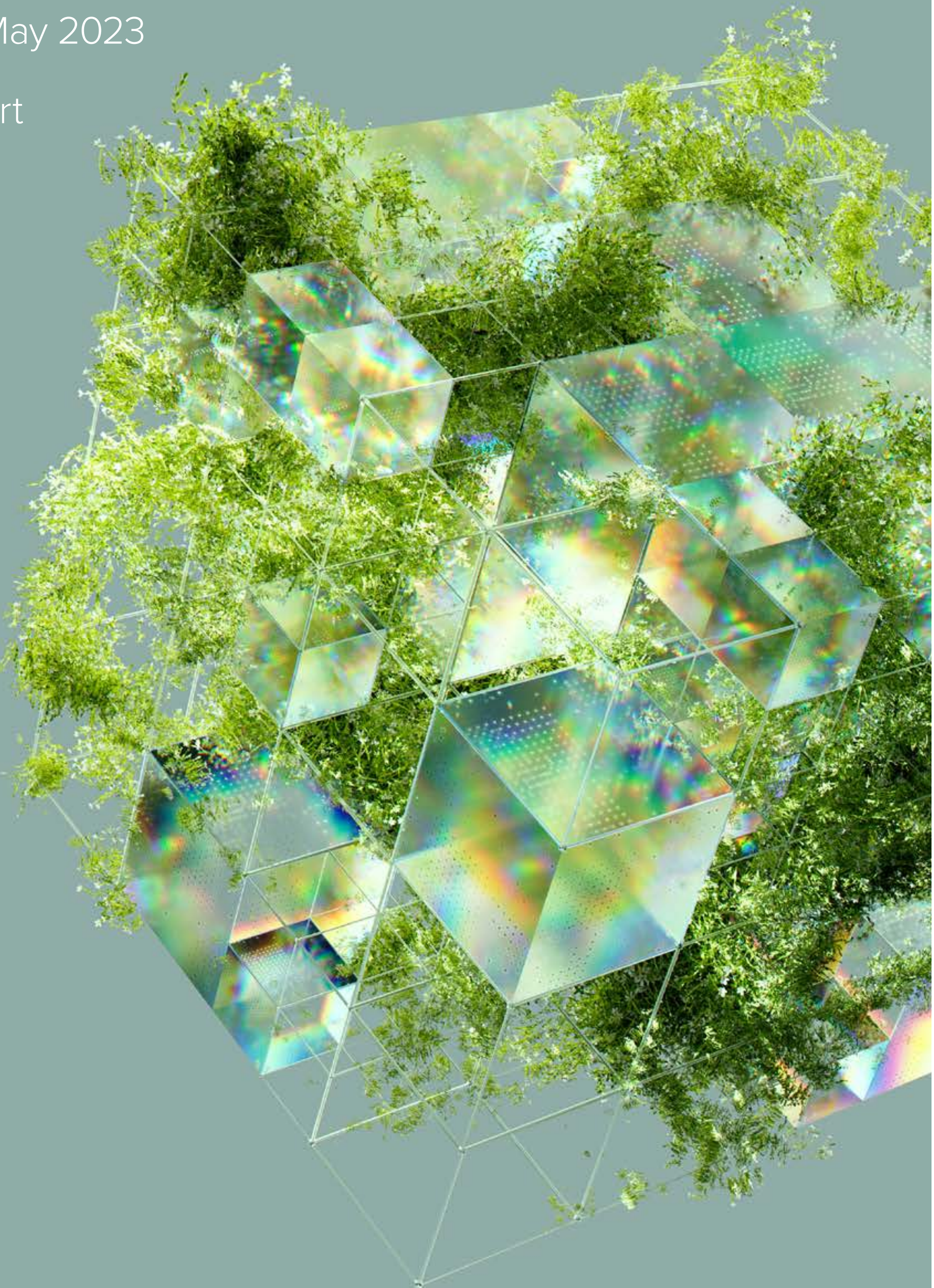
Part of the conference series
Transforming our future

Sustainability in the research and innovation endeavour

Held on 16 – 17 May 2023

Conference report



THE ROYAL SOCIETY

ROYAL SOCIETY OF CHEMISTRY

Introduction

On 16 and 17 May 2023 the Royal Society hosted a hybrid conference, developed in partnership with the Royal Society of Chemistry, on Sustainability in the research and innovation endeavour. This meeting, supported by Rolls Royce, forms part of the Royal Society's Transforming our future series.

Image: Delegates engage in roundtable discussions.

The Transforming our future conferences are unique, high-level events that address scientific and technical challenges of the next decade. The meetings bring together leading experts from the wider scientific community including industry, academia, government, and charities. They are organised with the support of the Royal Society's Science, Industry and Translation Committee.

The conference series forms part of the Royal Society's Science and Industry programme which demonstrates the Society's commitment to integrate science and industry across its activities, promote science and its value, build relationships, and foster translation.

"We need to draw upon a wealth of experiences that people with different roles can bring to this problem."

Professor Helen Sneddon, University of York.

This event, developed in partnership with the Royal Society of Chemistry, with significant input from many other individuals, academies and organisations, offered a forum to connect a broad range of people working within both wet and dry laboratory environments who have an interest in enhancing the environmental sustainability of research and innovation activities. These included senior leaders from industry and academia as well as scientists, technicians, and students working in a wide range of scientific environments including physics, engineering, chemistry, biology, and clinical research.

Image: Delegates engage in roundtable discussions.

It took a discursive approach to highlight and explore this topic, considering trade-offs and myths, examining examples of good practice and promising innovations, exploring current and future challenges, discussing how progress might be measured, and fostering opportunities for collaboration. Professor Helen Sneddon and Professor Roger Sheldon FRS served as scientific organisers.

This report is not a verbatim record, but a summary of the discussions that took place during the two days and the key points raised. Comments and recommendations reflect the views and opinions of the speakers and not necessarily those of the Royal Society or the Royal Society of Chemistry.

Executive summary

Environmental sustainability is an increasingly critical and challenging consideration within research and innovation settings. Decision-makers must substantially reduce the environmental footprint of wet and dry laboratories over the coming years, whilst maintaining high standards.

Image: Networking during the conference.

> "We, the people undertaking research and innovation, together with sustainability professionals, are best-placed to change the research culture to ensure that sustainability is a priority – that it is an integral part of the scientific process and not just an end goal. We are also best-placed to highlight where more data is needed to enable choices to be made, and to call out where regulations may need to change"
>
> Professor Helen Sneddon, University of York.

The UK benefits from a robust scientific research and innovation base across industrial, academic, and government-funded organisations. The environmental footprint of many wet and dry laboratories is, however, substantial. There is an urgent need to implement scalable technical solutions and drive quite radical cultural and behavioural change. Through a series of talks, panel sessions and roundtable discussions, this conference explored some of the most significant challenges and opportunities for the coming decade.

- A number of institutions have already conceived impactful initiatives. These include incorporating sustainability considerations into teaching curricula, driving sustained reductions in energy consumption of freezers and fume hoods, and developing tools to estimate Scope 3 impacts (indirect emissions associated with an entity's value and supply chains). Awards recognise individual contributions, and accreditation schemes such as the Laboratory Efficiency Assessment Framework (LEAF) offer structured guidance. There is considerable scope to learn from organisations operating in resource-limited settings where efficiency is paramount.

- In many cases there is a lack of good quality data to underpin both strategic and day-to-day decisions. This is particularly relevant when evaluating Scope 3 emissions, and there is an urgent need to engage with suppliers and support the standardisation of environmental impact reporting and disclosures across a range of processes and products. However, the research and innovation community should not wait until 'sufficient' data is available before initiating changes.
- Other challenges include the high prevalence of short-term staff contracts, which can stymie efforts to innovate and embed long-term change. Sustainability may not be well integrated into strategic decision-making, and initiatives are often poorly enforced. The complexity of trade-offs can disincentivise individuals from exploring and implementing changes, especially within small organisations that may lack time and expertise.
- Laboratory scientists such as technicians, estates managers, and bioinformaticians offer a 'frontline' perspective. To demonstrate commitment to sustainability, institutions could incorporate specific objectives into job descriptions. This would allow motivated staff sufficient time and status to devise and implement changes. Recruiting dedicated sustainability specialists could further accelerate this.
- Clinical research, which can involve significant contact with participants and families, presents its own unique set of challenges and opportunities. In some – but not all – cases, clinical trial design might be influenced heavily by sustainability considerations alongside clinical need and patient involvement.
- There is a significant opportunity for research funders and publishers to drive sustainability improvements through funding policies, by incorporating approaches that integrate peer review at the research design stage, and by publishing, null, or inconclusive results to minimise wastage and duplication. Working with regulators to devise standards – in a similar vein to health and safety legislation – may help to gradually embed accountability.
- A central platform to exchange resources and to share examples of good practice would be extremely valuable. Entities such as LEAF or indeed the UK's learned academies might offer value by bringing together a diverse range of stakeholders from industry and academia to enable the building of such a platform.

KEYNOTE

Towards sustainable sustainability research

Professor Helen Sneddon, University of York, highlighted important sustainability questions facing the research and innovation sector, explored examples of good practice, and set out some of the challenges and opportunities of the coming decade.

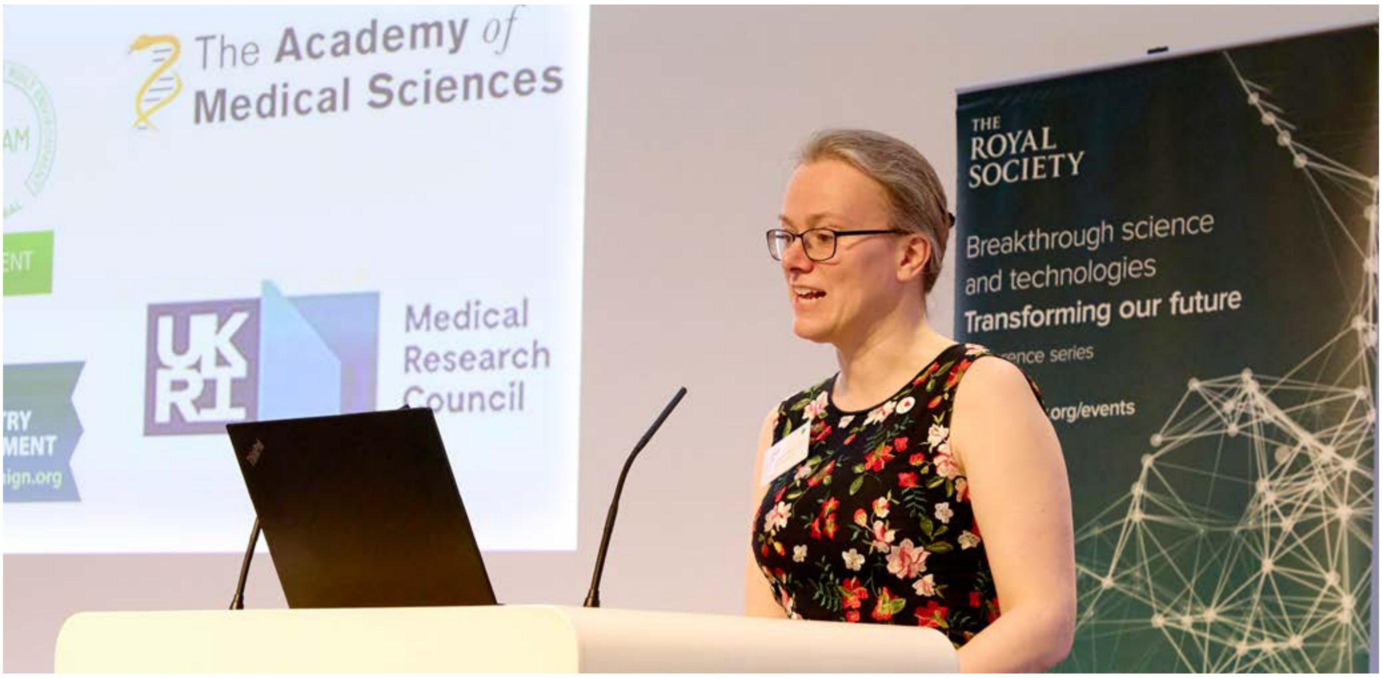


Image: Professor Helen Sneddon, University of York.

