Policy Position

December 2021

Risk-based regulation for per- and poly-fluoroalkyl substances (PFAS)

PFAS play an important role in some vital products that improve quality and longevity of life. With that recognition, concerns are increasing across the world about the adverse health impacts of PFAS, to humans and wildlife. All PFAS are persistent. All uses of PFAS should be assessed, using specific risk-based regulation based on sound science, with better environmental (bio)monitoring and grouping approaches to characterise exposure and hazard, respectively. Investment now in new scientific approaches, and in the skills base for the provision of scientific advice, will enable the health and environmental risks of groups of PFAS to be better understood. Release of toxic PFAS into the environment must be controlled in the near future. We need to know as soon as possible which of the many hundreds of PFAS are toxic and which are not. It is possible to achieve effective PFAS-specific regulation, to retain the safe and sustainable uses of PFAS in products and processes that are considered vital to future innovations of benefit to society. A ban on all PFAS as a group is neither practical, necessary, nor achievable. However, defined PFAS groups that are shown to present an unacceptable risk to humans or wildlife must be restricted or removed. This policy position provides a thought-starter for discussing a risk-based framework for PFAS regulation, to maintain high standards of health, safety, and environmental protection, and promote effective global action to reduce pollution.

Summary points

- **Based on concerns around unquestionable persistence of PFAS and potential toxicity of some PFAS, governments and chemical agencies need to regulate PFAS urgently all across the world.**
- **With experienced regulators and an excellent science base, the UK should take a leading role on developing risk-based PFAS regulation, using a set of sound principles for the management of chemicals in the environment as informed using state-of-the-art scientific evidence.**
- **We advocate taking a starting position that balances precaution, risk and impacts, given the scientific uncertainties and unknowns surrounding the potential for insidious long-term toxicity from some PFAS.**
- **Governments could involve citizens in a multistakeholder group – we introduce the concept of a 'PFAS Jury' to decide if PFAS uses are deemed as 'vital' or 'highly desirable'; this could help prioritise further urgent efforts**
- **For those PFAS which are defined as 'vital' or 'highly desirable' by wider society, human and wildlife exposure should be managed and reduced to levels of societally 'acceptable risk', informed by the best science.**
- **To address the safety data gaps for PFAS, new approach methods (NAMs) in exposure and toxicology science are emerging; global collaborative efforts, to address data gaps and share data, should increase to minimise any future animal testing and seek harmonisation of new evidence.**
- **Governments should decide whether PFAS deemed neither 'vital' nor 'highly desirable' by wider society should be deprioritised for science evaluation, and those of greatest risk phased-out or restricted without delay.**
- **We propose a potential framework for discussion based on a 'traffic light' approach for resulting action on PFAS, where grouped substances are prioritised for action by a central regulatory agency, based on both their functional need in society and highest risks of potential harm.**

Building Blocks, Challenges and Outcomes of a Proposed Framework for Risk-Based Regulation of Per- and Poly-fluoroalkyl Substances (PFAS)

The concerns relating to PFAS are real; PFAS must be regulated via risk-based evaluation, urgently, to prevent a potentially damaging and intractable issue now and for the next generations, with suitable controls put in place. A summary of a stepwise framework is presented in Figure 1, to consider how regulatory action and scientific efforts could evolve hand-in-hand to support urgent and effective risk-based control of toxic and persistent PFAS.

The key scientific challenges are:

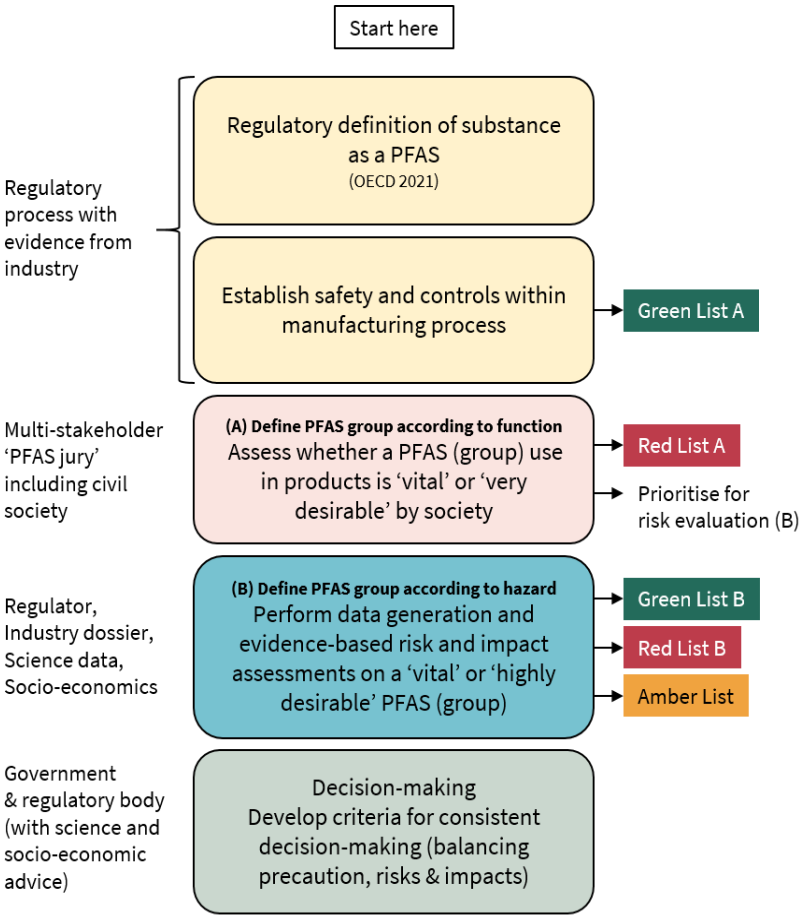
i) The data gaps and unknowns are extensive on the toxicology for hundreds of PFAS

ii) The data on real exposure levels to PFAS in the environment and in human bodies is sparse

iii) Addressing these scientific gaps using traditional toxicology and exposure assessment approaches for individual PFAS would take decades, be too costly and involve too many animals; we need investment in new scientific approaches

iv) To guide the science, a collaborative steer is needed from wider society to focus efforts on those PFAS that are most important for the future benefit of society. A distinction is made between scientific analysis, regulatory considerations and decisions taken by government with the input of civil society.

v) For PFAS with data, scientists can do a risk assessment now, and consideration of how vital the PFAS is can come after risk assessment has shown a moderate to high risk; but scientists cannot take the decision on what is 'acceptable risk'.



(A) Grouping based on sector, function and product types
(B) Grouping based on science, hazard and risk

Potential outcomes from the framework:

Green List A – occupational and environmental release can be strictly controlled for a PFAS used only in specified manufacturing processes – the PFAS is safe to use for the permitted manufacturing process. NB. PFAS that cannot be strictly controlled are treated in the framework the same as PFAS in end-products.

