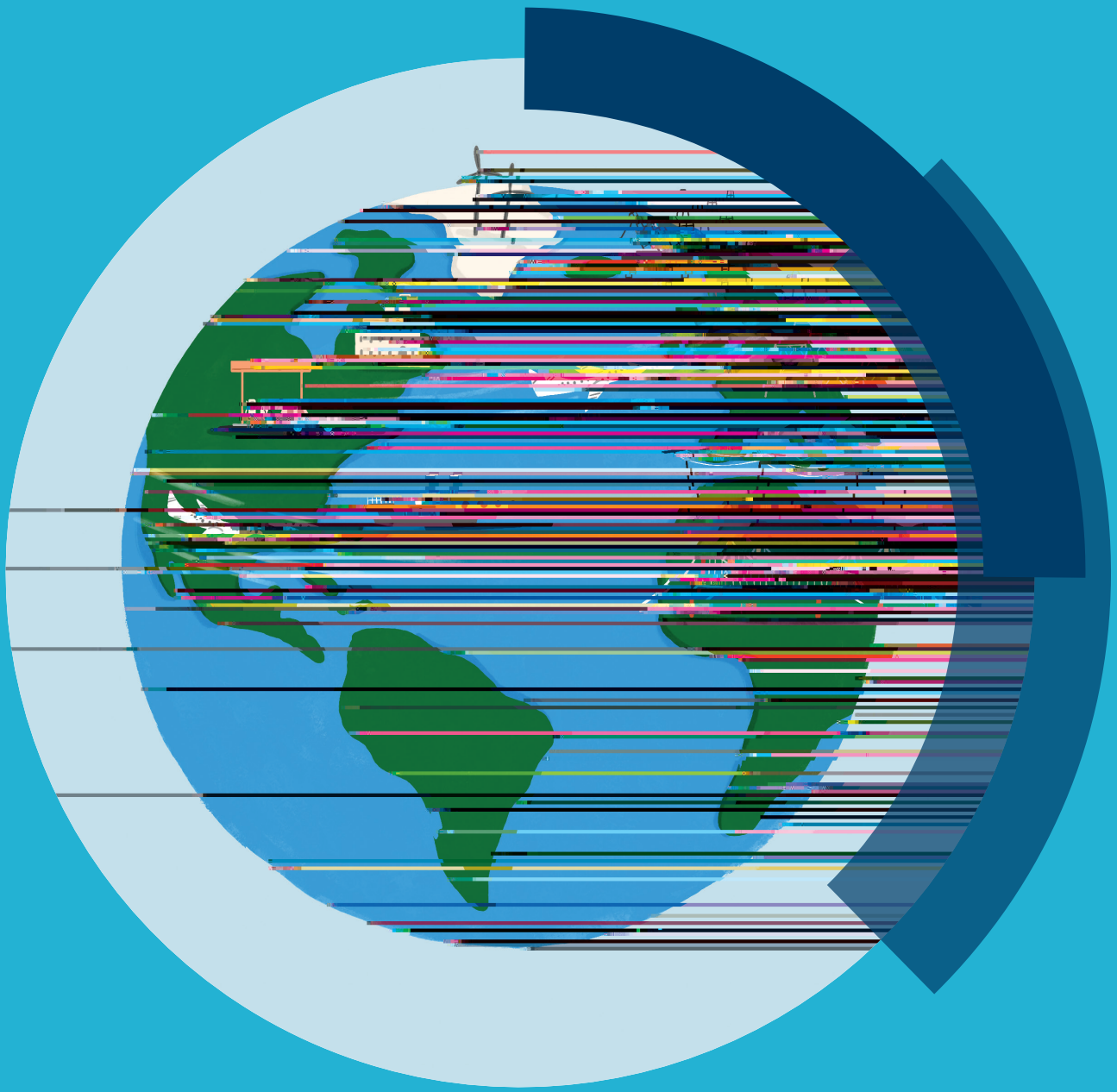

In a world where global challenges and advances in technology bring both uncertainty and new possibilities, the chemical sciences have a critical role to play. But what will that role be? How can we maximise the impact we make across academia, industry, government and education? And what actions should we take to create a stronger, more vibrant culture for research that helps enable new discoveries?

Our perspectives series addresses these questions through four lenses: talent, discovery, sustainability and knowledge. Drawing together insights and sharp opinion, our goal is to increase understanding and inform debate – putting the chemical sciences at the heart of the big issues the world is facing.