"We need to be able to make sensible judgments on trade-offs. We need data to allow us to act with confidence, knowing that we will make things better and not worse."

Professor Helen Sneddon, University of York.

On 17 May 2023 the World Meteorological Organisation announced that global mean surface temperatures are likely to exceed 1.5°C by 2027. Three interconnected planetary crises – climate change, biodiversity loss and environmental pollution – pose grave threats to ecosystems and human society. By 2050 the global economy is expected to double and the population to exceed 9.8 billion. Significant changes across all sectors of the economy and society are urgently needed.

Although research and innovation play a critical role in addressing global challenges and driving change, many wet and dry laboratories have a substantial environmental footprint. A study published in 2008 demonstrated that the energy needs of an average laboratory are 5 – 10 times higher than an office of equivalent size, and up to 100 times greater for laboratories with clean rooms or high process loads. Whilst a 2021 study indicated general energy efficiency improvements, considerable advances are still required. The University of Strathclyde found that laboratory activities accounted for 60% of organisational water use[1]. Analysis from the University of Exeter revealed that, worldwide, biological, medical, and agricultural research generates 2% of global plastic waste[2]. Less than 20% of climate targets set by publicly-owned companies fully align with the 2015 Paris Agreement.

1. University of Strathclyde. 2021 *Sustainable Laboratory Good Practice Guide*. See https://www.strath.ac.uk/professionalservices/media/ps/estatesmanagement/sustainability/sustdocuments/S-Labs-Good_Practice_Guide.pdf (accessed 18 June 2023).
2. Urbina M, *et al*. 2015 *Labs should cut plastic waste too*. *Nature,* 528(479). See https://doi.org/10.1038/528479c (accessed 18 June 2023).

Research from the University of Oxford established that procurement of laboratory consumables and equipment – in particular, the associated supply chains – had a greater impact on biodiversity than flights taken by university staff, or than the construction and operation of university buildings[3]. It is increasingly recognised that Scope 2 and 3 emissions of research and innovation activities – such as embedded carbon in laboratory instruments – must be accounted for, alongside the direct impacts of day-to-day operations.

Early work on sustainable science was influenced by the 12 Principles of Green Chemistry, developed in the 1990s by American chemists Paul Anastas and John Warner. These principles, still respected today in industry and academia, emphasise that green chemistry need not compromise the efficiency or rigour of research and innovation. Other resources have been developed over the past two decades including GSK's solvent sustainability guide[4] and the United Nations Industrial Development Organisation's global Green Chemistry toolkit[5]. Notable ongoing activities include developing bio-derived alternatives to acetonitrile, solvent down-cycling, and helium recycling. Researchers are also working to improve targeting of compounds and candidate molecules in drug discovery to minimise unnecessary experiments and reduce the 10 billion kilograms of reaction material that are wasted every year.

Other scientific disciplines likewise face sustainability challenges. Most biological research depends heavily upon single-use plastics. Engineers must consider noise pollution in design and implementation. Computational research requires energy to store data; the CERN facility, for example, accounts for one-third of the energy consumption in the Swiss canton of Geneva.

Many organisations and initiatives are driving change. The University of York is integrating green chemistry principles into all chemistry courses at undergraduate level. The University of Bath's 'green chemistry commitment' will likewise incorporate sustainable chemistry into core studies from early 2023. The Max Planck Sustainability Network takes an organisation-wide approach to enhance the sustainability of the entire scientific research environment. The International Sustainable Campus Network supports member organisations to exchange ideas and embed good practice. The Laboratory Efficiency Assessment Framework (LEAF) and the Laboratory Efficiency Action Network (LEAN) offer guidance and accreditation for STEM research settings.

Specific success stories include work from the University of Edinburgh which demonstrated that reducing standard freezer temperatures from -80°C to -70°C had no adverse impact upon sample storage and achieved energy savings of up to 40%. Repositioning the contents of fume hoods can also significantly reduce energy consumption, and recycling electrical waste can lessen demand for intensively-mined rare materials.

There are, however, few straightforward solutions. An improvement in one area can lead to trade-offs in another. Favouring catalytic rather than stoichiometric processes, for example, can generate catalyst-specific hazards. Feedstocks made from renewable materials may not be biodegradable. Implementing processes with a lower end-to-end environmental footprint may have implications for health and safety, regulation, or cost. The Royal Society of Chemistry's sustainable laboratories report, published in 2022[6], highlighted a distinct lack of data to help inform decision-making, quantify impact, and track improvement over time, in particular for routine laboratory activities. Insufficient perceived knowledge makes it challenging to implement changes with confidence, especially when there is resistance to change at an institutional level. Nonetheless, in certain cases, initiatives to enhance sustainability through greater efficiency and lower wastage can offer significant cost savings and other opportunities.

3. Bull JW, *et al*. 2022 *Analysis: the biodiversity footprint of the University of Oxford*. *Nature,* 604(7906):420-424. See https://doi.org/10.1038/d41586-022-01034-1 (accessed 18 June 2023).
4. Alder C, *et al*. 2016 *Updating and further expanding GSK's solvent sustainability guide*. *Green Chemistry,* 13. See https://doi.org/10.1039/C6GC00611F (accessed 18 June 2023).
5. UNIDO. 2020 *Green Chemistry Toolkit*. See https://greenchemistry-toolkit.org/ (accessed 18 June 2023).
6. Royal Society of Chemistry. 2022 *Sustainable laboratories*. See https://www.rsc.org/globalassets/22-new-perspectives/sustainability/sustainable-labs/sustainable-laboratories-report.pdf (accessed 18 May 2023).

Over the next decade, collaboration between resource-rich and resource-limited institutions within industry and academia will be crucial to achieve sustained results supported by adequate, high-quality data. This will be achieved only by engaging actively with a diverse range of stakeholders – from students, laboratory technicians and sustainability professionals to estates managers, senior investigators, and administrative teams.

> "By sharing best practice between disciplines, we can achieve some quick wins and delineate the problems to be solved. This should help to generate more data and to explore, verify and publicise new approaches"
>
> Professor Helen Sneddon, University of York.

Roundtable discussions

Fourteen in-person and five virtual roundtable discussions took place during the morning of 16 May. The following section is a summary of the key points raised in relation to laboratory sustainability.

Image: Delegates engage in roundtable discussions.

> "Signs of success are emerging, but there is still a long, long way to go"
>
> Conference participant.

Roundtable participants considered a number of themes including laboratory consumables and equipment, buildings and infrastructure, waste, computational research, chemical products and processes, and cultural and behavioural change in both resource-rich and resource-limited settings. They exchanged examples of good practice, considered barriers to change, and explored opportunities to advance sustainability initiatives within the research and innovation community over the coming years.

There was clear agreement that whilst promising initiatives and technical developments are emerging across industry and academia, there is no time to lose. It will be critical to find ways to accelerate the pace of change and to take bold action over the coming 5 – 10 years. Some highlights from the discussions are considered below.

Opportunities: data and metrics

- In general, laboratory suppliers and procurement teams would benefit from dedicated training in lifecycle assessments (LCAs). There could be an opportunity for UK purchasing consortia to offer tailored support. As an interim measure, institutions could seek basic information from suppliers such as a product's weight and constituent materials to conduct outline LCAs. Specialist communities and networks could take an initiating role.
- Regulation will be critical over the coming decade. Work will be needed to identify key regulatory stakeholders and establish what they will need to galvanise change over the next 5 – 10 years. Valuable lessons might be drawn from existing frameworks such as the Sustainable Markets Initiative (See Appendix A, page 55).
- Using simple 'nudges' to monitor and report energy consumption – such as computer calculators or smart meters – could have a substantial cumulative impact across an organisation.

- Centralising data collection – to include travel, consumables, and energy use – at the departmental or organisational level could help to target environmental impact reduction and could suggest avenues for consolidation such as equipment-sharing and pooled procurement.
- More research will be needed to enhance understanding of the mechanisms and timescales associated with critical processes such as biodegradation.

Opportunities: regulation and standards

- There are currently few standardised waste management frameworks across organisations and institutions, which leads to difficulties in undertaking comparative analysis. Take-back programmes to address packaging wastage could offer a promising opportunity if suppliers and research organisations can address storage challenges. There is a comparable opportunity to address concerns around contamination and general risk aversion towards recycling and material re-use.
- Environmental reporting standards and disclosures will require coordination and independent verification to help enhance and leverage the purchasing power of procurement consortia. Initial engagement with the largest suppliers may eventually have a knock-on effect across the supply chain. Mechanisms to enforce compliance within supply chains are urgently needed.
- Although there is a clear need for more data, consensus is rarely guaranteed. Decision-makers should not necessarily wait until 'sufficient' data is available on a given issue. In some cases, it is logical to aim high; in other cases, establishing minimum enforceable standards would be a judicious starting point.
- Attempting to ringfence savings from early efficiency initiatives might, over time, allow some degree of re-investment into more substantial sustainability activities.

"We need to stop talking and start acting."

Conference participant.

Opportunities: cultural and behavioural change

- Those making the case for sustainability must frame their arguments in appropriate language. For example, medical scientists may wish to understand potential reductions in disease burden per tonne of CO_2 saved. Commercial managers will want to comprehend how changes might impact their bottom line.
- Targets should not only be ambitious at a strategic level but must articulate what this means for departments, groups, and individuals. Strategic plans must be underpinned by robust monitoring and enforcement mechanisms.

Image: Networking during the conference.

- Establishing an open asset database within each institution – or group of institutions – can help to minimise duplication, deal more effectively with legacy equipment, and benefit institutions that may not have access to specialist facilities. In some cases, it will take courage to move towards more collaborative ways of working.
- Exploring ways to balance sustainability with health and safety will be crucial. These may include addressing and reducing the incineration of solvents, and generating additional risk assessment data around contaminants.
- Reliance on short-term contracts for technical staff, accompanied in some cases by limited career progression, can lead to high staff turnover and loss of knowledge, expertise and ideas. When initiatives are perceived as voluntary it is easy for them to become 'someone else's job'. Allocating dedicated time to sustainability activities in job descriptions, performance reviews and reward systems, establishing sustainability champions, or where funds allow, recruiting sustainability specialists, may mitigate these problems.
- There is a significant opportunity for well-resourced laboratories to learn from innovative approaches adopted by researchers operating in resource-limited settings, who are often required to build efficiency into new systems and extract maximum value from a minimum of resources.
- Penalties or even bans on certain activities – such as short-haul flights – may be inevitable in many institutions within the next decade.
- There is a significant opportunity to take a more 'creative' and resourceful approach to teaching to drive innovation in experimental design and inputs, and to place sustainability considerations on an equal footing to other parameters such as quality of results, yields and process speeds.

"Culture-setters are critically important in driving progress."

Conference participant.

Other opportunities

- Currently, water quality and usage are not widely incorporated into evaluation of Scopes 1, 2 and 3 emissions. This will need to change to provide a fuller picture of the environmental impacts of specific activities.
- Some researchers have called for funders to mandate sustainability-linked terms and conditions into grant rounds. Funders must, however, remain mindful of the varying levels of resources and expertise across institutions when establishing 'reasonable' expectations. Pump-priming grants (grants intended to facilitate the collection of pilot data for 'pump-priming') are likely to be crucial as dedicated money is rarely available within operational budgets. Recruiting green chemists to funding panels and bodies would be particularly valuable.
- Experiment design should take into account the future of the reagents used. For example, using greater quantities of one solvent rather than small amounts of multiple solvents, could have a significant cumulative impact upon waste reduction efforts. Further research and development are urgently needed to identify mechanisms to recycle solvents and other by-products.
- Establishing a central platform or resource, in multiple languages and with a diverse user base, might serve to curate good practice across both academia and industry.

Key challenges

- In some organisations sustainability initiatives are still perceived as voluntary 'add-ons'. The impact of individual actions may be limited, and tangible benefits from sustainability interventions may not accrue directly to those initiating and / or implementing changes. This enables some stakeholders to simply 'shift' a problem elsewhere, rather than address it. Institutions must integrate sustainability considerations into the earliest stages of strategic decision-making.
- The complexity and scale of the issues at stake can feel overwhelming. Insufficient data can stymie decision-making. Trade-offs with time, cost, or health and safety can make it difficult for individuals to make the case for bold change. This is particularly relevant in light of steep price rises for standard consumables and building materials.
- Waste management and recycling policies may vary significantly between local authorities. This can influence the extent to which institutions can make positive changes. Collaboration within central and local government would enable standardisation of recycling systems and waste disposal.