Green list B – PFAS use in end-product is considered 'vital' or 'highly desirable' by wider society, data on safety are available, risks are evaluated and designated no/low concern – PFAS is safe to use for the permitted processes and products.

Amber List – PFAS use in end-product is considered 'vital' or 'highly desirable' by wider society, data on safety are available, risks are evaluated and designated medium or high concern – restricted use is allowed until alternatives to PFAS are available and targeted environmental (bio)monitoring is performed.

Red List A – PFAS use in end-product is determined as not 'vital' or 'highly desirable' by wider society – recommendation by a 'PFAS jury' to the regulator to phase out PFAS use, no requirement for further safety data to be generated.

Red List B – PFAS use in end-product determined 'vital' or 'highly desirable' by wider society, but data on safety are not available, the risk is not acceptable without any data – PFAS use is phased out.

Figure 1: *The building blocks and potential outcomes of a science-informed, risk-based framework for action on PFAS*

1. Introduction

The term PFAS (as defined by the Organisation for Economic Co-operation and Development (OECD), 2021 – see section 4 below) represents a large group of thousands of fluorinated chemicals used globally since the 1940s in a multitude of different products and processes for their unique water-, oil-, heat- and stain-resistant properties. However, due to their high stability in the environment and resistance to biodegradation, all PFAS are persistent, and many are highly mobile in global waters. PFAS are present in groundwater, freshwater systems, the marine environment, in wildlife and in our human bodies. We do not truly know the harm that may be evolving as there are many scientific evidence gaps. PFAS have been associated with adverse human health effects, and effects in wildlife, in exposed populations following localised pollution events. Regulations aiming to control exposure to PFAS and mitigate the risks are now emerging around the world to prevent potential harms from accumulative pollution from multiple chronic and diffuse sources.

2. Function and uses of PFAS

PFAS are a large group of more than 4,700 highly fluorinated substances with a carbon backbone, produced since the 1940's and known for their superb and unique water-, oil-repellent and stain-, heat-resistant properties. PFAS are used in wide-ranging and specific applications[1] such as hydraulic fluids, biocides, flame retardants, fire-fighting foam, floor polishes, construction materials, protective clothing, food packaging, heat-resistant non-stick cooking surfaces, medical devices, and insulation of electrical wires, to name a few. Typically, PFAS have not included fluorinated gases (F-gas) (e.g. used as refrigerant gases) but these could now be included under the broad scope of the OECD 2021 definition. Many PFAS are expensive to manufacture and are produced in low amounts in niche and very specific applications.

A detailed list of examples can be found in Table 1.

Table 1: *Major properties and industrial applications of PFAS*[1]

Industry/Application area	Key properties	Typical uses	Typically used PFAS*
Chemical/petrochemical industry	Chemical resistance Good mechanical properties Thermal stability Cryogenic properties	Gaskets, vessel liners, pumps, valve and pipe liners, tubing, coatings, expansion joints/bellows, heat exchangers	PTFE, PFA/MFA ETFE, ECTFE FEP FKM, FFKM TFE-P
Electrical/electronic industry	Low dielectric constant High volume/surface resistivity High dielectric breakdown voltage Flame resistance, Thermal stability Low refractive indices	Wire and cable insulation, connectors, optical fibres, printed circuit boards	FEP, PTFE, PFA, MFA ETFE, ECTFE PCTFE amorphous FP
Automotive/aircraft industry	Low coefficient of friction Good mechanical properties Cryogenic properties, Chemical resistance Low permeation properties	Seals, O-Rings, hoses in automotive power steering, transmissions, and air conditioning, bearings, sensors fuel management systems.	FKM, PTFE FFKM THV

Industry/Application area	Key properties	Typical uses	Typically used PFAS*
Coatings	Thermal/weather stability Low surface energy Chemical resistance	Cookware coatings, coatings of metal surfaces, powder coatings, waterproof clothing	PTFE PVDF, ETFE FEVE, PFA
Medical	Low surface energy, stability, purity Excellent mechanical properties Chemical resistance	Cardiovascular grafts, heart patches, ligament replacement, packaging films for medical products	PTFE, PCTFE
General architectural/fabric/ film applications	Excellent weatherability Flame resistance Transparency Low surface energy Barrier properties	Coated fabrics and films for buildings/roofs, front/backside films for solar applications	ETFE, PTFE, PVDF PCTFE, PVF, THV
Polymer additives	Low coefficient of friction Flame resistance Abrasion resistance Antistick properties	Polyolefin processing to avoid surface defects and for faster processing. Additives for inks, coatings, lubricants, anti-dripping agents	THV, FKM PVDF, PTFE
Semiconductor industry	Chemical resistance High purity Antiadhesion, insulation, barrier properties Thermal stability	Process surfaces, wafer carriers, tubing, valves, pumps and fittings, storage tanks	PFA, ECTFE PCTE, PTFE amorphous FP
Food packaging	Chemical resistance, Excellent mechanical properties, barrier properties	Packaging films for portioning, handling, transport, improving shelf-life	PTFE, PCTFE
Energy conversion/storage Renewable energies	Chemical/thermal resistance Ion-transportation High weatherability High transparency Corrosion resistance	Binder for electrodes, separators, ion-selective membranes, gaskets, membrane-reinforcements, films for photovoltaics, coatings for windmill blades	PVDF, Fluoroionomers (PFSA), THV, ETFE ECTFE, PTFE, FEP PVF

*Abbreviations –
ECTFE Ethene–chlorotrifluoroethene copolymer
ETFE/ET Ethene–tetrafluoroethene copolymer
FEP Fluorinated ethene–propene copolymer
F(F)KM Fluoroelastomers, perfluoroelastomers
MFA Methylfluoroalkoxy copolymer
PCTFE Polychlorotrifluoroethylene
PFA Perfluoroalkoxy/propylfluoroalkoxy copolymer
PTFE Polytetrafluoroethylene
PVDF Poly(vinylidene fluoride)
PVF Poly(vinyl fluoride)
TFEP Tetrafluoroethene–propene copolymer
THV Tetrafluoroethene–hexafluoropropene–vinylidene fluoride terpolymer

Many important sectors of the economy are end-users of PFAS, such as telecommunications, aerospace, automotive, building and construction, electronics, medical devices, etc. As there are not always suitable alternatives for practical applications of many PFAS, banning PFAS from use as a class could cause significant disruption to large sectors of the global economy and the future of innovative products that could benefit human quality of life and longevity.

3. What is the concern about PFAS?

Humans and wildlife are exposed every day to hundreds of natural and man-made chemicals from products and their environment, usually with minimal attributable adverse effects thanks to the effective regulation, risk management of hazardous chemicals and the due diligence of responsible industries. PFAS are unique in relation to other general industrial chemicals because of their unusual bio-persistence, broad use at low levels in niche applications and regulation that is perhaps not as effective as it might be to identify toxic PFAS.