[redacted]

Our planet faces critical challenges – from plastics polluting the oceans, to the urgent need to find more sustainable resources. But where will new solutions come from? How can we achieve global collaboration to address the big issues? And where can the chemical sciences deliver the biggest impacts?

[redacted]

Talent is the lifeblood of the chemical sciences. But how do we inspire, nurture, promote and protect it? Where will we find the chemical scientists of the future? And what action is required to ensure we give everyone the greatest opportunity to make a positive di erence?

[redacted]

[redacted]

Contents

1 Executive summary 05

2 Definitions 07

3 Background 09

3.1 Topic 10

3.2 Scope 10

4 Trends and drivers 11

4.1 Societal and environmental 12

4.2 Economic 12

4.3 Technological 12

4.4 Legislative 12

5 Gaps and technical challenges 13

5.1 Theoretical understanding of degradation mechanisms 14

5.2 Characterisation methods and performance standards 14

5.3 Manufacturing and recycling processes 15

5.4 Chemical-science based challenges 15

6 Opportunities for cross-industry collaboration 16

6.1 Knowledge framework 17

6.2 Circularity projects 18

7 Collaboration enablers 20

7.1 Supply chain buy-in 21

7.2 Problem definition 21

7.3 Collaboration with other disciplines 21

7.4 Current state of information 21

7.5 Fun80T EMC /Span <</Lang (en-GB)/MCID 108 >>BDC BT /Span<</ActualTex15m0 0 0C Di41

IMPROVING PERFORMANCE OF SUSTAINABLE NON-METALLICS SOLUTIONS FOR CORROSION:
A SYNERGY REPORT

Non-metallics could transform the way that industry deals with corrosion, enabling businesses to transition from corrosion control to corrosion prevention strategies. Developing sustainable non-metallic solutions may reduce long-term corrosion costs for businesses, significantly benefitting the global economy. Cross-industry collaboration has the potential to build on existing chemical science knowledge within this topic and generate solutions that will benefit multiple industries and sectors. Without collaboration, individual businesses could face longer timeframes and higher costs for innovation.

Corrosion costs the global economy 2.5 trillion USD each year (£1.9 trillion), which is equivalent to 3.4% GDP. Businesses use corroding materials like iron and steel in components, products and infrastructure across many applications, but the industry contributes significantly to global CO_2 emissions. It is not sustainable – environmentally or economically – to continue using these corroding materials at the current rate. Regulation may also increase urgency for businesses to find new sustainable solutions for corrosion. Non-metallics could o er a solution for replacing and protecting existing corroding metals, but currently they are too risky for industry to adopt.

The Royal Society of Chemistry brought together a diverse group of experts representing independent and governmental technology organisations and multiple industries and sectors. Together we identified two opportunities to improve the performance of non-metallics and build industry's confidence in adopting sustainable solutions for corrosion:

1. Knowledge frameworkto develop fundamental understanding, standardise characterisation and testing methods, and predict performance.
2. Circularity projectsto deliver manufacturing and recycling processes that ensure existing and new non-metallic solutions are sustainable.

Collaboration is essential for developing these opportunities. It can de-risk the economic burden of research and development, reduce the potential for duplicating work and leverag multidisciplinary skills to deliver solutions faster. Key findings from this work highlight the need for cross-industry collaboration to advance our understanding, deliver solutions that build confidence in multiple industries, and influence key areas of funding, regulation and policy that could support innovation.

Recommendations made by participants to progress these opportunities are:

1. Validate findings with more industries and supply chains
2. Gain a baseline understanding of current relevant work in this area
3. Initiate cross-industry knowledge sharing and networking to define focus areas

Improving the performance of non-metallic solutions for corrosion presents a significant opportunity for the UK chemical science community to collaborate. Involvement in the Roy Society of Chemistry's Synergy programme will enable businesses to build relationships with a wide network of academics and other companies concerned with this topic, advance knowledge required to find solutions and gain external support for innovation.

In 2020, we are seeking input from businesses operating across the supply chain, independent and government funded research and technology organisations, and experts academia to continue developing the opportunities for collaboration in this report.

IMPROVING PERFORMANCE OF SUSTAINABLE NON-METALLICS SOLUTIONS FOR CORROSION:
A SYNERGY REPORT

3.1 Topic

Corrosion is a natural process that converts metal into a more chemically stable form, leading to material deterioration[2]. It is a complex phenomenon, o en influenced by multiple chemical and mechanical factors including temperature, pressure and microbial activity.