- Some suppliers may provide no environmental impact data rather than risk criticism for inadequate information. 'Greenwashing' (where a product is marketed as being more environmentally sustainable than is supported by evidence) can also make it difficult for procurement teams and researchers to make informed decisions.
- Insufficient data means that the relative environmental impacts of refurbishing an existing building compared to constructing from scratch often remain unclear.
- Whilst Scope 3 emissions tend to account for a substantial proportion of an institution's environmental impact, it is difficult to be sure whether evaluations are sufficiently comprehensive.
- Debates around how to delineate so-called 'worthwhile' and 'wasteful' research are highly contentious, and there are few established mechanisms to evaluate and enforce such definitions.
- Small organisations, including start-ups, often lack the time, expertise and resources to place sustainability considerations at the centre of their operations.

> "We need to develop ways to articulate our arguments in a language that will appeal to decision-makers."
>
> Conference participant.

Image: Professor Martyn Poliakoff FRS participating in roundtable discussions.

Genuine life cycle thinking in the research process: where are we and what do we need?

Dr Laurence Stamford, University of Manchester, highlighted how data and life cycle assessments can be used to improve laboratory sustainability.

"In future, suppliers should be expected to provide a full life cycle assessment on all their products. Enforcing this policy would help buyers to make informed decisions"

Dr Laurence Stamford, University of Manchester.

A recurrent issue in endeavours to enhance the sustainability of laboratory research is that there is not enough data at sufficient granularity to enable decision-making or to ensure efforts are targeted appropriately. For example, uncertainty around energy consumption inhibits the ability to decide whether to reuse old equipment or buy new, more efficient equipment, or whether single use plastics should be recycled or replaced with autoclaved glass. Life cycle assessments (LCAs) can help to answer such questions.

LCAs are calculations that assess the environmental impacts at each stage of life of a commercial product. Since they are undertaken on a product-oriented level, consider the impacts of scopes 1, 2 and 3, and incorporate other data, they offer more explicit assessments of data and system boundaries than most other calculations of environmental impact. The following sections illustrate the potential for LCAs to improve laboratory sustainability.

Increasing data granularity

In most institutions the granularity of data on energy consumption is poor. Although many buildings are metered, sub-metering is difficult. Precise attribution of energy usage to specific rooms or laboratories is rarely possible. Calculator tools which provide the average energy consumption for laboratory equipment can help to solve this problem, as can monitoring devices which calculate consumption directly from equipment.

Image: Dr Laurence Stamford, University of Manchester.

Improving scope 3 estimates

A comprehensive understanding of upstream and downstream activities in the research endeavour is frequently lacking. Current sector-wide scope 3 estimates are typically based on input-output data. Such data is calculated by multiplying the money spent in a particular economic category by the average emissions factor for that category. Whilst this method has been used in the past to compensate for missing data from other areas, it can produce highly inaccurate results. Scope 3 emissions within LCAs are calculated based on a particular product or process rather than an entire sector and can therefore improve these estimates.

Diversifying metrics

The sustainability strategies of most research organisations focus on reducing carbon and greenhouse gas (GHG) emissions, and in some cases plastic and water consumption. Including a wider range of metrics and targets, such as the UN Sustainable Development Goals, would likely prove more informative. For example, actions to reduce GHG emissions can generate other environmental impacts such as ecotoxicity or photochemical smog. If these are not adequately measured, they are likely to be omitted from strategies and planning. In addition, LCAs typically cover 10 to 20 different environmental impacts.

Linking existing data

A future priority will be to incorporate existing data collection services into LCA estimates to enhance understanding of the environmental impacts of research equipment. Reasonable estimates for energy consumption or data from laboratory inventory software such as LabCup have the potential to feed into LCAs which, together with interaction with suppliers, can fill in important gaps in our understanding. In future, it will be important to prioritise the allocation of sufficient resources for data collection to enable such calculations and help inform decision-making.

Background data: a compass for the sustainability journey

Dr Emilia Moreno Ruiz, ecoinvent Association, explained how the ecoinvent database is providing scientists and other stakeholders with the data needed to make informed decisions around environmental sustainability.

"It is important to consider various indicators, not just carbon footprint, when making decisions on shifting production and consumption patterns."

Dr Emilia Moreno Ruiz, ecoinvent Association.

Over the last 20 years, patterns of production and consumption of goods have evolved substantially. For laboratory science specifically, this has led to an increase in single-use plastics, a greater number of appliances and the introduction of disposable kits. Many of these changes have been positive, facilitating and accelerating laboratory work, maximising reproducibility, and reducing the risk of cross-contamination. However, the consumption of energy, water and resources and the volumes of waste generated have increased dramatically.

The ecoinvent database

ecoinvent, a Swiss non-profit association, has constructed a database of 'background data' to help map these changes and elucidate their impact on the environment. The database contains 19,000 datasets, is updated annually, and covers all sectors worldwide. It aims to 'fill the gaps' in the entire product value chain, clarifying the environmental impacts of up- and down-stream activities. The datasets offer an average representation of human activities or technologies in different countries. Examples include data on electricity-generating technologies (such as hydropower, photovoltaics, coal, gas, nuclear and wind), waste treatment (including incineration, open burning, landfill and dumping) and the manufacture of substances such as chemicals or plastics. The database also shares information on the specific mix of materials or energy that might be required for different appliances or products depending on their location of manufacture or disposal.

Image: Dr Emilia Moreno Ruiz, ecoinvent Association.

Informing robust decision-making

Life cycle assessments (LCAs) can help us understand the impacts of changes to products and services upon climate, water use, resource depletion, human toxicity potential, biodiversity, and more. The ecoinvent database is used to inform full and simplified LCAs, environmental product declarations (EPDs), the greenhouse gas (GHG) protocols for scopes 2 and 3, and other types of sustainability reporting. Many LCA and product lifecycle management software applications also draw on the database in their calculations.

Data on the entire life cycle of a product allows database users to calculate environmental impacts depending on a preferred metric or indicator, such as carbon footprint, water footprint, and effects on human health or biodiversity. Users can tailor the outputs according to requirements or standards, and can determine the main contributors, or 'hotspots', in the value chain. Understanding where 'hotspots' are located helps to prioritise resources, budget effectively and minimise rebound effects and shifting energy burdens, for example from one appliance to another. Users can then decide where to allocate resources for more in-depth data collection or start taking action to mitigate the most detrimental effects. They can also use the database as a benchmark – an average representation of technologies – and to fill data gaps.

The ecoinvent database is modular: in addition to providing background data from an item's lifecycle and value chain, it allows the user to add their own data (for example, from on-site energy monitors). In this way, the database enables closer calculation of the true impacts of a product on the environment.

Enabling labs and institutions to assess equipment to truly improve research sustainability

Andy Evans, Green Light Laboratories Ltd, discussed how understanding standards and carefully assessing appliances can help reduce energy consumption in laboratories.

A common problem when procuring 'sustainable' laboratory equipment is that standards around energy consumption and efficiency are often not fit for purpose. Many standards are poorly defined and allow considerable variation between products with the same ratings. As certain standards directly inform others, this is highly problematic, and makes it difficult for consumers and institutions to make informed decisions based on information provided by manufacturers. Several case studies from Green Light Laboratories Ltd offer relevant guidance.

Image: Andy Evans, Green Light Laboratories Ltd.

"There are so many aspects of performance other than energy that need to be taken into account when understanding the efficiency of appliances."

Andy Evans, Green Light Laboratories Ltd.

Ambient condition standards

Ambient conditions are important for measuring the energy consumption of a product. For example, measurements of a fridge taken in warm external conditions will indicate high energy consumption, and vice versa. There is, however, no standard that defines the testing temperature. This means that manufacturers can take measurements in an environment that suits sales, eg a cold room. The resulting data is unlikely to mirror ambient conditions during product use, meaning that eventual running costs – a critical element in procurement decisions – may be higher than expected.

Useable net capacity standards

In a study conducted by Green Light Laboratories and the University of Bristol (pending publication), the usable net capacity of 16 ultra-low temperature (ULT) freezer models was shown to be lower than the published net capacity in every model. This may be because the associated standard is poorly defined.

Door recovery time standards

Current standards for the time a fridge or freezer takes to 'recover' its set temperature after the door has been opened assume that the process of opening and closing a door takes 15 seconds. This does not accurately reflect the typical time taken to open an appliance in a laboratory. Case studies conducted by the University of Nottingham and Green Light Laboratories indicated that although some appliances use more energy, their temperature recovery times are much lower than those of other models.

Accurately assessing equipment

Developing higher-quality standards is a clear priority. Another solution might be to establish an efficiency rating for commercial or scientific equipment, similar to that for domestic appliances. Many aspects of performance, not only energy consumption, would need to be considered. These might include maintenance costs and overall lifespan, heat output, packaging, water usage, and recyclability. Insurance costs and the need for modular upgrades are also important.

Eliciting fully quantifiable information from manufacturers is likely to offer more robust indications of energy efficiency and overall performance. By seeking independent verification of data sources and methods, or even testing models in the laboratory before purchase, researchers can ensure that performance, rather than price and energy consumption, is prioritised. Considering running costs in addition to the initial cost of the appliance and increased access to accurate and reliable data will help consumers and organisations to make informed decisions in the coming years. Green Light Laboratories Ltd. is continuing to develop data-rich case studies of different equipment to help achieve sustained improvements.

PANEL DISCUSSION

Monitoring, metrics and life-cycle assessments: data for decision-making

Chaired by Dr John Broderick, Royal Society of Chemistry, Dr Laurence Stamford, Dr Emilia Moreno Ruiz and Andy Evans discussed collaboration, trade-offs and regulation to improve standards and data-sharing within laboratory sustainability initiatives.

Image: (left to right) Andy Evans, Dr Emilia Moreno Ruiz, and Dr Laurence Stamford.

> "Producing a result without providing the corresponding uncertainty data reduces the credibility of the life cycle assessment."
>
> Dr Emilia Moreno Ruiz, ecoinvent Association.

Data

- Data acquisition is important when deciding whether to make changes that may or may not have implications for environmental sustainability. For example, there are several instances where switching from fossil fuel-based plastics to another material has a greater negative impact than keeping the original product. Moving towards bio-based plastics, for example, may be a positive way forward, but impacts on biodiversity and land use (and therefore shifting burdens as other crops are displaced) should be taken into account. Accurate data will enable decision-making that takes tradeoffs into account.
- Data used to assess the 'sustainability' of a product should be made publicly available, and all life cycle assessments (LCAs) should be published with appropriate evaluations around certainty, incorporating reasonable parameterised uncertainties. In addition, databases to support LCAs should made as easy to understand for the end user as possible, even if the data within them is inherently complex.

Manufacturing

- Accurate monitoring equipment, able to identify variability in energy consumption to within 1%, can help improve the quality of data collected. Where possible, general laboratory equipment should have independent controls, with 'per degree' temperature levels that can be set, and digital screens for displaying temperature and other settings easily.

- It is important that manufacturers create opportunities for buyers to test products before purchase. Reviewing the quality of manufacture, and treating manufacturer data with caution, is integral to understanding recyclability, energy consumption and the human time required to use the equipment, which all contribute to the product's lifespan and environmental impact.
- Manufacturing regulators have a responsibility to ensure that equipment standards are high-quality and to provide the consumer with appropriate data. Regulating agencies and government legislators should clearly define criteria such as 'warm-up time', 'door opening time', 'recovery time' and 'peak temperature', as interpretation varies among manufacturers and suppliers.
- Manufacturers will need to be incentivised and supported to present emissions data. The reporting of emissions presented by manufacturers should be compulsory, and all reporting should be independently reviewed by an external organisation to enhance credibility. There may be a role for a neutral third-party organisation to facilitate collaboration between manufacturers, regulators and consumers to set more rigorous standards.

Employers building sustainable practices into job descriptions within research and innovation organisations would be beneficial, empowering staff (including procurement officers, workshop and repair workers and laboratory scientists) to conduct equipment testing and be able to interpret standards appropriately. The introduction of sustainability officers is likely to add significant value. In many cases, individuals from a laboratory science background would be ideal candidates.