PFAS predominantly contain carbon, fluorine, and hydrogen atoms. The carbon-fluoride bond is one of the strongest in nature, making PFAS highly persistent, resistant to biodegradation and potentially bio-accumulative. PFAS released into the environment, can contaminate soil and drinking water sources for years and have been found in surface waters such as rivers and lakes[2,3] and in the human body[4]. Issues are not just local, but once in the environment, PFAS can travel the globe from source to anywhere in the world[3]. As well as evidence of biological and environmental persistence, there is increasing evidence of toxicity and adverse health effects in humans[5] from some PFAS, particularly following direct exposure pollution incidents.

Often the toxic hazard characterisation data are not available to show how toxic a particular PFAS might be, and there is a wide variation in properties across different groups of PFAS. Concerns are being raised globally about the known and potential adverse effects of long-lasting PFAS on human health and the environment. PFAS are used in everyday consumer products and evidence as to whether exposures lead to transfer and uptake into human blood circulation is not available in most instances.

The scientific community are concerned that if growth in the use of PFAS in products continues unchecked or low-level releases into the environment continue to go unmanaged for the years and decades ahead, people's bodies and those of wildlife will continue to accumulate PFAS and harmful effects could emerge in wider populations. We need to better characterise the potential hazards associated with PFAS and assess the risks, and most importantly this needs to be done in a timely way.

4. How have PFAS been used worldwide for decades without needing full safety evidence?

PFAS have been in use globally for decades since the 1940s and many were used prior to the implementation of safety testing. Widespread chemicals regulations came into effect during the 1970s and 80s and the EU REACH chemicals regulation commenced in 2004. Some PFAS are polymers and have, therefore, been exempt from EU REACH as substances of intrinsic low concern due to low bioavailability. Many newer PFAS inventions, of which there are thousands of distinct chemical analogues, are manufactured, imported, or used at amounts lower than 1 tonne per annum (tpa) and therefore, minimal data are required by regulation. Based upon the Environment Agency (England & Wales) report (2021)[6], "approximately 100 individual PFAS are supplied to the UK market in amounts greater than 1 tonne per year. However, this may not include all PFAS in use, as [UK REACH] registration is not required for PFAS manufactured or imported below the threshold of 1 tonne per year".

Evidence on toxicity, bioaccumulation and environmental persistence has been focused on some individual PFAS chemicals, such as PFOS (perfluorooctane sulfonate) and PFOA (perfluorooctanoate). Over the decades more and more 'alternative' PFAS substances have been created unchecked and unmonitored. This now creates a difficult legacy challenge for regulators as it would be time and resource intensive to test and

evaluate all the individual PFAS on the market using traditional approaches to toxicity testing. New toxicological and biomonitoring methods are emerging and could in principle address the data gaps, combined with new regulatory frameworks, to address the risks and impacts to society and the environment and hence help regulators and decision-makers to take pragmatic action.

5. OECD definition of PFAS for regulatory application

To bring consistency and hopefully global harmonisation to the task, a credible and workable definition is needed. A carefully crafted definition for PFAS was developed by the OECD in 2021[7], removing earlier ambiguities in previous definitions. This OECD definition aims to provide a standardised system that can be used for systematic characterisation and create a globally harmonised system of regulation.

The OECD 2021 definition
"Any fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group ($-CF_3$) or a perfluorinated methylene group ($-CF_2-$) is a PFAS"

Crucially, compared to previous definitions used, this OECD definition was extended to include complexes without the perfluorinated methyl moiety ($-CF_3$) and complexes with aromatic side chains, as long as a perfluorinated methylene group ($-CF_2-$) is present. We support a globally harmonised use of this definition and the reconciled terminology described in the OECD report[7]. Within this policy position we have used the term PFAS to mean the compound or compounds under this terminology that share the same trait above for having a fully fluorinated methyl or methylene carbon moiety as defined by the OECD definition.

Given the diversity of PFAS, there is the ability to continually reinvent multiple PFAS analogues of the same beneficial and functional properties at low tonnages, notably <1tpa thus negating any legal requirement to generate meaningful safety evidence under UK/EU REACH. Regulating every PFAS individually will result in a 'chemical whack-a-mole' i.e., once one PFAS is banned/restricted, another slightly modified PFAS can pop up and take its place in a product. This leads to the inevitable pitfalls of regrettable substitution and makes regulation ineffective.

There have been suggestions[8] of using persistence alone as a criterion for regulation. However, with current knowledge, we believe such indiscriminate action could lead to unnecessary damage to very beneficial industries and ban highly desirable and very useful, some may say vital, products from the market. Such products could be fundamental to quality and longevity of life and economic prosperity, and in reality, pose little or no risk to health and the environment. As all PFAS are persistent, grouping approaches may be useful to identify the more toxicologically benign and harmful classes of PFAS and assess bioaccumulation. New PFAS are continually emerging in the market, an accurate estimation of the number of PFAS in use remains elusive. We can expect groups to change and evolve over time.

6. The complexity, gaps, and uncertainties in PFAS science

Understanding how PFAS exposure can affect biological function and cause adverse effects in organisms is a complex and uncertain area of science involving chemical, toxicological, and epidemiological evidence. Developing harmonised, pragmatic and science-based regulation, where risks and benefits for people and the environment from PFAS can be managed, is proving challenging and taking too long, as key data gaps remain.

PFAS chemicals occur in solid (e.g., fluoropolymers), liquid (e.g., fluorotelomer alcohols) and gaseous (e.g., hydrofluorocarbon refrigerants) forms, each having different physical and chemical properties. However, from the evidence to date, the intrinsic hazards they pose are not solely related to their physical nature. Therefore, a simple grouping approach using only physical form would be inadequate. Chemical and toxicological properties, exposure parameters and their fate in the environment and in the bodies of humans and wildlife may contribute to grouping approaches. To date, however, the basic fate and behaviour of PFAS in the human body remains uncertain.

Case Study - Data gaps in perfluorooctanoic acid (PFOA) half-life

The data gaps in our understanding of PFAS is exemplified by the challenging conundrum that exists in estimating PFOA half-life once in the human body i.e., how long it takes to clear 50% of the circulating substance from the body into urine/faeces. Values have ranged from less than a year to 14.9 years based on various human biomonitoring studies. The single clinical study on this by Campbell et. al. 2016[9] gave an estimated half-life of 120 – 220 days; human observational studies provide a range of values from 1.2 years to 14.9 years[11]. Another estimate of PFOA half-life is ~1.5 years by Xu et al. 2020[10] where background exposures were subtracted out, although the authors did not measure other potential sources of exposure and confounders.

The review paper by Dourson & Gadagbui (2021) [11] explored the likely causes of this discrepancy. The clinical study[9] is well conducted with numerous monitoring times but is focused on a limited population of patients in various stages of cancer who experienced a higher oral dose of PFAS during medical treatments than what might be expected in a normal human population exposed to PFAS say from drinking water or everyday products. Several of the observational studies were conducted in worker populations that have higher than background exposures. The differing estimates of half-life in human observational studies may be the result of different or multiple exposure routes, exposure pathways or inter-individual differences – the influences of which remain largely unknown. Additional thought is needed in determining which of the various human studies are most appropriate for estimating PFOA half-life. It is possible that arriving at a single value may remain difficult for PFOA half-life and a kinetic profile describing the fate of the substance in the body with time may be more useful.

