Figure 2**). Exposure of polymers to ultraviolet radiation causes photooxidative degradation which breaks down the polymer chains which, in turn, generates free radicals (*12*). The presence of radicals, including carbonyl radicals, can enhance the adsorption of organic compounds onto microplastics.

The type of the microplastic is also a determinant for pharmaceutical adsorption behaviour and susceptibility to degradation. Each microplastic investigated responded differently after ultraviolet and visible light exposure. A yellowing developed for aged PS and PA microparticles, while a brown-reddish colour formed for aged PVC. Plastic

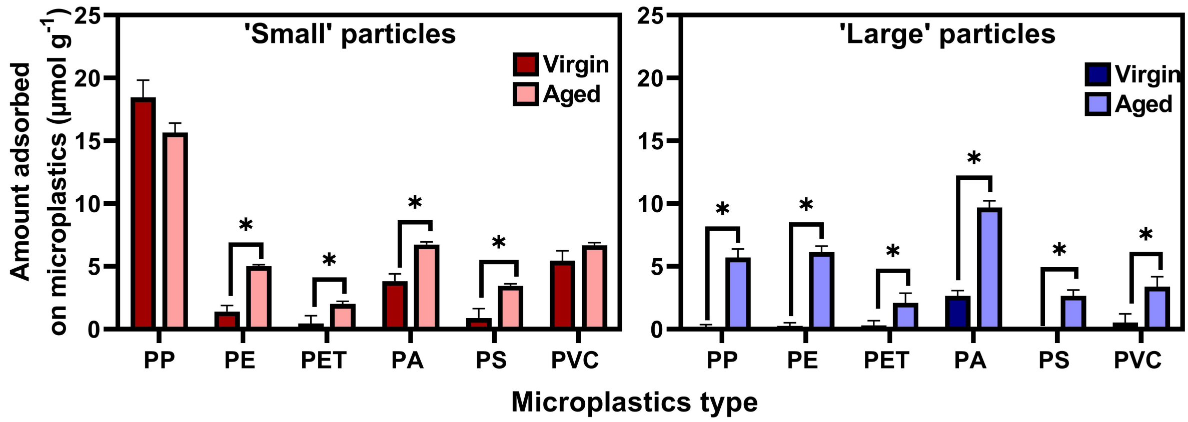

Figure 2. *Adsorption of pharmaceuticals onto 'small' and 'large' polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polyamide, polystyrene (PA), and polyvinyl chloride (PVC). *Significant difference between the virgin and aged particles, t-test p < 0.05.*

degradation is often associated with a colour change; however, this does not occur for all plastics. Aged particles of PP, PE, and PET did not change colour. In contact with a mixture of pharmaceuticals, PP, PA, and PVC showed greater pharmaceutical adsorption compared to PS, PE, and PET. Concerningly, PP is the most widely produced plastic, primarily used for single-use items, and the most reported in freshwater (*7*).

Pharmaceutical hydrophobicity was identified as a driving factor for microplastic interaction. In a mixture containing ibuprofen, carbamazepine, fluoxetine, ofloxacin, and venlafaxine, fluoxetine demonstrated the greatest rate of adsorption onto microplastics. Fluoxetine was the most hydrophobic pharmaceutical in this study. It is also reported to have the greatest ecotoxicological effect on the water quality indicator organism, *Daphnia magna*.

This investigation showed that polymer composition, microplastic weathering, and the pharmaceuticals' hydrophobicity are key factors affecting the adsorption of pharmaceuticals onto microplastics. Research is ongoing to further understand if microplastics are a vector or a sink for pollutants such as fluoxetine.

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Upcoming meetings

#EnvChem2023: Chemistry of the Whole Environment

Following the hugely successful #EnvChem2022 at the University of York, **#EnvChem2023** will be held at **the University of Glasgow June 1st and 2nd 2023.**

#EnvChem2023 provides a forum for early career and established researchers working in environmental chemistry and ecotoxicology to share their latest research findings.

This meeting, organised by the RSC Environmental Chemistry Group, SETAC UK, and BMSS Environmental and Food Analysis SIG will comprise presentations and posters on the following themes:

- Environmental processes in soil, water and air
- Emerging contaminants and novel techniques
- Food and environment nexus
- Atmospheric chemistry
- Ecotoxicology

Call for abstracts

We request abstracts in the themes listed above. A template and contact details will be provided on our website.

Registration will open closer to the time. Please look out for more details. https://www.rsc.org/events/detail/75546/envchem2023-chemistry-of-the-whole-environment

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State-of-the-art in Analysis of Complex Environmental Matrices: Webinar series.

Following our successful biennial series on Analysis of Complex Environmental Matrices, the Separation Science Group, ECG, and Water Research Forum are happy to announce our webinar series, to be held in the January/February 2023.

- There will be 90-minutes online meetings every other week.
- Presentations from two UK leading environmental analytical chemists each session.
- Dedicated time to discuss the future of the field.

Webinar One

9 January 2023 12.00-14.30

Brett Sallach, University of York, Increasing our understanding of xenobiotic uptake and fate in plants using single cell mass spectrometry and **Barbara Kasprzyk-Hordern,** University of Bath, Wastewater based epidemiology and One Health.

Webinar Two

January 23rd 2023 12.30-2pm

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

Webinar Three

February 6th 2023 12.30-2pm

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

Webinar Four

February 20th 2023 12.30-2pm.

Mark Perkins, Anatune, Rapid analysis of soils and water using selected ion flow tube mass spectrometry (SIFT-MS) and **Richard Cross**, CEH, Monitoring microplastics in the environment – experiences in detection and interpretation of microplastic contamination in increasingly complex media.

Registration is for all the webinars: shorturl.at/tIPT0