"Good intentions don't necessarily lead to good outcomes. If you don't look at the data, you may find that changing products or equipment doesn't achieve what you were expecting."

Dr Laurence Stamford, University of Manchester.

"It is important to have relevant standards in place to capture all the appropriate data, and for that data to be made available. This way, undesirable results can't be hidden."

Andy Evans, Green Light Laboratories Ltd.

Green Labs and LEAF: from seed to LEAF

Martin Farley, University College London and Green Lab Associates, outlined the history of the Laboratory Efficiency Assessment Framework (LEAF) and discussed future priorities for the scientific community to help determine the 'true carbon cost of science'.

The Laboratory Efficiency Assessment Framework (LEAF) was initiated in 2018. The programme includes tools and calculators, online resources, and engagement and training activities to enhance the environmental sustainability of research at both the laboratory and institutional level. The accreditation scheme offers Bronze, Silver and Gold awards, and the framework has been adopted by over 100 wet and dry institutions mainly within the UK academic community, though not exclusively. LEAF is supported by the UK Reproducibility Network and the National Technician Development Centre. It seeks to accommodate the diverse needs and priorities of different laboratories, some of which are necessarily more resource-intensive than others.

LEAF was inspired by a growing awareness of the environmental footprint of laboratory-based research in several countries, and by the opportunity to devise solutions to address some of the low-hanging fruit. In general, recycling and re-purposing materials costs less than disposal. Errors in supply chain and human behaviour result in wastage in the order of thousands of pounds. Publication policies favouring positive research outputs mean that unproductive experimental methodologies persist. Highly motivated teams and individuals lack adequate data from the laboratory and from scientific suppliers to guide decision-making.

As LEAF continues to evolve within academic – and industrial – research environments, a number of key considerations have emerged for the coming decade.

Image: Martin Farley, University College London / Green Lab Associates.

"We need to convert ideas into a language that will speak to the scientific community. These are the people that we have to engage and convince."

Martin Farley, University College London and Green Lab Associates.

Data and metrics

Environmental footprint data from suppliers and even within different organisational departments lack consistency. Data gaps around procurement and Scope 3 emissions are especially significant. Pan-European collaboration, particularly when developing lifecycle assessments and purchasing guidelines, will be critical in establishing standardised methodologies for tendering, evaluation, reporting, and in making the case for change.

Staff contracts

Many institutions issue short-term contracts for both research and support staff, especially at junior levels. Temporary employees may not have time to propose and develop sustainability measures, nor to establish a reputation in order to achieve influence beyond their immediate remit. Significant and lasting change will be possible only if sustainability measures form a central component of core employees' job descriptions.

Technical staff

The contributions of technical staff – including technicians, laboratory managers and estates teams – are not consistently acknowledged. Over the next decade LEAF will foster mechanisms that support technical staff to contribute to sustainability targets. This will be more achievable if research funders permit certain technicians to be included as direct (rather than estates) costs on grant applications.

Regulation

Sustainability measures are largely implemented on a voluntary basis. The fact that individuals are rarely directly accountable for energy consumption and overhead costs weakens incentives to enhance efficiency locally. Pressure from institutions and grant funders to spend budgets can lead to unnecessary and even wasteful expenditure. Lessons might be learned from health and safety regulations and equality accreditation schemes such as Athena SWAN.

Continued innovation

Even if all laboratories deployed every sustainability solution currently available, the research and innovation community would not be able to achieve net zero. Targeted and ambitious investment is urgently needed to advance the frontiers of what is possible. The UK Medical Research Council is aiming for its institutes to achieve gold level in LEAF by 2025 and it is hoped that future grant calls will reflect these investment needs.

LEAF is ultimately a largely bottom-up initiative. Despite significant impact over the past five years, there are limits to what grassroots actions alone can achieve. If LEAF is to grow into a non-profit entity over the coming years, it is likely that organisational targets will need to be incorporated into the accreditation framework to accelerate and embed lasting change.

PANEL DISCUSSION

Sustainable research: perspectives from technicians, analysts and laboratory scientists

Panel Chair Lee Hibbett, University of Nottingham, facilitated a discussion with Hannah Johnson, Prinses Maxima Centrum Utrecht, Dr Richard Gammons, University of York, Dr Bethan Coulson, Johnson Matthey and Dr Loïc Lannelongue, University of Cambridge.

Image: (left to right) Dr Bethan Coulson, Dr Loïc Lannelongue, Dr Richard Gammons, Hannah Johnson, and Lee Hibbett.

Technicians, analysts, bioinformaticians and other scientists have a broad view over laboratory activities and are well-placed to understand where and how sustainable practices might be introduced. Many have indeed initiated recycling and waste reduction systems within laboratories. However, balancing day jobs with sustainability roles can be challenging. The discussion considered priorities for the coming years.

"We need to start estimating the carbon footprint of computing before running experiments. Since the financial costs of computational tasks are low, their environmental impacts have been largely ignored until now."

Dr Loïc Lannelongue, University of Cambridge.

Culture: frameworks

Creating a culture of sustainability within an organisation can offer opportunities to include all staff in relevant initiatives and to empower those with specific interests. The introduction of frameworks, such as the Laboratory Efficiency Assessment Framework (LEAF), can support these efforts.

- Organisations must include data-driven commitments in sustainability statements to minimise 'greenwashing'.
- Government agreements, such as the Dutch Green Deal on Sustainable Healthcare (a sustainability action plan between hospitals, companies and regulators), can offer approved frameworks.
- Introducing organisation-specific frameworks and launching initiatives, such as Sustainability Champions or the National Union of Students (NUS) Green Impact Scheme, can foster knowledge transfer and collaborative working between students, scientists and professional services staff.
- External frameworks, such as the European Federation of Clinical Chemistry and Laboratory Medicine Guidelines for Green and Sustainable Medical Laboratories or the FAIR (Findability, Accessibility, Interoperability, and Reusability) Guiding Principles, can offer laboratory scientists practical guidance in their efforts to reduce the research footprint.

Culture: education and systems change

- Educating researchers about the financial and environmental impacts of lost data can encourage sustainable data storage practices. Teaching undergraduates and postgraduates about sustainable practices can also help embed sustainability into research culture.
- Working to change mindsets around good quality negative data and 'failed' studies, and sharing this data, can minimise duplication and 'wasted' experiments.
- Encouraging researchers to begin with the end in mind (ie plan every step until completion) when using equipment, designing experiments and collecting data can ensure that all appropriate data points are collected for computational analysis. This reduces the amount of time, and therefore energy, needed for analysis.

Standard setting

Regulating environmental impacts of laboratory activities through government-level standards – in a similar vein to health and safety – could be a game-changer. In addition, refining and increasing the number of legislative sustainability standards, for both 'wet labs' and computing, encourages behaviour change.

- Establishing sustainability-specific roles in every organisation, or at least allocating funds and time to sustainability activities, should become standard. Sustainability practitioners can encourage staff to follow relevant guidelines to help achieve consistency across the organisation. There is also a need for such roles to be introduced at entry level within departments in order to drive small-scale changes and guide teams.
- Allowing technicians, for example, to spend a given percentage of their time on sustainability projects and introducing sustainability into performance reviews can serve as a win-win.
- Increasing the number of staff in an organisation's repair workshop may increase the amount of equipment that can be repaired.
- Developing a core team of software engineers for computational analysis within every organisation can enhance the efficiency of projects.
- Including compulsory sustainability assessments alongside risk assessments can embed 'green' thinking into laboratory culture.
- Introducing electrical devices for routine tasks, rather than paper, is not necessarily more environmentally friendly. Some studies have shown that notebooks are better than tablets in almost all categories of environmental impact[7]. As a result, caution should be taken before investing in tablets, for instance for undergraduate laboratory practical sessions.
- Introducing policy changes within organisations, such as modifying the standard freezer temperature from -80°C to -70°C, can help to focus objectives and provide continuity to sustainable projects after key players have left organisations.

7. Suksuwan A, *et al*. 2020 *Environmental LCA on three note-taking devices*. *Procedia CIRP,* 90(310-315). See https://doi.org/10.1016/j.procir.2020.02.125 (accessed 27 July 2023).

Collaboration

Collaboration across different scales is an essential element in improving laboratory sustainability within companies, institutions, and universities.

- Collaboration between laboratory groups in the same building can help consolidate shipping, reducing both costs and packaging.
- All stakeholders, including researchers, technical staff, students, procurement teams and estates departments, should be involved in developing and maintaining sustainable practices within organisations. Working groups with quarterly meetings can facilitate this.
- Discussions between universities and companies can facilitate sharing of sustainable ways of working and provide the option for collaborators to use the same company for waste recycling, making it more cost effective. It can also help maintain an aligned strategy when interacting with suppliers to enable sustainable purchasing.
- Working with local commercial partners can improve waste management systems. For example, collaborating with local recycling companies can result in the collection of polystyrene from laboratories (typically sent to landfill) and its conversion into high-value dense polystyrene bricks, which can be resold.

> "Bridging the gap between estates departments, academics and technical managers is vital. We need to reduce siloed thinking and working groups can help with this."
>
> Lee Hibbett, University of Nottingham.

Monitoring tools and emissions calculators

- Despite improvements to the volume and quality of data around carbon emissions, more sophisticated calculators are required. Tools such as Green Algorithms, which enables researchers to calculate the carbon footprint of their computing projects, are extremely useful, but in cases where emissions cannot be monitored easily, additional tools are required. For example, in high-performance computing every action is logged, but the corresponding carbon footprint is not always readily available.
- Confusion around whether monitoring tools provide enough high-quality data, as well as little awareness that such tools exist, contributes to the difficulty of collecting these data. Technical staff within organisations have an important role to play in sharing the tools with other researchers and informing colleagues of any developments in technology.
- Tool developers should seek to understand end users' needs and help indicate circumstances in which tools are most effective. Communicating with technicians and lab scientists will enable further development.

Suppliers and procurement

- Supporting estates and procurement teams to access green electricity, durable and reliable electrical products, and consumables with less embedded carbon, can dramatically reduce carbon emissions. Encouraging responsible procurement can help scientists make informed decisions. Stock in procurement systems is often ordered by price first, rather than a balance between the price and the product's environmental footprint. Changing this might make choosing products easier.
- In the absence of rigorous sustainability standards for equipment and consumables, environmental data direct from manufacturers must be treated with caution. Supplier transparency around product carbon footprint, for example by introducing labels on packaging or advertising, would enable consumers to make informed decisions.
- Governments have a role to play in incentivising manufacturers to develop software that remains compatible with older models of equipment or to provide replacement parts for such models. Suppliers could be incentivised to take back packaging to be recycled, free of charge, if consumers are unable to identify alternative disposal mechanisms.
- Maintenance contracts with suppliers should be informed by sustainability goals to allow consumers to retain equipment for longer.

> "We are trying to talk to Dutch funding bodies to get them to support sustainable practices within institutions by introducing sustainable policies."
>
> Hannah Johnson, Prinses Maxima Centrum Utrecht.

Waste and equipment

- Initiatives such as sharing agreements can allow laboratories within an organisation to share equipment and spare parts. If managed by a central team, distribution and part reuse can be extremely efficient.
- Recycling schemes such as UniGreenScheme, which collects and resells unwanted equipment from UK universities, are good, but ideally should be the last resort.
- International suppliers should work with relevant local stakeholders to ensure that their packaging can be recycled or reused in all countries in which they operate.
- Involving technicians, analysts, bioinformaticians and other laboratory scientists directly in environmental efforts is likely to accelerate the transition to more sustainable laboratory research and innovation cultures.

"There needs to be more transparency from our suppliers, and we need to have conversations with them about really happens to our laboratory waste."

Dr Richard Gammons, University of York.

"Many of our experiments get duplicated because our data is not findable, accessible, interoperable or reusable (FAIR). This results in a waste of resources. Education is needed to change attitudes towards data sharing and storage."

Dr Bethan Coulson, Johnson Matthey.

Making science greener: community perspectives and solutions

Dr Deirdre Black, Royal Society of Chemistry, reflected on the *Sustainable laboratories* report and considered a number of priorities for the coming years.

Image: Dr Deirdre Black, Royal Society of Chemistry.

> "There is an important role for both bottom-up initiatives that empower individuals, and top-down policies and investment. These approaches need to meet in the middle."
>
> Dr Deirdre Black, the Royal Society of Chemistry.