7. New approach methods for addressing the toxicological hazard and exposure data gaps

The choice of whether to use a 'persistence only' or a 'risk-based' approach (considering persistence, toxic hazard, and exposure/bioaccumulation) to regulation of PFAS defines the nature of the scientific research needed to make due progress i.e., the former requires a low level of new science, the latter requires a more considerable scientific programme and the resources to implement. The application of science, however, can help to support innovation and control use of vital PFAS for the benefit of society. Care is needed in defining the most appropriate scientific research and data generation, as developing a traditional toxicology testing programme (e.g., as per EU REACH testing guidelines) to address all the scientific gaps would be insurmountable and lead to a large increase in animal testing for PFAS that would likely take decades. The development of non-animal testing approaches and new approach methods (NAMs) is a scientific strength in the UK, with the National Centre for the 3R's established in 2004 (https://nc3rs.org.uk). The US EPA has chosen to adopt NAMs as the main basis for addressing hazard data gaps for PFAS, and to attempt categorisation[14].

Investment into evaluating the safety of PFAS is imperative if society is to continue using vital PFAS chemicals in a safe and sustainable way in everyday and innovative new products. Given the many potential sources of exposure to PFAS, defined exposure models may be extremely conservative. It is better

to actually monitor levels of PFAS in the environment (freshwater and marine waters), and in the blood/tissues of humans and wildlife over time to monitor trends of real levels of exposure, e.g., monitoring PFAS levels in drinking water sources and in human serum. Such monitoring is routine in the US i.e., in programmes such as NHANES (National Health and Nutrition Examination Survey), which has monitored PFAS in human participants[12] for more than 20 years using a standardised analytical method. Investment is needed in all parts of the world to routinely monitor the levels of PFAS compounds in the environment and in people. The expectation is that levels could in fact be low, but we have limited evidence to prove it, and given the persistence we may be wrong in that assumption.

Case Study – US EPA's scientific approach to PFAS testing

The United States has introduced PFAS Action Act of 2021[13] delegating responsibility to the US EPA to regulate PFAS and to determine whether to designate all PFAS as hazardous substances individually or in groups. The US Environmental Protection Agency (EPA) aims to reduce its mammalian study requests and funding by 30 percent by 2025 and eliminate such studies by 2035. In its objective to establish New Approach Methodologies (NAMs) that fill critical information gaps, the EPA aims to develop a suite of assays for investigating the biological activity of PFAS chemicals and provide peer-reviewed guidance on their use. For this the EPA assembled a PFAS Chemical Library, procured 430 unique PFAS substances, and devised specialised categories[14] to assign related compounds into based on chemical structure. The EPA then selected 150 representative PFAS chemicals from each category that best translate to the wider PFAS landscape. Toxicological responses, such as developmental toxicity, immunotoxicity, mitochondrial toxicity, neurotoxicity, endocrine disruption, and general toxicity, were measured using specific *in vitro* assays as indicators of mode-of-action relevant biological activities.

To establish scientific confidence in NAMs, the EPA aims to characterise the scientific quality and relevance of existing animal tests, then develop a scientific confidence framework to evaluate the quality, reliability, and relevance of the *in vitro* NAMs to known end effects in intact organisms. The insights gained will be used to create a harmonised scheme of grouping PFAS to enable health-based guideline values and risk assessments to be defined for different classes of PFAS with similar toxicological effects. To achieve this, a computer-based categorisation method, PFAS ToxPrints[15] has been developed, which grouped the 150 tested PFAS into 34 structural categories based on their *in vitro* effects, covering more than 90% of PFAS tested. It is anticipated that targeted animal studies may still be needed to test representative PFAS belonging to each of the identified categories e.g., to assess for potential cancer and reproductive/developmental effects. However, this number of animal studies would be far lower than would be expected if all PFAS were being tested individually in the absence of the ToxPrint categories and using a traditional paradigm.

To support the advancement of scientific knowledge, foster innovation and global collaboration and develop a strong skills base, for PFAS science and other challenging issues for chemicals used in society, we urge the UK government to invest in a Science Hub for Applied Research in Chemicals Regulation and Standards. World-class scientific know-how in the use of NAMs for toxicity testing and other new risk assessment technologies such as physiologically based kinetic (PBK) modelling and biomonitoring, would help assess the safety of PFAS but indeed for application to any other new chemicals arriving into the market. This will require significant new investment but result in the development of highly trained scientific and technical specialists in chemicals regulation for all chemicals not just PFAS, supporting innovation at the same time as ensuring human health and environmental protection using sound science.

8. A regulatory framework for PFAS – what form could it take?

It is not effective to assess the safety of the thousands of PFAS in use today or those which could be in use in the future with current techniques. It would be too costly, too resource intensive and use too many

animals in testing. Therefore, to direct risk assessment in the most useful, efficient, timely and relevant way there needs to be (i) criteria for prioritising those substances that require a full scientific safety evaluation and (ii) a pragmatic way of performing a risk assessment for a single PFAS or ideally for a PFAS that is defined as representative of a group/category of PFAS. Banning all PFAS on persistence alone would take little scientific resource but could have massive unintended consequences for society with loss of important products and disruption of vital processes. The level of societal backlash to a regulatory policy based on persistence alone could be too high to make progress. Similarly doing nothing, when we have good evidence of the toxicity of some PFAS[6], is not an option as we must protect public health and environmental species.

A framework based on a multi-step 'traffic-light' decision-tree approach around PFAS use in society and on the basis of safety risk and impact assessments may be useful for regulatory action. We propose a green, amber, and red list approach (as depicted in Figure 2), to take appropriate regulatory action based on a defined level of acceptable risk according to an agreed set of criteria, as defined by the regulator working with science advisory mechanisms within government. This approach is designed to be proportionate, iterative, and agile, to ensure it accounts for evolving scientific evidence on PFAS.

Step 1 – Defining the chemical to be assessed – Is it a PFAS?

The framework starts by ascertaining whether the chemical(s) concerned is a PFAS, based on the OECD (2021) definition[7]. If the chemical concerned is not a PFAS, it is outside of the scope of this framework. If the chemical concerned is a PFAS, it then becomes important to distinguish whether the PFAS is used in a controlled way in a manufacturing process or is present in an end product.

Step 2 – Is the PFAS present in a manufacturing process or an end product?