The estimated global cost of corrosion is 2.5 trillion USD each year (£1.9 trillion), which is equivalent to 3.4%[1] GDP. In 2018, we produced 1,809 million tonnes of potentially corroding iron and steel globally, and our demand is increasing[3].

Each year industry spends $1.2 trillion on methods to

3.2 Scope

This section summarises the current and future trends that could be driving industry to adopt sustainable non-metallics for avoiding corrosion. Using methodology outlined in section 9.1, we analyse the political, economic, social, technological, legal and environmental factors that workshop participants highlighted.

In this section, we discuss how public perception and environmental awareness, future regulatory changes, climate change, advancements in key technologies and business

As well as the trends and drivers influencing innovation in this topic, participants also discussed the potential gaps and technical challenges that industry may need to solve to develop non-metallic solutions for corrosion.

This section summarises three gaps in knowledge:

- theoretical understanding of degradation mioen-GBtallic solutions f

The framework would:

The first work stream would develop parallel decommissioning and manufacturing processes. These could o er reuse options for existing non-metallics at the end of their life, address recyclability concerns and avoid large volumes in landfill. Non-metallic material recovery and subsequent conversion into feedstocks for other applications at scale would also maximise the material value in line with circular economy principles.

At the same time, the second work stream would develop alternative feedstocks from non-fossil derived sources so that industry could develop new non-metallics that are sustainable by design. Advancements in this area could create a portfolio of commercially available sustainably produced non-metallics that reduce our reliance on finite hydrocarbon sources. Alongside developments from the first work stream, designers could incorporate degradation processes into new materials so that they degrade at the end of their lifetime.

Underpinning both these work streams is a chemistry

The two opportunities for cross-industry collaboration developed by experts aim to improve the through-life performance of sustainable non-metallic materials and increase industry's confidence in adopting them for avoiding corrosion. However, these are long-term areas of development that require significant buy-in from across the supply chain, a baseline understanding of current knowledge and appropriate mechanisms to enable knowledge sharing and collaboration.

Through this work, we identified five key areas that will be important for enabling collaboration.

7.1 Supply chain buy-in

Both knowledge framework and circularity project opportunities require action from the entire supply chain including manufacturers, designers, end-users, waste management organisations, and regulatory and standards bodies. To deliver advancements in these areas will require industry to adopt a new mindset for sharing data and knowledge, collaborating with competing and non-competing businesses and interacting with stakeholders across the entire system

A selection of these stakeholders have contributed to this initial piece of work, but industry recognises that wider support and early buy-in from organisations across the entire supply chain are needed to progress these opportunities.

7.2 Problem definition

The opportunities identified so far are high-level and we need to define specific projects that industry can work on collaboratively to initiate any action. Encouraging key stakeholders to share knowledge about key materials, applications and lessons learnt would enable industry to define common challenges to focus on initially.

While some activities such as the Defence Academic Pathways and Composites Leadership Forum[10] are facilitating collaboration in areas related to this topic, there are currently limited opportunities for di erent industries and their supply chains to share knowledge and define specific cross-industry problems that they can work on collaboratively.

7.3 Collaboration with other disciplines

This work focuses on chemical-science related opportunities for collaboration. While there is an appreciation that chemistry is important in delivering each of these opportunities, experts highlighted the importance of working across disciplines, especially at the research and early technology development stages.

Collaboration with engineering, biological sciences and modelling will especially be important for delivering solutions and scaling them up. Industry recognises that sharing knowledge between key disciplines at an early stage will be important for defining short-term specific interdisciplinary research projects and long-term areas for collaboration.

7.4 Current state of information

Throughout this work we drew on knowledge from di erent industries and disciplines, but in order to progress these opportunities, we need a detailed understanding of what information exists currently. We know that knowledge exists in silos because it is challenging for di erent industries to share information outside of their organisation or sector.

We also know that relevant work is taking place on degradation mechanisms in coatings and composites, and on applying circular economy principles to non-metallics.

Industry recognises that getting a baseline understanding of the work going on in this area would help identify developments that complement our focus and identify gaps we need to address.

7.5 Funding mechanism for collaboration

The final enabler for collaboration is funding. Through this work, experts highlighted the importance of funding at all scales and timeframes to initiate and sustain collaboration. Initially small scale public funding can coordinate early stage knowledge sharing and problem definition. Large scale funding would ultimately de-risk longer-term collaborative projects around data sharing and scale-up.