The Royal Society of Chemistry (RSC) has a membership base of over 50,000 individuals from across the international scientific community. The RSC uses the surplus from its global publishing and knowledge business to offer support and resources to thousands of chemical scientists to help them make the world a better place.

Between summer 2021 and January 2022, the RSC engaged with over 700 scientists from 70 countries to determine the extent to which researchers are incorporating sustainability considerations into their work, and to explore some key barriers and solutions. Desk research and a survey were supplemented by discussions with individuals at a range of career stages and in different roles within industry and academia. Findings were collated into the RSC's Sustainable laboratories report[8], published in late 2022.

8. The Royal Society of Chemistry. 2022 *Sustainable laboratories*. See https://www.rsc.org/globalassets/22-new-perspectives/sustainability/sustainable-labs/sustainable-laboratories-report.pdf (accessed 18 May 2023).

The report depicted a widespread interest in sustainable science and indicated some early adoption of relevant measures, generally at local levels. It highlighted differences between 'systemic and cultural' versus 'technical' challenges and solutions. It also revealed significant variation in knowledge and skills both within and between organisations. Some small-to-medium sized enterprises (SMEs) and startups lack the time, funds, and infrastructure to implement sustainability measures. Recycling opportunities may be limited by local council waste management policies. Many respondents lacked specialist expertise in-house and were unclear how they might access external advice. A common theme was that whilst it can be relatively straightforward for individuals to implement actions within their immediate control, achieving systemic changes within complex organisational structures requires considerable time and buy-in from multiple stakeholders.

In some cases, respondents admitted feeling ill-equipped and overwhelmed by the scale of the challenge. Several priorities for the coming years emerged.

Education and training

Organisations such as Beyond Benign are working to incorporate green chemistry and systems thinking into secondary education curricula and STEM degrees. Opportunities to include formal sustainability criteria within degree and training accreditation are being explored. The RSC report highlights the need to improve areas like cost-benefit and lifecycle analysis methodologies to support business and strategic cases for change.

Trade-offs

Trade-offs can appear, for example in balancing health and safety and environmental sustainability in areas like the use and disposal of personal protective equipment (PPE) or when ensuring sufficient ventilation. People with the right expertise need to have time to understand what changes, if any, might be possible, and to develop new protocols and guidance.

Scientific conferences

The RSC is supporting efforts to integrate sustainability into mainstream chemistry conferences. This would help to maximise the value of events which can involve significant air travel and to build awareness and knowledge among much wider audiences of practising scientists.

Buildings

The UK Research Partnership Fund and Research England have joined forces to offer funding to nine pilot capital projects in universities across the UK. These projects will explore novel approaches – deploying technologies like microgrids, sensors, solar panels and fuel cells – to minimise the environmental footprint of research facilities. Evaluation findings will be shared with UK Research and Innovation (UKRI) and with the wider scientific community to inform future priorities.

Digitisation and automation

Increasing use of physical automation, sometimes combined with AI, makes it possible to run large numbers of experiments, sometimes in parallel. In addition to more efficient use of resources, this can also enable more reproducible science through standardisation and sharing of research protocols and data.

Publishing

Publishers have an important role to play in supporting the research sustainability agenda. This includes models like registered reports which introduce peer review at the research design phase, thereby reducing waste and maximising the value from experiments and trials. There is also a need for spaces to share negative, null or inconclusive results to avoid duplication and maximise learning. Encouraging and enabling the sharing of data and, where relevant, code, is also very important but remains challenging for various reasons including standardisation, privacy and accessibility.

Recognition

Prizes for individuals and initiatives in environmental sustainability of research already exist, such as the Green Gown Awards UK & Ireland and the Cochrane-REWARD prize for scalable initiatives to reduce research waste. In 2021, the RSC created Horizon prizes for teams and collaborations. These recognise people in a range of roles and can be awarded for outputs such as protocols, software, and research tools as well as traditional research outputs like publications and patents. These types of recognition programmes can increase the profile of, and incentivise engagement with, the sustainable science agenda.

In autumn 2023 the RSC will be launching a programme of small grants to enhance sustainability in research and innovation by supporting initiatives with wider benefits like workshops, networks, resource-sharing, and broader cultural change. The Sustainable Laboratories report will provide a rich source of qualitative data to inform this new programme and other initiatives over the coming years.

Enabling greener biomedical research: findings from a workshop run by the Academy of Medical Sciences' FORUM

Professor Frank J Kelly FMedSci, Imperial College London, presented findings from an Academy of Medical Sciences' FORUM workshop on enabling greener biomedical research held in March 2023, hosted in partnership with the Medical Research Council (MRC) and the National Institute for Health and Care Research (NIHR).

Image: Professor Frank Kelly, Imperial College London.

Multiple initiatives currently exist for improving the sustainability of biomedical wet lab and clinical research, but green practices have not yet been embedded into the research system. The Academy of Medical Sciences' FORUM, MRC and NIHR hosted a workshop, bringing together academia, industry, health services, patients and regulators, to explore this topic and potential solutions in further detail. During discussions, participants at the workshop emphasised the need for:

- Top-down support for bottom-up activities and initiatives;
- Development of a research workforce (particularly including research support personnel) with specialist skills in green research practices;
- Co-ordination of sustainability efforts in scientific research, perhaps through a central entity, which could help develop common metrics and standards, and bring together relevant information and case studies;
- Additional data and tools to assist decision-makers – especially researchers and project coordinators – to quantify, evaluate, and reduce environmental impact; and
- Training mechanisms for researchers, including students, and research support personnel to improve sustainability awareness and actions.

To prompt behaviour change to reduce environmental impact, messaging from funders and regulators should be clear. Greener research practice should be seen as an important part of good research practice, and incentives, rewards and recognition for greener research practice should be introduced.

Participants at the workshop noted that sustainability initiatives within clinical research are behind those in other fields. To accelerate the adoption of greener practices in clinical trials, researchers should learn from progress made in green laboratory practice, demonstrate acceptability to regulators and trial participants, create capacity in the clinical trials workforce, and involve patients in trial design.

A summary of the findings of the workshop can be found in the event report[9].

9. Academy of Medical Sciences. 2023 *Enabling environmentally sustainable biomedical research*. See https://acmedsci.ac.uk/more/events/enabling-environmentally-sustainable-biomedical-research (accessed 4 August 2023).

PANEL DISCUSSION

Enabling greener clinical research

Professor Paula Williamson FMedSci, University of Liverpool, was joined by Dr Sophia Lentzos, National Institute for Health and Care Research (NIHR), Jim Elliott, Health Research Authority, Jürgen Wieland, Novartis, and Professor Susan Michie FMedSci, University College London, to discuss how sustainable practices can be embedded into clinical trials.

Image: (left to right) Jim Elliot, Dr Sophia Lentzos, Jürgen Wieland, Professor Susan Michie, Professor Frank Kelly, and Professor Paula Williamson.

At present, evaluation of clinical trials tends to focus on maximising efficiency (and / or speed) rather than reducing environmental impact. Researchers are encouraged to measure patient-relevant health outcomes, and improve the robustness of trial design, conduct and analysis. Methods and results must be shared in the UK International Standard Randomised Controlled Trail Number (ISRCTN) registry. Such efficiency measures have helped to reduce research waste, which reduces environmental impact, but more can be achieved if sustainability is targeted directly. The healthcare investment community takes an increasing interest in an organisation's sustainability practices, and, with 90,000 clinical trials currently being conducted in the UK, greener clinical research practices present a significant opportunity to reduce the environmental impact of research. The following key points emerged from the panel discussion:

Collaboration

- Collaboration between laboratory groups, industries, sectors – both nationally and internationally – is vital to enhance the sustainability of clinical trials. Organisations such as the Sustainable Healthcare Coalition (a collaboration of academia and industry partners) and the Sustainable Markets Initiative have been undertaking enabling work to promote greener clinical research practice, but more can be done across sectors.
- Improved collaboration could include increased data-sharing of environmental impacts such as the carbon intensity of clinical activities. Pre-competitive engagement within industry and between other organisations, including information exchange, is likely to minimise duplication.

- Involving mid-level employees – such as project and people managers – within companies, universities and other organisations is essential. These stakeholders often have the authority to decide which grassroots initiatives to recognise and scale-up, and are also responsible for executing long-term organisational sustainability ambitions.

Finance and cost

- Conducting trials more efficiently may result in lowering costs, providing funding for more activities with the same overall budget.
- Whilst cost savings from efficiency improvements may increase the research that can be conducted using a given budget, it is possible that consumption, and therefore environmental impact, remains unchanged. This is termed the rebound effect and should be guarded against in efforts to reduce environmental impact.
- Self-funding models, which allocate efficiency savings generated by optimisation activities to further environmental initiatives, could enable previously unfunded voluntary projects to receive financial support.

Training and skills

- Training within funding organisations to educate staff, grant panels and boards could help develop criteria and benchmarking to evaluate the sustainability of grant proposals, and to embed sustainable practices in research.
- Training for researchers to be able to understand the principles of carbon emission measurements and life cycle assessments would improve the design of more environmentally sustainable clinical trials. Where appropriate, researchers should also be able to conduct such assessments should they be necessary.
- The development of online toolkits, such as the Sustainable Healthcare Coalition's pathways guidance[10], would help practitioners evaluate the environmental footprint of clinical trials and guide decision-making.

> "To improve sustainability, we need to work in partnership with the people and communities the research is for and about."
>
> Jim Elliott, HRA.

Behaviour and systems change

- Factors that affect behaviour change, such as an individual's capability (knowledge, skills, physical capacity), opportunities (whether they have the physical and / or socioeconomic opportunity), and motivation, should be considered before sustainable policies are put in place.
- To identify areas within an organisation to target for change first, the potential impact of a given change in policy upon behaviour and environmental impact should be assessed. Considering the following criteria can help: what the impact of the change in policy is likely to be (eg on carbon emissions), how feasible the proposed change is, and how the change will affect other parts of the system (ie if there will be any 'spill-over' effects).
- Key stakeholders in trials – including patients, trial managers and other researchers – should be identified at an early stage to understand who is most likely to implement and be impacted by policy changes, and how.

Encouraging greener clinical research practice

- Conducting greener research practice whilst maintaining research integrity and quality may cost more money. In the future, research funders may need to consider funding less research, acknowledging that it will be of higher quality if there are clear indications of how environmental impact will be minimised. They may also choose to fund initiatives to enhance the sustainability of biomedical and clinical research.
- To incentivise greener research practice, in the future, publishers could consider accepting papers only if the environmental impact of a study remains within a certain threshold. They could also publish carbon emissions of studies alongside articles.

Efficiency and clinical trial design

- Studies that involve patients in their development tend to recruit and retain participants more successfully than those that do not. Such studies tend to produce results more quickly and thus reduce costs, waste and environmental impact.
- Consolidating or adjusting the frequency of shipments of supplies and samples between patients, hospitals and labs can reduce material and fuel consumption, packaging and costs.

10. Coalition for Sustainable Pharmaceuticals and Medical Devices. 2015 *Care Pathways: Guidance on Appraising Sustainability (Main Document).* See https://shcoalition.org/sustainable-care-pathways-guidance/ (accessed 01 August 2023).

- Reducing on-site visits and increasing online patient participation could lower the environmental impacts and travel costs, as well as improving inclusivity for patients with restricted capacity. However, patients should be able to participate in person if preferred. Explaining this to participants can help improve inclusivity and convey the importance of environmental considerations.
- Any changes to clinical trial design should be evidence-based to avoid unintended negative environmental impacts. For example, providing new devices for remote monitoring or symptom recording to clinical trial participants may not necessarily be more environmentally friendly – the embodied carbon within such devices should be considered.
- Clinical research will only become 'green' through collaboration, behaviour change, funding of sustainable projects and training to empower practitioners to reduce environmental impact.

"Getting project managers and people managers involved in sustainable programmes is as important as engaging c-suite executives, such as CEOs and COOs."

Jürgen Wieland, Novartis.

"Understand the problem before rushing to intervene. In order to solve any sustainability issue, you need to understand individual behaviours as well as the system in which the problem sits."

Professor Susan Michie FMedSci, University College London.

"Clinical trialists are not necessarily sustainability experts. We welcome anyone who wants to help us make clinical research greener."