PFAS chemicals are not only constituents in a diversity of products that people use on a daily basis but can also be used as an important precursor or aid in the manufacturing of other products, such as being used inside electronic devices, as lubricants for heavy machinery, or durable coating on equipment. The highly stable nature of PFAS means they are extremely useful in manufacturing processes and exposure to workers and environment could be near zero in a managed process. The generation of PFAS-containing waste would also need to be regulated by the manufacturer. Intermediate PFAS containing materials that are transient and not present in the end-product, could be treated as being part of a controlled manufacturing process. In the case where PFAS is used both in the manufacturing process and in the end-product, the conditions pertaining to both needs would need to be satisfied.

Step 3a – If the PFAS is used in the manufacturing process – can its environmental release be strictly controlled?

Many industrial processes involve the use of hazardous chemicals in the manufacturing process. However, these pose little or no risk to the environment and human heath because of effective containment and risk management practices. PFAS chemicals should be treated as safe, if used strictly in a manufacturing process where its occupational and environmental release can be controlled over the entire life cycle of the product, including its disposal. These PFAS could in principle be part of *Green List A, where their use is permitted under strict containment measures, within the approved manufacturing settings*. The PFAS can be used with occupational risk management measures in place, to protect worker health, and limited to a particular tonnage threshold. This would need to be monitored to ensure compliance.

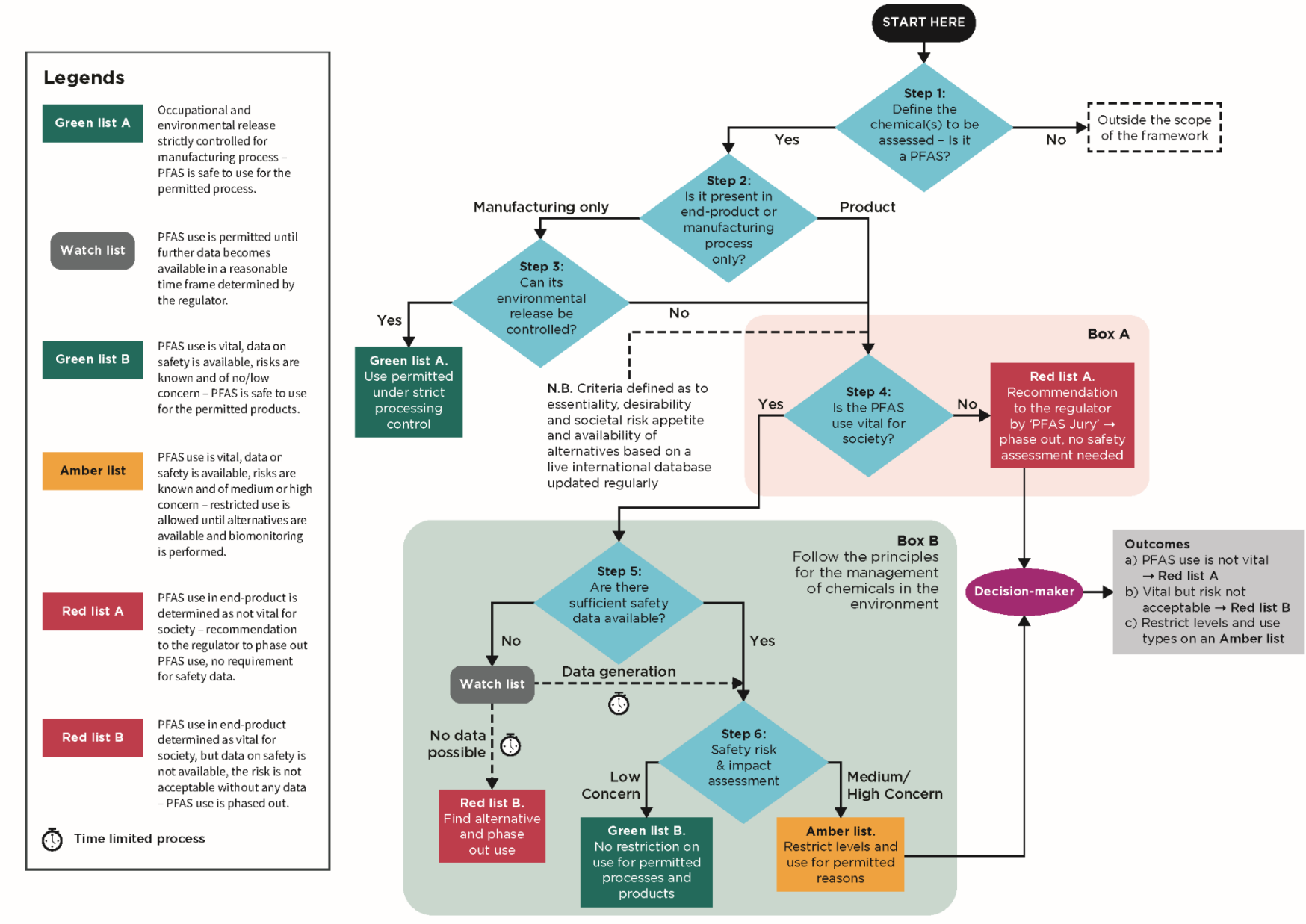


Figure 2: *A proposed risk-based framework based on a decision-tree approach around PFAS use and scientific evidence*

This situation does not put an obligation on the manufacturer to generate safety data for the PFAS being used solely in the approved manufacturing process to generate a non-PFAS containing product, but based on evidence of persistence there is an obligation to have data to show minimal PFAS exposure to workers and minimal PFAS release to the environment. A suitable emission policy would need to be enforced rigorously in case accidental pollution occurred, of what could be a PFAS of unknown toxicity.

If, however, the environmental and occupational release of the PFAS cannot be strictly controlled during the manufacturing process, and/or the PFAS remains present in the end-product, then the PFAS should be regulated based on the branch of the framework concerning PFAS use in an end-product.

Step 3b – Is the PFAS present in the end-product or is its release uncontainable in a manufacturing setting?

Many PFAS chemicals are present in products to which the public and consumers are exposed without any protections. Indeed, PFAS containing food, drinking water and medicines are ingested, and cosmetics, clothes and medical devices are in contact with the skin. Routes for any PFAS inhalation are poorly understood.

Exposure assessment and how to do it needs to be considered in this pathway. The question remains about whether chronic low exposures lead to bioaccumulation of PFAS in humans and wildlife over a lifetime. We know that PFAS can be measured in human blood and in animals, but are they causing adverse health effects from general exposure sources? This is a large uncertainty and where there are significant data gaps. Assessing all PFAS would take too long, therefore pragmatic approaches based upon reasonable assumptions will need to be developed.

In addition, there are many products used in the market, such as smart phones and other electronics, where the PFAS is safely isolated from direct exposure to the skin and environment. If in such cases, the environmental exposure of the PFAS is controlled throughout the life cycle of the product, including its reuse, recycling or disposal, the importance of such a product to our daily lives may justify its continued safe and sustainable use.

It is a significant ask to generate scientific evidence for every PFAS in every product type and so some triage is necessary to focus scientific effort and resources onto situations that require urgent action according to risk. Potentially new ways of evaluating risk are needed in a first tier of risk analysis. At this stage, before extensive and time-consuming resources are committed to exploring the scientific evidence, we ask if the product and the PFAS use is vital to society.