Professor Paula Williamson FMedSci, University of Liverpool.

Quantifying and reducing Scope 3 lab emissions: challenges and opportunities

Juliane Miani, École Polytechnique Fédérale de Lausanne, explained how an online CO_2 calculator developed within the School of Life Sciences can help to calculate Scope 3 carbon emissions and inform sustainability policies at the individual, laboratory and institutional level.

Image: Juliane Miani, École Polytechnique Fédérale de Lausanne.

The École Polytechnique Fédérale de Lausanne (EPFL) is a Swiss public academic and research institution, specialising largely in natural sciences and engineering. EPFL's School of Life Sciences benefits from a dedicated sustainability team who work to help reduce the environmental footprint of research laboratories notably by ascertaining sources of carbon emissions, quantifying the associated footprint, and identifying opportunities for change.

The team established an inventory of laboratory emissions covering indirect Scope 2 emissions (from energy consumption) and indirect Scope 3 emissions (from value chains). Although Scope 3 emissions often represent the majority of a laboratory's carbon footprint, they can be difficult to quantify and address. In the School of Life Sciences, sources of Scope 3 emissions include (but are not limited to) business travel, commuting, food consumption, procurement, and internal services such as glassware washing and an animal facility.

> "Perfect is not on the menu. When precise data is not available, orders of magnitude estimates are a good starting point to identify emission reduction opportunities."
>
> Juliane Miani, École Polytechnique Fédérale de Lausanne.

Developing the CO_2 calculator

To attempt to quantify these emissions, the sustainability team developed a user-friendly online CO_2 calculator which connects directly to several institutional databases. Laboratory staff are invited to input information relating to their business travel, commuting practices and meals taken on campus over the previous year. Data is anonymised and aggregated to maximise cooperation, and estimates based on university-wide surveys are applied for individuals who chose not to participate.

Purchasing lists are downloaded from EPFL's centralised procurement system. Product identification numbers (United Nations Standard Products and Services Code®) and purchasing prices are combined with monetary emission factors specific to the scientific research sector to estimate the carbon footprint of each item. Whilst the calculator cannot yet attribute emissions to specific internal services, it is anticipated that the carbon footprint of these services is likely to be significant.

The type of research undertaken in a laboratory influences both the carbon footprint and the relative contributions of various emissions drivers. For example, one of EPFL's wet laboratories with 15 members is estimated to generate 360 tonnes of CO_2 equivalent per year for the emission sources assessed, of which procurement accounts for 80%. A dry laboratory with nine members, in contrast, produced sixteen times less CO_2 equivalent; of that, the majority was due to business travel.

Introducing tangible changes

Mitigation strategies are required at individual, laboratory and institutional levels:

- EPFL now prohibits air travel for any trip that can be taken by train in under six hours. Commuting via public transport is strongly encouraged.
- All campus cafes serve a vegetarian-only menu one day per week.
- Sustainability criteria are incorporated into all procurement tenders.
- The School of Life Sciences has dedicated staff to maintain and repair laboratory equipment to increase their useful life.
- Laboratory teams are advised to anticipate their consumable needs and make bulk purchases to minimise packaging and transportation for delivery. Procurement of second-hand or refurbished equipment is preferred, and equipment-sharing between research teams is encouraged.
- Scientists are encouraged to optimise and streamline their code to reduce computing needs.

It is possible, and necessary, to start estimating and reducing emissions despite patchy and imprecise data. Orders of magnitude estimates are helpful to identify leverage points and opportunities to reduce Scope 3 emissions. There is no single straightforward solution, and far-reaching cultural and behavioural changes will be needed from all staff and stakeholders.

Unpacking Scope 3 emissions: using life cycle assessment studies to estimate and reduce the carbon footprint of lab consumables

Isabella Ragazzi, University College London, discussed a novel study conducted by UCL Sustainable Resources and Sustainable UCL to quantify the carbon footprint of common laboratory supplies and identify strategies to reduce emissions across the product lifecycle.

"We need a lot more research on how to recycle solvents and novel bio-based polymers, and more LCAs to verify the emissions savings of these polymers. We also need LCAs for reusable options"

Isabella Ragazzi, University College London.

Over 1,000 universities worldwide have made net zero commitments. University College London (UCL), has pledged to achieve net zero carbon emissions across all operations by 2030.

Studies indicate that in many institutions Scope 3 emissions account for 50 – 80% of carbon impacts. Single-use plastic is increasingly under the spotlight: the annual quantities of plastic waste generated by biological, medical and agricultural research worldwide is approximately double the volume produced by the entire UK economy.

The carbon footprints of plastic consumables have typically been estimated using economic emission factors. These assign a single emissions value to a broad material, such as plastic or rubber, offering little guidance for sustainable procurement beyond minimising the quantities of products that are purchased. Life cycle assessments (LCAs) offer a more granular – if time-consuming – mechanism to identify variation in carbon emissions over the entire lifecycle of a product.

Image: Isabella Ragazzi, University College London.

The UCL study

During 2022 and 2023, a team at UCL conducted a meta-analysis of 18 LCAs to develop proxy emissions factors for common laboratory consumables including nitrile gloves, pipette tips and cell culture dishes (especially those made from polypropylene and polyethylene), chemicals and solvents such as ethanol and acetone. The study integrated the impact of different disposal mechanisms – landfill, incineration, and recycling – into a formula to estimate carbon emissions for each product.

The study demonstrated that a product's carbon footprint is influenced strongly by the sources of energy and electricity that are procured by manufacturers and suppliers and which directly determine embedded carbon. Polymer production and raw material extraction accounts for the largest portion of emissions, at 26 – 50%. Incineration, if relevant, contributes a further 30 – 54%. Perhaps surprisingly, transporting products is responsible on average for only 5% of the carbon footprint.

The footprint of a typical UCL laboratory researcher, from consumables, is estimated at 662kg of CO_2 equivalent per year. This assumes that two-thirds of consumables are plastic-based, one-quarter are solvents, and that all disposal takes place through incineration.

Applying the findings

The results of the study suggest that researchers should consider the following avenues to reduce the carbon footprint of laboratory consumables:

- Replacing virgin polymers with waste-based alternatives such as products made from used cooking oil. This could reduce emissions by up to 70%.
- Minimising the use of polystyrene, which is not currently recyclable, and investing in research and development of alternatives.
- Recycling polymers: if all virgin polycarbonates and polypropylenes were recycled, rather than incinerated or sent to landfill, their emissions would fall by two-thirds even after autoclaving.
- Taking a fully circular approach by using recycled polymers in manufacture, and recycling them at end of life, would offer reductions of up to 90%.
- As far as health and safety regulations permit, minimising the use of nitrile gloves, or reusing them. These contain particularly high levels of embedded carbon emissions.

Organisations engaged in research and innovation also have an important responsibility beyond the laboratory in lobbying manufacturers and suppliers to maximise the proportion of their energy supply that is purchased from renewable sources.

From second generation feedstocks to first class consumables: Eppendorf's contribution to improving sustainability in laboratories

Dr Florian König, Eppendorf, outlined the environmental benefits of Eppendorf's bio-based laboratory consumables and discussed barriers that must be overcome to enable their manufacture and use on a larger scale.

Image: Dr Florian König, Eppendorf.

Eppendorf is committed to setting and achieving sustainability targets, including sustained reductions in carbon emissions. Recent work has focussed upon minimising the carbon footprint of feedstocks and production whilst maintaining product quality to satisfy customer requirements.

Reviewing the carbon emissions of consumables

Life cycle checks of Eppendorf's 5ml plastic laboratory vessels offered some initial indications of the relative carbon emissions of feedstocks, production, packaging, distribution, and disposal. Checks revealed that raw materials and production accounted for a significant proportion of the associated carbon footprint. Eppendorf now purchases 100% renewable energy for all production sites (except one which is in transition). This has generated a 56% reduction to Scope 1 and 2 CO_2 emissions between 2019 and 2021. The company has also secured an International Sustainability and Carbon Certification (ISCC) PLUS certification for its Oldenburg production site.

Introducing bio-based consumables

These changes have underpinned the research and development behind Eppendorf's bio-based consumables, which include tubes and pipette tips. Eppendorf Tubes® (without a cap) are currently manufactured using 90% second-generation feedstocks, applying the ISCC mass balance approach. Bio-based materials principally consist of recycled cooking oil and associated residues. The ISCC framework requires full accounting and auditing of bio-based materials that enter and exit manufacturing and supply chains. Eppendorf is committed to transparency and is working to make these data publicly available. A transition to 100% bio-based feedstock for the cap production is planned within 2023.

A full life cycle assessment (LCA) recently compared vessels conventionally manufactured from polypropylene and polyethylene with Eppendorf's Tubes® BioBased. This included cradle-to-gate analysis[11], aligned with the ISO 14044 LCA guideline, and cradle-to-grave evaluation, accounting for international distribution. Results of the LCA indicated that raw materials and distribution presented the most significant environmental impact 'hotspots', including, but not limited to, carbon emissions. Bio-based feedstocks offered a 16 – 27% reduction in CO_2 emissions compared to virgin polypropylene and high-density polyethylene, depending on the chosen feedstock scenario.

Future challenges

In order to achieve maximum impact upon the environmental footprint of laboratory activities, scale-up of bio-based consumables will be required. A number of challenges remain:

- Increasing the availability of bio- and waste-based feedstocks. Competition for these resources is intensifying and means that prices remain high.
- Encouraging laboratory researchers to better anticipate their consumable needs to avoid relying exclusively upon near-immediate delivery.
- Reducing undesirable side-effects such as increased freshwater ecotoxicity associated with (current) agricultural practices surrounding bio-based feedstocks.
- Identifying alternatives to disposal to move towards a more circular manufacturing and supply chain.

> "Our product vision is based on a clear understanding of customers' requirements. We are committed to delivering competitively priced products of the same quality whilst demonstrating that these are more environmentally sustainable."
>
> Dr Florian König, Eppendorf.

11. The carbon impact of a product from its production date to the date it becomes commercially available.

Case studies in Scope 3 emissions

Martin Farley, Juliane Miani, Isabella Ragazzi and Dr Florian König considered a number of themes around manufacturing, Scope 3, and emissions factors.

Image: Dr Florian König and Juliane Miani.

Emissions factors

- Economic emission factors (also known as monetary emission factors) are often considered to be generic and unreliable measures of a product's environmental impact, and can be compared unfavourably to life cycle assessments (LCAs) which tend to offer greater depth and precision. However, they may prove useful when estimating the aggregated carbon footprint of lengthy product lists.

- The French initiative Labos 1point5, led by the French national centre for scientific research (CNRS), has produced relatively precise economic emissions factors based on thorough analysis of comprehensive data at the industry, company, and product levels. At EPFL, for example, these emissions factors are used wherever possible for deep-dive evaluation. Comparative analysis tends to rely more upon generic economic emission factors, which currently offer more consistent comparisons between products. It is anticipated that more precise background data will be made available in centralised databases as LCAs are undertaken for a broader range of products over the coming years.

- LCAs may be particularly useful for individual researchers who utilise a relatively small range of products in their day-to-day work. Sustainability and procurement professionals, operating on a larger scale or at organisational level, are likely to benefit from access to monetary emissions factors.

- Data is particularly useful when disaggregated on a regional basis. For example, emissions associated with transport and distribution of products can vary considerably based on local demand and therefore the volumes contained within each shipment.

Raw materials

- Polystyrene is widely used in both laboratory consumables and packaging, but at present is not recyclable in the UK[12]. Further research is urgently needed to explore opportunities for recycling, and whether it is feasible to replace the polystyrene in consumables such as petri dishes with alternatives during manufacture.

12. However, polystyrene is 'up-cyclable', and can be manufactured into bricks for resale (see page 25 for more information).

- The majority of plastic consumables in laboratories are manufactured using polyolefins. Although these are cheap and effective on a practical level, they are not easily biodegradable and thus contribute to the large volumes of plastic waste generated from research laboratories. Polyhydroxyalkanoates, produced organically from plastic waste by microorganisms, possess comparable properties to polyolefin-based products and thus offer a promising alternative. They are, however, considerably more expensive to extract and purify. This barrier must be addressed urgently.

"It is important to know when to use precise data from life cycle assessments and when it is better to take a more comprehensive approach"

Juliane Miani, École Polytechnique Fédérale de Lausanne.

"Life cycle assessments are most useful when a laboratory uses a large number of products made from the same material, as they can facilitate deep analysis"

Isabella Ragazzi, University College London.

Towards the sustainable manufacture of active pharmaceutical ingredients

Dr Steve Swallow, AstraZeneca, discussed how new tools and technologies, waste stream recycling, and reductions in active pharmaceutical ingredient (API) synthesis steps can increase the sustainability of API manufacturing.

Image: Dr Steve Swallow, AstraZeneca.

Active pharmaceutical ingredients (API) are the core components of pharmaceutical drugs. They are manufactured under highly controlled, reproducible conditions to achieve consistent quality and purity. Starting materials are combined with reagents and solvents in a sequence of 'stages', known as a 'route'. Each stage generates waste streams and losses. A 10% loss of input mass, to give 90% yield, is usually considered acceptable by manufacturers.

API manufacture accounts for up to 25% of AstraZeneca's manufacturing carbon footprint, and thus represents a significant opportunity to reduce organisational environmental impact. The production phase, specifically the use and disposal of organic solvents, is the largest contributor.

"The long lead times between drug development and production mean that we must start thinking about carbon reduction in manufacturing now."

Dr Steve Swallow, AstraZeneca.

Optimising manufacturing routes

Optimisation of manufacturing routes by removing stages and improving yield can reduce waste. For example, a route comprising six stages, each with a 90% yield, provides an overall yield of just 53%, necessitating almost double the volume of starting material. This demonstrates the importance of optimising API synthesis protocols for high yields.

In addition, routes with more stages generate higher volumes of waste. Dr Swallow's team used a novel method to predict waste volumes across different routes to demonstrate that reducing 16 stages to nine cut waste production by more than 60%.

Using new tools and technologies to help reduce waste

- Process mass intensity (PMI) is a common metric to indicate waste in API manufacturing. It reflects the mass of all starting materials used to manufacture one kilogram of product compared to the mass of the final API product. However, PMI does not consider carbon footprints, energy and water usage, nor the environmental impact associated with the construction of reagent catalysts. AstraZeneca and others have developed a tool that integrates life cycle assessment with PMI to account for carbon footprint and energy and water use to improve benchmarking and design for API manufacturing.
- Dr Swallow's team deployed a novel photoredox reaction to reduce the number of stages in ceralasertib synthesis from nine to seven and decrease the PMI by a further 20%, approximately. This highlights the importance of investing in the development of new bond-forming technologies to shorten manufacturing routes.
- AstraZeneca is also driving waste reduction using flow processes. These continuous flows of reactants and reagents differ from traditional batch reactions (which are mixed in a vessel for a specific amount of time) and can allow reagents with lower carbon footprints to be integrated into production routes.
- Membrane technologies offer a low-energy mechanism to separate molecules based on size and shape, thus filtering waste streams and reducing waste. Dr Swallow's team established that filtering waste methanol used in vessel cleaning during API manufacture significantly upgraded the solvent to the point it could be reused in vessel cleaning. After filtration, up to 80% of the solvent is of suitable quality for reuse. This has the potential to reduce methanol waste by approximately 200 tonnes per year.

Future opportunities to improve sustainability

Whilst innovations and new technologies in route design have helped AstraZeneca move towards sustainable manufacturing, more can be done to accelerate the transition. Baseline emissions require quantification so that emissions reduction targets can be met successfully. The development of new green technologies, such as solvent-free chemistry, and improved access to bio-renewable input materials, will be crucial. Precompetitive collaborative efforts between industry and academia are likely to prove instrumental in addressing these challenges effectively.

Rolls-Royce's journey to sustainable aviation R&D

Rachael Everard, Rolls-Royce, discussed the ways in which Rolls-Royce is changing both its research methods and end products to better align with organisational sustainability goals.

Image: Rachael Everard, Rolls Royce.

The aviation industry is responsible for emitting 900 million tonnes of CO_2 per year, representing approximately 3% of all global emissions. Flying is becoming more popular in emerging economies, especially in Asia, and by 2030 it is expected that over six billion people will be flying annually. As a major producer of aviation engines, Rolls-Royce has committed to lowering the environmental impact of all its operations, including reducing product energy demand and waste, optimising resource efficiency and introducing circularity into plant processes. Collaboration between university technology centres and advanced research centres is a crucial ingredient in efforts to reduce carbon emissions.

"Much of this work must be done in collaboration with other companies and organisations such as academic institutions."

Rachael Everard, Rolls Royce.

Making engineering research more sustainable

Rolls-Royce has approximately 50 sites worldwide that rely on energy intensive processes such as welding, acid baths, machining, furnacing, and 3D printing. The organisation has set science-based targets to enhance the environmental sustainability of research into engine development.

A coolant recycling process, developed by Rolls-Royce in collaboration with a small-to-medium sized enterprise (SME) supplier, was rolled out across all UK Rolls-Royce sites. This has since saved over 9,000 litres of coolant per year and has eliminated associated disposal costs for contaminated waste.

Rolls-Royce is also reducing its demand for finite raw materials such as titanium and uranium by deploying novel additive manufacturing methods including advanced near net shaping, a type of laser 3D printing. This also serves to lessen negative social and environmental impacts associated with resource extraction.

It remains challenging to balance the optimisation of efficiency in manufacturing processes with product safety, operation and durability. Collaborations with the University of Loughborough and other academic institutions have helped by introducing new digital programmes. These have enabled the testing of engines – a process which burns approximately 100 gallons of fuel per hour – to be reduced from weekly to biannually. Testing is increasingly undertaken using sustainable aviation fuels (SAFs), which can be produced from biological material such as crops, food waste (including cooking oils), or generated synthetically by electrolysis. The lifecycle carbon footprint of SAFs is typically 80% lower than that of conventional jet fuel.

Making products more sustainable

90% of Rolls-Royce's emissions can be attributed to the use of end products by customers. As such, Rolls-Royce is pursuing incremental efficiency gains in gas turbines – such as making engines hotter, larger and lighter – to minimise fuel burn and thus emissions.

Rolls-Royce also aims to increase the uptake of SAFs and pioneer new technologies such as electrical aviation. SAFs can be integrated into most Rolls-Royce engines without requiring alterations to the infrastructure. Rolls-Royce have also released several hydrogen-powered and electrical aeroplane engines, such as a new air taxi eVTOL (electrical vertical take-off and landing) aircraft. Collaboration between universities and other companies has accelerated the conversion of conventional aviation engines into green hydrogen engines, an exciting development in the journey towards zero-carbon aviation.

Currently, Rolls-Royce also recycles up to 96% of aeronautical engines, reusing parts within its own supply chain. However, composite materials typically used to make hydrogen engines are more difficult to recycle. In addition, the need for more electrical components (for example, in electrical aeroplanes) means that Rolls-Royce relies increasingly upon the availability of rare raw materials. These trade-offs must be considered when formulating and refining company strategies and sustainability goals.

The Cell and Gene Therapy Catapult: our approach to sustainability

Dr Anan Høst Ragab, the Cell and Gene Therapy Catapult (CGTC), discussed how CGTC is measuring its environmental footprint, how this informs the organisation's strategy and the changes it is making using the data.

Image: Dr Anan Høst Ragab, Cell and Gene Therapy Catapult.

The Cell and Gene Therapy Catapult (CGTC) collaborates with academia and industry to develop and manufacture advanced therapy medicinal products (ATMPs) for treating injury and disease, and to accelerate clinical adoption of and patient access to these treatments.

Since manufacturing environments generally produce more carbon emissions than research and development centres, CGTC has an important role to play in reducing the environmental impact of scientific activities and disseminating best practice. Over the past few years CGTC has developed its green agenda, introducing a cross-organisation corporate sustainability team supported by members from the CGTC Green Committee and the Guy's and St Thomas' NHS Foundation Trust sustainability team. In addition, CGTC participates in net zero initiatives with the other UK Catapults. The organisation has three green strategic goals, including enhancing the sustainability of facilities and consumables, promoting an environmentally responsible workplace and developing a pathway to achieving a net zero carbon footprint.

CGTC's London-based Technology and Process Innovation laboratories piloted LEAF (the Laboratory Efficiency Assessment Framework) and gained bronze accreditation in August 2022. LEAF is due to be integrated into the three other CGTC sites in the UK in 2023. CGTC is conducting numerous data collection studies to establish which areas of the ATMP manufacturing process should be targeted for change.

"Moving to closed, intensified, and automated processes early can reduce both costs and waste for cell and gene therapy developers. This is likely to reduce greenhouse gas emissions and we are working now to quantify this and disseminate it to the wider cell and gene therapy industry"

Dr Anan Høst Ragab, Cell and Gene Therapy Catapult.

Using data to inform changes

Scope 1 and 2 emissions, and some scope 3 emissions, were quantified for Streamlined Energy and Carbon Reporting conducted by the CGTC sustainability team. This assessed emissions from purchased electricity, combustion in owned or controlled boilers and furnaces, heat, steam and cooling, business travel and some goods and services. Initial outcomes included updating the organisational business travel policy, introducing an e-car lease scheme and increasing the number of e-car charging points, the adoption of renewable energy guarantees of origin (REGO)-certified green electricity and a policy to launder personal protective equipment rather than relying on disposables.

CGTC employs monitoring software which provides information on the operations of cleanroom processes. The monitoring and subsequent modelling has estimated that heating, ventilation and air conditioning (HVAC) of cleanrooms may account for up to 91% of emissions of the manufacturing process (3,700 tonnes of CO_2 per year based on a 7,700m^2 cleanroom area). To decrease reliance on HVAC and thereby reduce footprint, production processes must become more closed and intensified, potentially also leading to increased yield.

For example, the development of a stem-cell derived therapy requires billions of cells which, for early-stage developers, are usually grown manually in individual flasks and require a number of highly skilled operators in high grade cleanroom facilities. CGTC's new automated system uses bags, rather than solid flasks, reducing volumes of plastic. By connecting these bags to bioreactors, scale-up manufacture becomes a closed process, and automation is increased, requiring fewer operators in a less energy intensive cleanroom. Cost of goods studies have shown that although the automated system may lead to higher consumable costs, the volumes of waste, and costs associated with facilities and staff, decrease. In addition, yields tend to be higher, generating a lower per unit cost overall.

Developing evidence-based approaches in collaboration with universities and other experts, despite difficulties in acquiring sufficient data, is helping to build sustainable infrastructure on which the cell and gene therapy industry can grow. These approaches also reduce costs and build awareness of the organisation's impact, improving accountability by tracking commitments over time. A future priority will be to improve quantification of scope 3 emissions to enhance understanding of the full picture.

Sustainability at The Atomic Weapons Establishment: the Hub as an example for the future

Dr Olivia Marsden, The Atomic Weapons Establishment (AWE), outlined how laboratory buildings, such as the new Hub at AWE, can be designed and constructed in line with environmental sustainability strategies.

Image: Dr Olivia Marsden, AWE.

The Atomic Weapons Establishment (AWE) provides warheads for the UK's nuclear deterrent and offers services to support nuclear threat reduction and counter-terrorism efforts. As a result, many AWE sites are nuclear-licensed and contain hazardous materials such as chemicals, explosives and radioactive products, all of which have the potential to negatively impact the environment.

AWE's environmental strategy centres around reducing carbon emissions, implementing the circular economy, and enhancing biodiversity at its sites. Staff are involved in all stages of the process and by the end of 2023, it will be mandatory for every employee to complete an internally-organised sustainability course.

AWE is also embedding sustainability considerations in all new construction and development. The AWE Hub, due to open in 2026, will provide sustainable laboratories, offices and accommodation along with conventional low-hazard radiological laboratories and workshops. It is expected to achieve an 'excellent' rating under the Defence Related Environmental Assessment Methodology (DREAM) framework, which will require a biodiversity net gain onsite of at least 20%.

"It's the people who are important, which is why involving staff and providing education around sustainability across AWE will help minimise impacts on the environment."

Dr Olivia Marsden, AWE.