Step 4 – Is the PFAS vital for society?

Defining which PFAS use is vital for society should be a choice taken by citizens and governments and should be informed by the scientific and socio-economic evidence. This is best done in a transparent way to ensure all stakeholders know the rationale of why a decision has been taken. This process is represented by the **Box A** in Figure 2.

We advocate the establishment of a '*PFAS Jury'* where policymakers and members of wider society, review the advice presented by independent technical experts and sociologists/socio-economists, and this multistakeholder 'Jury' takes the ultimate decisions on which PFAS products and applications are vital for the future functioning of society and its prosperity. The realistic risks to environment and health must be

considered as paramount, but also in the context of the economic impacts of various options as to what could happen if an application or product was discontinued. A *'PFAS Jury'* would be a new concept, and could be established by the government including representatives of wider society, including civil society, industry, scientists and others, and they would be given the remit of making informed decisions on which PFAS and products needed to be evaluated in full for their safety and risk management, because they were deemed as 'vital' or 'highly desirable'.

The term 'essential use' is being discussed in legal terms in the EU for deciding whether PFAS are important for society, but there are different ways to look at 'essentiality': (a) the product as a whole is necessary for the health and safety or critical functioning of society – 'essentiality' as defined in the Montreal Protocol[16], and (b) the constituent PFAS chemical(s) concerned has no suitable and safe alternatives at this point in time. A product or PFAS may not be 'essential', but 'highly desirable' for society and a low risk may be considered an 'acceptable risk' that the wider public, appropriately informed, wishes to take. Being appropriately informed may include explicit product labelling when a PFAS is contained within a product, for example. Transparency in terms of a PFAS hazard profile would be necessary.

A 'PFAS Jury' should also take into account the availability of any suitable and safe alternatives that could reasonably replace the PFAS used in the product, even if functional performance was reduced. The suitability of the alternatives should take into account the unique physical properties conferred by the PFAS chemical for the proper functioning of the product (such as the thermal stability, repellency, breathability, etc.), as well as socio-economic analysis that makes the PFAS use highly desirable or irreplaceably vital. This process should involve all relevant stakeholders, including diverse and inclusive representation of the general public, together with experienced high calibre scientists as key contributors to decision-making. Ultimately it is a decision for the government about whether use of a safer but less functionally effective alternative should be mandated to replace PFAS, if one exists.

Is the PFAS vital for society?

Answer – No: If the products are not judged to be important and vital to society, then the significant resources that are required to assess safety could be disproportionate to a lack of benefits. In such circumstances, in this model, **the recommendation would be to stop use of a PFAS if risk outweighs benefit**, as part of *Red List A,* where their use should be phased out immediately. This should not be decided just by scientists, and we recommend that it would require a societal framework to make such decisions, led by government and a range of stakeholders, including scientific experts.

Answer – Yes: Industry and/or government scientists perform a scientific evaluation, generating data and performing a human health and environmental risk assessment.

Step 5 – Are safety data available for the vital PFAS or other relevant analogue PFAS'?

Once the PFAS use (or indeed a group of PFAS) has been established as vital, safety data review and evaluation can then be performed and the risks and impacts on health and environment assessed. This process should be carried out by a regulatory authority supported by knowledgeable scientists. Where safety data on the PFAS is not available but could in principle be generated, the PFAS could possibly be used with restrictions as part of a time-limited *Watch List*, where the use of the PFAS is permitted until further data becomes available in a reasonable time frame determined by the regulator. Environmental and biomonitoring should be carried out during this period.

The time limited nature of the *Watch List* means that the incentive to generate the data falls on the body/industry most likely to benefit from the longer-term use of the PFAS. This body could at Step 5 decide that the investment necessary for data generation does not justify the use of the PFAS concerned, and therefore allow the Watch-list period to lapse, no data are generated and the product to be phased out as part of *Red List B*.

If the unknowns or risks associated from continued use of a PFAS with no data on safety is considered too high, at the end of the time limit the PFAS should automatically be listed in *Red List B* – meaning their use needs to be phased-out within a predetermined period and an alternative substance used in its place; environmental and biomonitoring should be carried out by the respective competent authority to monitor presence over years.

The Watch List approach and Red List B addresses the overwhelming data gaps that are present for many PFAS in the market today and applies a precautionary principle for PFAS that lack available safety data.

Step 6 – Safety risk and impact assessment - What does the safety and socio-economic data say?

The available safety data would then be assessed by the regulatory body to conduct safety risk assessment and a given use of PFAS, with specific exposure considerations, determined to be either of low concern or medium/high concern. The PFAS of low concern can then be used for the specified purpose as part of *Green List B*, because the PFAS used in the product has been deemed vital for society as well. Certain conditions for continued use of the PFAS could be applied at this stage.

The PFAS with medium/high risk should be included in an *Amber List*, meaning their use is permitted only for the vital applications determined by the '*PFAS Jury*' and impact assessments need to be carried out. Stricter restrictions on its exposure to humans and the environment would need to be in place, while frequent environmental and biomonitoring should be carried out by the respective competent authority. There may need to be an aspect of 'the polluter pays' principle to enable this to happen. The *Amber List* should also act as a list to prioritise scientific research into possible further evidence gathering e.g., on toxic effects and environmental impacts, as well as remediation of legacy PFAS exposure and innovation in search of safer alternatives. Any PFAS in the *Amber List* should be immediately replaced when a safe and suitable alternative emerges, and the PFAS transferred into the *Red List B* in Step 5.

Steps 5 and 6 are represented in **Box B**, and we advocate using the principles for the management of chemicals in the environment, as detailed in the section below to define criteria for risk management.

Some important points of consideration

- **The positioning of societal importance of PFAS could occur in 2 places** in this framework. The considerations represented in Box A, where a multi-stakeholder '*PFAS Jury*' including citizens, as informed by the industry and scientific and socio-economic evidence, could also be placed following Step 5 and 6, succeeding the outcome of a scientific evaluation and where the known risk to health or environment is moderate or high. This latter placement of an evaluation of societal importance in the event that no scientific data were available, could mean substantial time and resources could be spent on data collection and analysis, and risk and impact assessments of substances, which may not later be deemed as vital for society anyway. In the positioning of Box A at the beginning of the process, significant resources can be focused on those PFAS that are most important to keep in use in society.

- **Scientists inform the decision-maker; scientists do not take the decisions.** The decision-maker in the UK setting is likely to be a government representative/agency with regulatory powers or a government Minister. The UK can take a responsible leading role but PFAS pollution cannot fully be tackled in the UK alone and scientists collaborate across boundaries. PFAS pollution is a global problem, one that requires global cooperation and collaboration to make the step-change in improvement that is needed at global level.