Designing sustainable buildings

The Hub's design was informed by eight broad considerations including onsite biodiversity, energy usage, procurement, travel, water and waste. Reports and biodiversity heritage statements have been created to meet DREAM targets, an embodied carbon study was undertaken, and the building now includes:

- A low-temperature hot water system;
- Photovoltaic panels;
- Energy-optimised boilers to maximise efficiency;
- Water and electricity meters to collect data for ongoing analysis and to ensure that flow rates meet requirements;
- Recycled construction aggregates;
- Light sensors to detect room occupancy and to adjust for daylight;
- Cycle storage facilities;
- Optimised pedestrian access; and
- Equipment with 'A' efficiency ratings.

Improving the sustainability of construction

AWE will monitor noise and air quality onsite to ascertain how nesting birds and other organisms – in addition to local residents – will be affected during the development and use of the building. Construction waste will be minimised by using rainwater and by recycling or reclaiming waste materials for temporary site works. Targets have also been set to ensure low energy consumption.

Improving operational sustainability

The Hub will also include a centralised purchasing and storage facility to reduce use and storage of chemicals and consumables, and a bay to enable scientists to reuse and share scientific equipment and spares. Waste will be segregated for recycling or safe disposal where applicable. As all AWE staff will be based in the Hub, equipment will be maximally utilised, reducing equipment 'downtimes'.

Challenges include balancing the optimum daylight factor and acceptable aesthetics with the overall design. Equipment purchases need to be carefully considered: for example, the global warming potential of some refrigerants is five or more. However, despite the trade-offs, the Hub remains a positive example of a building designed and constructed with sustainability in mind that is anticipated to fulfil the needs of AWE staff.

Case studies from industry

Rachael Everard, Dr Anan Høst Ragab, Dr Olivia Marsden and Dr Steve Swallow discussed knowledge transfer across industry and academia, and opportunities and trade-offs associated with efforts to improve the sustainability of research and innovation activities.

Image: (left to right) Dr Anan Høst Ragab, Dr Olivia Marsden, Dr Steve Swallow, Rachael Everard, and Professor Helen Sneddon.

- Improving dialogue between industry and academia can offer opportunities to share best practice. Cross-sector knowledge transfer, such as integrating problem-solving strategies from engineering settings within the chemical sector, is also useful in tackling common challenges.
- Many companies have to explore trade-offs when considering how to make their production processes more sustainable. For example, in the coming years there may be times when the environmental footprint of a given manufacturing process becomes too high, and the process must be superseded. Careful planning of targets in any project and even post-launch improvements can minimise associated risks. Other examples include undertaking comparative modelling of the relative carbon footprints of demolition, reconstruction and refurbishment before considering designs for new buildings.
- Many pharmaceutical companies have established research programmes investigating the use of laboratory and research materials to understand their environment impacts, as well as to identify opportunities to reduce the impact of consumables, such as single-use plastics.
- Some companies are also exploring technologies to monitor the level of activity in a particular room to adjust cleaning schedules, thus helping to reduce the amount of energy and consumables used. In addition, the air changes in a particular clean room may be dynamically changed according to the activities occurring in each of them. For example, areas with experiments that have low rates of particle generation (ie closed processes) can spend less energy on HVAC (heating, ventilation and air conditioning) than areas with open processes.

- Monitoring is also used at the end of production to strictly control waste release. Waste emissions are sorted depending on the local council requirements for the manufacturing facility. For instance, if organic components reach a particular level in wastewater, it may be sent for incineration to ensure dangerous substances are removed. Further monitoring technologies may have a positive role to play in improving waste sorting.
- Behaviour changes can be encouraged by implementing systems to raise awareness of sustainable practices within organisations. Several companies have been using tools such as traffic light labels on consumables and introducing greener solvents to procurement catalogues to foster a culture of continuous improvement.

"We don't know what we don't know. This is why dialogue across sectors and between industry and academia is so important. We are all trying to tackle the same problem"

Dr Anan Høst Ragab, Cell and Gene Therapy Catapult.

"Understanding the baseline of projects is important for measuring and understanding the scale of the carbon emission challenge"

Dr Steve Swallow, AstraZeneca.

PANEL DISCUSSION

Panel discussion with funders

Professor Richard B Flavell CBE FRS chaired a panel discussion with Dr Andrew Clark, Royal Academy of Engineering, Alison Robinson, the Natural Environment Research Council, Alyson Fox, Wellcome Trust, and Dr Rachel Grimley, Cancer Research UK, to address what actions funding bodies are considering implementing to enhance the sustainability of scientific research and innovation.

Image: Dr Rachel Grimley, Dr Andrew Clark, Alyson Fox, Allison Robinson, and Professor Dick Flavell.

Funding bodies are major players in the UK's research and innovation landscape. They are grappling with the dual challenge of implementing net zero strategies at an organisational level and exploring how sustainability considerations might influence funding policies and frameworks during the coming years.

"Funders can no longer sit by. We need to listen to the science that we fund to ensure that research and innovation contributes to the challenge of meeting a 1.5°C ceiling. We are not there yet."

Alison Robinson, NERC.

UK Research and Innovation (UKRI) has pledged to achieve net zero carbon emissions across its operations by 2040. Activity is in place to deliver against this commitment, with progress by the Natural Environment Research Council (NERC) accredited by The Carbon Trust in June 2023. The Wellcome Trust has launched its sustainability strategy, informed by collaboration with UKRI and with other organisations. The strategy recognises the critical importance of addressing Scope 3 emissions in any path to net zero. The Royal Academy of Engineering (RAEng) applies its vision to 'harness the power of engineering to create a sustainable society and an inclusive economy for all' in its funding strategy, recognising that innovations in engineering will make strong contributions to the transition to net zero. Cancer Research UK (CRUK) released its Position Statement on Environmental Sustainability of Research in August 2022, and is now exploring sustainability considerations within research infrastructure specifically. CRUK also notes that engaging supporters and reconciling them to sustainability debates is an important element of sustainability decision-making for charities.

All speakers highlighted the importance of strategic collaboration between their organisations, and of cross-funder assurances. They explored the difficulties associated with introducing additional layers of regulation and compliance, and emphasised that changes to funding policies must be informed by input from researchers and associated professional staff.

Funding decisions

- Expectations placed upon institutions and researchers by funding bodies will carry weight when underpinned by clear organisational sustainability commitments from funding bodies themselves. UKRI's Scope 1 and 2 emissions, for example, currently exceed those of a large university. Many UKRI institutes contain energy intensive infrastructure, and UKRI intends to prioritise sustainability impacts within infrastructure grants in the near future.
- In general, environmental impact assessments are not yet used to officially screen funding applications. The RAEng does, however, ask applicants to clarify how a proposal would support a sustainable society, and responses can influence outcomes. Where all else is equal, proposals that demonstrate a clear sustainability benefit are likely to be given a higher priority. However, in areas where the environmental impact data is less clear, decision-making consistency can be a challenge.
- There was general agreement that funding bodies should avoid – either directly or indirectly – placing additional bureaucratic constraints upon grant recipients, and that standard-setting should be led by regulators. Funders can support frameworks that share best practice amongst the scientific community.
- Funders must balance sustainability with other considerations such as cost, time, potential impact and the international context. Some funder expectations currently discourage sustainable choices – for example encouraging cheap travel rather than eco-travel or setting rigid timelines on capital expenditure. Re-evaluating these expectations would be judicious. Institutions undertaking research in resource-limited settings may have fewer opportunities for mitigating activities with higher sustainability costs, especially where fieldwork is essential to project delivery. In addition, some researchers who choose not to participate in conferences and events that require air travel may currently feel penalised; care must be taken to avoid this.
- Co-operative initiatives, including a concordat recently instigated by UKRI, will be important in achieving consistency across the funding community and in encouraging institutions to explore broader environmental considerations such as biodiversity and ecosystem services. Collaboration between diverse organisations including charities, public and private sector funders and the UK Catapult Network will be essential.

"Applicants worry that being honest about the environmental impacts of their proposals might cost them the grant. Clarity is necessary, but it is tricky for both applicants and funders to achieve a suitable balance."

Professor Dick Flavell CBE FRS.

"A funder should not serve as a restriction to those doing the research. We need to balance carrot and stick approaches."

Dr Andrew Clark, Royal Academy of Engineering.

"We can keep on saying that 'it is complex', but we can't postpone taking action because we don't yet have all the answers. We need to be proactive in setting policies and expectations and can adjust these over time if needed. Otherwise, we won't progress, and it is clear that we don't have any more time."

Alyson Fox, Wellcome Trust.

Responsibilities

- Responsibility for mitigating environmental impact should not be placed solely upon individual researchers, particularly those in the early stages of their careers for whom international travel can be an important element in establishing networks and impact. Funders are likely to place higher expectations at the institutional level.
- One solution might be to include a sustainability or life cycle assessment as a deliverable in the first year of each grant proposal, to be refined over subsequent years as research programmes evolve.
- Award panels commonly include external advisors. These individuals will need to be equipped with tools and guidelines to enable them to interpret environmental impact assessments and specialist data to evaluate grant proposals fairly and consistently.

Additional considerations

- Certain sustainability measures generate extra costs. For charity funders such as CRUK, careful communication with donors and fundraisers will be required to manage expectations around these trade-offs. In general, funding bodies may need to consider reducing the number of awards made annually to reflect the higher costs of undertaking intentionally sustainable research and innovation.
- In some cases, however, activities to enhance sustainability can offer significant cost savings. In recent years, for example, Novartis managed to significantly reduce the aggregate costs of pre-clinical and clinical research by implementing modified operational designs inspired by sustainability concerns.
- Funders can offer valuable support in other ways, through providing specialist expertise, toolkits, and networking opportunities to strengthen relevant capacity in sustainability issues at all levels.

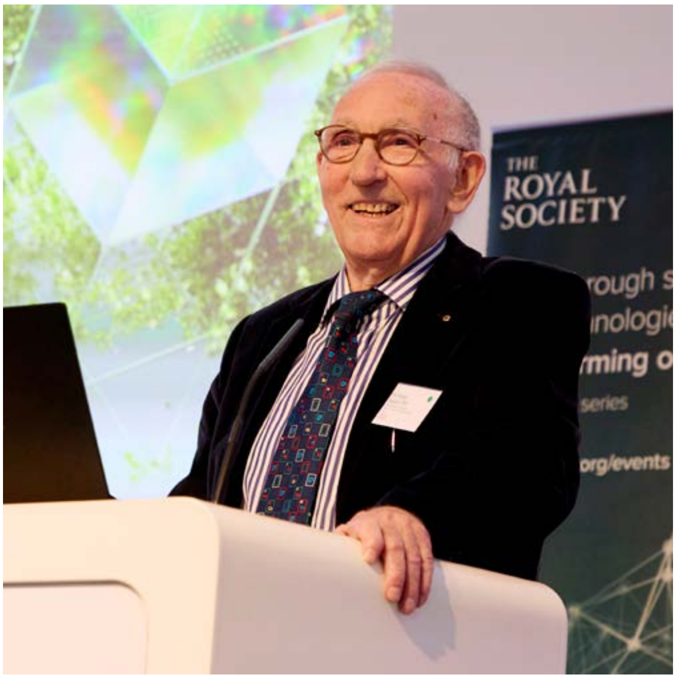


Image: Professor Roger Sheldon FRS, Delft University of Technology.

"Consistency is essential. The sustainability assurances that funding bodies seek must be coherent. This is also about moving the needle – if we, as funders, don't try to push harder we risk simply maintaining the status quo."

Dr Rachel Grimley, Cancer Research Horizons.

"We have come a long way since I was doing my first experiments in 1958, but there is still more to be done for lab sustainability. We need to foster opportunities for collaboration, such as getting involved in networks or attending conferences like this one."

Professor Roger Sheldon FRS, Delft University of Technology.

The Royal Society is a self-governing Fellowship of many of the world's most distinguished scientists drawn from all areas of science, engineering, and medicine. The Society's fundamental purpose, as it has been since its foundation in 1660, is to recognise, promote, and support excellence in science and to encourage the development and use of science for the benefit of humanity.

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The RSC's Sustainable laboratories report draws on the views and experiences of scientists about how to conduct research in a more environmentally sustainable way without compromising aspects like research safety, quality and impact. The report also highlights some of the challenges and opportunities relating to the wider research ecosystem and is the basis for the RSC's ongoing efforts to support the scientific community in reducing the environmental impacts of research.

To find out more about the RSC Sustainable laboratories report, visit **rsc.li/sustainable-labs**

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