- **Current UK/EU REACH regulations do not mandate toxicological safety data to be provided for a PFAS when it is manufactured, imported, or used at <1tpa.** This means that for many PFAS there are no hazard characterisation data. Consideration needs to be given as to whether this situation is fit for purpose for highly persistent and functionally interchangeable substances such as PFAS. At least some basic hazard information should be mandated even at less than 1tpa; this could be in the form of *in silico/in vitro* hazard evaluation data, and ideally attempts made to place PFAS into groups based on predicted hazards. This would also be the case for alternatives with the same persistent properties.

- **Care should be taken in banning PFAS without understanding the alternatives** (which also may be manufactured at <1tpa) to avoid unintended and potentially worse consequences from the use of other more harmful or equally persistent substances. There should be a continuous review of the alternatives used to quickly identify new evidence on safety.

- **It is important to revisit the criteria of vital use, green and amber lists** at reasonable periods of time to take into account emergence of any safety data on PFAS or its alternatives that may alter safety risk assessments.

- **It would be useful to establish a global database of potential PFAS alternatives**. Reassessments should consider innovations in material sciences and the availability of alternatives periodically. Such a database should be continuously updated to scan for the emergence of substitutions from academia or material research facilities in the public and private sector, globally.

- **The safety and risk assessment process is resource intensive and needs to be performed by competent scientists**. It may be more cost-effective to prioritise safety risk assessment on PFAS that are deemed to be highly desirable and vital, rather than performing risk assessments on thousands of different PFAS only to then decide that their use is not strictly necessary or there exists a suitable alternative that can easily replace its use. It is with that view in mind that we suggest the PFAS put forward for full safety data and risk assessment be pre-determined by the '*PFAS Jury*'.

- **The decision on PFAS use should involve all relevant stakeholders** and is a decision better taken by the government of the day as representatives of the people. This is to ensure all aspects necessary to judge the vital nature of a PFAS use are considered. This is partly a socio-philosophical and ethical question which may not be within the current remit/expertise of the regulatory authority tasked with safety and technical data assessment.

This framework approach is accessible to non-scientists to the point of performing a risk assessment and implementing the findings. Although scientists are not the decision-makers, there are well established principles for the management of chemicals in the environment that may be useful to implement here.

9. Principles for the Management of Chemicals in the Environment

In our document, Principles for the Management of Chemicals in the Environment, we set out a package of complementary principles that would lead to pragmatic and proportionate decision-making for all chemicals.

A proportionate outcome from PFAS regulation can be achieved, whilst always putting people, the environment and best science at the heart of decision-making – considering the principles from the 1992 Rio Declaration on Environment and Development[17], of which the UK is a signatory – to assure a safe and sustainable outcome for all innovations and for our diverse populations of human beings and wildlife. We believe that when implemented as an interconnected set, the principles in our document Principles for the Management of Chemicals in the Environment working together can provide a sound foundation for flexible and agile regulatory decisions on PFAS that support innovation, whilst at the same time protecting health and the environment (Table 2). The consequence from having to consider the dimensions of all these principles can lead to an agile and proportionate outcome by those who grow used to working with them.

Table 2: *Principles for the management of chemicals in the environment and potential context for PFAS regulations*

Principle	Potential Context for PFAS regulation and future use
1. Integration principle (Rio Principle 4)	Ensure all decisions on PFAS relevant policy consider the potential for adverse environment and health outcomes, and that decisions improve the environment rather than make it worse
2. Sustainability principle (Rio Principle 3)	Ensure that inaction and decisions do not adversely affect the next generation
3. Global partnership principle (Rio Principle 7)	Given the persistent nature of PFAS in water and the fact they can be used, and pollution generated anywhere in the world, yet disperse in waters, collaborate globally to address the issue. Develop a live global list of alternatives to enable industry to replace PFAS in their products with safer and innovative alternatives.
4. Capacity building principle (Rio Principle 9)	Help those countries who are less well-regulated to understand the issues, build capability to improve the global outlook on PFAS pollution
5. Precautionary principle (Rio Principle 15)	Identify the risks and uncertainties and scientific data gaps. Take a precautionary starting position and proportionate regulatory action, with a view to generating more data to reduce uncertainty.
6. Risk & impact principle (Rio Principle 17)	Perform a risk and impact assessment as data allow
7. Mutual recognition principle	Understand the views of other countries and trading partners on the issue
8. Innovation principle	Look for innovative alternatives to PFAS or innovative solutions to managing their use to prevent harm
9. Citizens' 'Right to Know' principle	Inform and consult with citizens as to the proposed actions for PFAS management
10. Pollution prevention principle	Prevent any possible incidence of pollution by manufacturers

11. Polluter pays principle (Rio Principle 16)	If pollution happens by accident, the polluter pays heavily for the damage done
12. Rectification at source principle	Rectify the issue with the manufacturer/users/waste generators.
13. Impacts on other region principle (Rio Principle 12)	Do not ship PFAS or PFAS waste to harm other parts of the world. Understand the supply chains.

10. The need for simplified, connected, and consolidated regulatory action in the UK

PFAS are used in a range of products and applications, that cut across the regulatory purview of several UK government agencies. Manufacture of PFAS as raw materials, is currently limited to two UK companies; there are others worldwide. Many product manufacturers use PFAS, either in a process or as a constituent of a final consumer product.

The UK's responsibilities for chemicals regulation are spread across departments and regulatory bodies such as the Department for Environment Food and Rural Affairs (Defra), Business, Energy and Industrial Strategy (BEIS), Department of Health and Social Care (DoHSC), Health & Safety Executive (HSE), Environment Agency (EA), Foods Standards Agency (FSA), UK Health Security Agency (UK HSA, formerly PHE), and the agencies of the devolved nations in Scotland and Wales. Laws are enforced by local authorities' trading standards. Northern Ireland must follow EU laws as part of the Northern Ireland protocol following UK exit from the EU. The manufacture and import of PFAS in Great Britain (GB) fall under UK REACH regulation. Myriad product regulations including construction products, electronics, cosmetics, home improvement goods fall under the remit of the new Office for Product Safety & Standards (OPSS), foods within the Foods Standards Agency (FSA), and medicines under the Medicines and Healthcare Regulatory Agency (MHRA). Regulation involves complex network of stakeholders.

Products containing PFAS chemicals and environmental release from factories and via waste streams are managed and enforced by different and unconnected government agencies, and by the devolved national authorities. The need for chemicals sciences data and the skills in different government bodies varies accordingly. This fragmentation can make it challenging to work on a coordinated chemicals management plan for a broad class of chemicals such as PFAS and to arrive at consistent conclusions on any chemical where there are multiple sources of exposure.

It is the view of the RSC that PFAS should be regulated in the short term within UK REACH for known substances of concern but ultimately using specific new regulation as supported by a regulatory framework and accompanying technical guidance. Currently in England & Wales, the environmental aspects of PFAS exposure have been given priority and are actively being looked at under the UK REACH restriction programme with respect to environmental protection by the Environment Agency (England & Wales) working together with the Health & Safety Executive and Defra policymakers.

The UK has a strong regulatory base on which to build but its actors and experts are often disconnected. It is important that the UK maintains and invests in a strong scientific base for chemicals regulation. Due to the disparate responsibilities for chemicals regulation following EU exit, the UK now needs **a consolidated UK Chemicals Standards Agency**. Branded as such, this could in principle be a virtual umbrella body that pulls the expertise, know-how and consistency of policymaking under one consolidated and well-connected network for chemicals policy. PFAS regulation could be one of the first cases where the benefits and strength of such a body in forming risk-based regulation can be demonstrated across the piece.

In practice, a **UK Chemicals Standards Agency could turn the current fragmentation of chemicals regulation across departments into a strength** – by bringing more effective connectivity without massive structural change but with a new sense of visible authority and collective responsibility. PFAS regulation is a perfect example for this – they are chemicals that are used everywhere and there are perspectives from a range of government departments, but the dots are not well-connected and there is limited central coordination. If a UK Chemicals Standards Agency could have overarching responsibilities and powers to convene all of the departmental players together, then it is possible that a consistent approach to risk-based regulation for PFAS could be developed. This will rely on world-class scientific expertise and global collaborations with those interested in taking appropriate action on PFAS. Ideally such skills and expertise should be fostered within a research hub aligned to the needs of a chemicals agency and dedicated to developing the science required to underpin effective regulation.

11. Regulation as part of a global chemical strategy for PFAS

In our previous work '[A chemicals strategy for a sustainable chemicals revolution]', we indicated four strategic pillars that are important to consider when developing chemicals policy: Education, Regulation, Innovation and Circular Economy. This policy position predominantly discusses the *regulation* pillar for PFAS, but all four pillars are relevant to ensure improvements in PFAS pollution are realised.

Applying a chemical strategy approach to PFAS

Education – increase consumer awareness of PFAS uses, importance to society, hazards and risks and transparency of decisions taken and law implemented. Incorporate awareness on the PFAS issues in further education programmes. Share knowledge globally and build worldwide capability through UN forums.

Regulation – design frameworks based on science and societal impacts, that lead to workable legislation to achieve an outcome that keeps us safe whilst enabling innovation that benefits society [*this position paper*].

Innovation – development of technologies and processes that better control PFAS exposure to humans and environment; developing safer alternatives to PFAS with the same functional benefits. Innovation in methods to assure safety.

Circular Economy – challenging for persistent and toxic PFAS, unless exposure can be completely controlled; data on supply chains of PFAS use; considering safe and sustainable end of life solutions, and life cycle analysis considerations, e.g., ultimate incineration of PFAS wastes in cement kilns.

The starting position in this paper, based on the evidence today and given the many unknowns and data gaps, is that PFAS manufacture and use must be regulated to ensure relevant data are generated to ensure continued safe use. The question is what type of regulatory framework is most effective to promote effective UK and also global action. Many regulatory authorities in the world support risk assessment and risk management of chemicals as a pragmatic, protective and effective basis of regulation. We advocate the use of a societally acceptable, risk-based regulatory framework, using state-of-the-art scientific evidence integration to support pragmatic and effective decision-making for PFAS.

Given that PFAS pollution of water knows no boundaries, we advocate for global collaboration on PFAS policy, and hope that bodies such as UNEP, UN SAICM, OECD, ECHA, US EPA and associated science-policy interfaces can foster such collaboration. [The RSC has called for an independent intergovernmental panel for chemicals and waste to be established] at UN level on a par with the IPCC and IPBES, and it is expected that given PFAS use is such an important global issue it should be given a priority in such a knowledge sharing and horizon scanning forum. Effective regulation is a key pillar of reducing PFAS pollution, but not the only pillar. Further work is needed globally on education, innovation, and circular economy aspects.

12. Concluding Remarks

The Royal Society of Chemistry includes members and stakeholders across academia, government, charities, NGOs, and the private sector. Guided by the best scientific evidence and expertise in the chemical sciences, the RSC can play a crucial convener role in the ongoing discussion on how to best manage PFAS. New and targeted science is needed to support decision-makers to in taking effective action that reduces PFAS pollution and ensures public safety and environmental protection.

We call on all governments to take certain actions that would support progress on PFAS:

- Focus dedicated regulatory resources to regulate all PFAS uses via risk-based evaluations informed by scientific evidence
- Call via the UN for the establishment of a new intergovernmental panel for chemicals pollution – where PFAS science, evidence and risk assessment should be an early topic of knowledge sharing.
- Call for a continually updated, global authoritative database to be established on PFAS alternatives

In the UK, we call on the government to:

- Consider establishing a credible and authoritative multi-stakeholder 'PFAS jury' to decide for the UK which PFAS are 'vital' or 'highly desirable' for the benefit of future society
- Establish a UK Chemicals Standards Agency – an umbrella body that connects all relevant agency actors for which chemicals safety is an important topic
- Invest in a new world-class applied research hub for chemicals policy – including research on the science to support and advance PFAS regulation, to support global collaboration.

Contact

The Royal Society of Chemistry would be happy to discuss any of the issues raised in our statement in more detail. Any questions should be directed to the RSC Policy & Evidence Team at policy@rsc.org.

This document was prepared by Camilla Alexander-White and Oishik Banerji (RSC Policy & Evidence Team) with support from Louise Oldham and Hannah MacDonald, and following RSC engagement events in 2020-2021 with the RSC expert member community, members of the RSC Environment & Regulation Collective and involving members of the international scientific community. Special thanks to Dr David Megson (Manchester Metropolitan University) for working with the RSC and chairing these events.

About us

With about 45,000 members in over 100 countries and a knowledge business that spans the globe, the Royal Society of Chemistry is the UK's professional body for chemical scientists, supporting and representing our members and bringing together chemical scientists from all over the world. Our members include those working in large multinational companies and small to medium enterprises, researchers and students in universities, teachers, and regulators.

Abbreviations

BEIS	Department for Business, Energy and Industrial Strategy
Defra	Department for Environment, Food and Rural Affairs
DoHSC	Department of Health and Social Care
EA	Environment Agency (England & Wales)
ECHA	European Chemicals Agency
EPA	Environment Protection Agency
EU	European Union
FSA	Food Standards Agency
GB	Great Britain – comprising of England, Scotland, and Wales
HSE	Health and Safety Executive
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
MHRA	Medicines and Healthcare products Regulatory Agency
NHANES	National Health and Nutrition Examination Survey
OECD	Organisation for Economic Co-operation and Development
PBPK	Physiological based pharmacokinetic modelling and simulation
PFAS	Per- and poly-fluoroalkyl substances
PHE	Public Health England, replaced by UKHSA since April 2021
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RSC	Royal Society of Chemistry
SAICM	Strategic approach to international chemicals management
SETAC	Society of Environmental Toxicology and Chemistry
UK	United Kingdom
UKHSA	UK Health Security Agency
UNEP	United Nations Environment Programme
US	United States

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