In this report, we discussed the initial findings on cross-industry opportunities for collaboration over the next 25 years to increase industry's confidence in adopting non-metallics for avoiding corrosion. Experts in academia and industry identified two opportunities in chemistry that could transform the way that industry could use non-metallic coatings and materials to avoid corrosion in a sustainable way:

1. Knowledge framework to develop fundamental understanding, standardise characterisation and testing methods and predict performance of non-metallics.
2. Circularity projects to deliver manufacturing and recycling processes that ensure existing and new non-metallic solutions are sustainable.

We identified a sizeable opportunity to build on existing chemical science knowledge to advance this topic through collaboration. We know that current knowledge and technology exists for understanding degradation mechanisms in non-metallics and characterising chemical and physical properties to identify and test degradation. Howeve advances in chemistry that incorporate real-world data and standardisation across industry could significantly improve the reliability of models to predict performance in non-metallics.

We also know that chemistry will play a huge part in ensuring that we develop and desig new non-metallics that are sustainable, by developing alternative feedstocks and end-of-life options based on circular economy principles.

Opportunities outlined in this report could not only create sustainable solutions for corrosion based on non-metallics, they could also significantly improve industry's confidence in adopting them across wide applications and at scale. Ultimately, developments in this area could have a positive impact on the economy and our environment by significantly reducing the global cost of corrosion, lowering the associate risks of corrosion when failures occur and contributing to the transition to a circular economy.

We recognise that no single organisation can deliver these opportunities alone. Through consultation with experts, we defined three recommendations for further work to stimulate cross-industry collaboration on this topic:

1. Validate findings with organisations across the supply chain to ensure that we achieve support from all required stakeholders.
2. Gain a baseline understanding of current relevant work to identify potential partners and define areas to focus on.
3. Initiate cross-industry knowledge sharing and networking to define specific problem statements that are common across multiple industries.

We are now seeking input from businesses operating across the supply chain, independ and government funded research and technology organisations and experts in academia to continue developing the opportunities for collaboration identified from this initial piece of work.

If you are interested in being involved, please contact:

Jenny Lovell
Synergy Programme Manager, Royal Society of Chemistry
Email: synergy@rsc.org

9.3 Data

Drivers and challenges	Open access database of reliable chemical data for selecting and applying non-metallic materials that can feed models that predict performance in di 9n <</Lang (en-GB)/	MCII20 6 192.int envnen	vnenvnw S Q q 1 0 0ng [	92.ins. 0 m 62.988 0 l S	Q q 1 0 0 1 314.479 658	2048 c07.6733 Tm [(app

About the Royal Society of Chemistry

We are an international organisation connecting chemical scientists with each other, with other scientists, and with society as a whole. Founded in 1841 and based in London, UK, we have an international membership of around 50,000. We use the surplus from our global publishing and knowledge business to give thousands of chemical scientists the support and resources required to make vital advances in chemical knowledge. We develop, recognise and celebrate professional capabilities, and we bring people together to spark new ideas and new partnerships. We support teachers to inspire future generations of scientists, and we speak up to influence the people making decisions that a ect us all. We are a catalyst for the chemistry that enriches our world.

About Synergy

Synergy is the Royal Society of Chemistry's programme for industry, tackling complex chemistry topics through collaboration. We bring together businesses who face similar chemistry-related challenges and develop opportunities to solve them collaboratively. Through the programme, businesses can share knowledge with experts in di erent industries and sectors, reduce risks in research and development, and bring solutions to multiple markets faster.

In October 2019, 22 experts from across industry and academia came together for a workshop on the subject of corrosion. The aim was to explore how collaboration across chemistry could improve our understanding of the performance of non-metallic coatings and materials, enabling industries to develop their own solutions for their own markets.

Recommended readers

This report is for technical and non-technical experts operating in industries that manage corrosion, including:

- Industry and academic participants of the Synergy programme.
- Technical managers in relevant industries and supply chains.
- Academics working on corrosion, non-metallics and materials.
- Regulatory and standards bodies in the area of corrosion.
- Government organisations working in the area of sustainable corrosion management.

Stakeholders with decision-making capacity to drive collaborations that work to reduce the economic and environmental impact of corrosion may particularly find this report useful.

Acknowledgements

ROYAL SOCIETY OF CHEMISTRY

Thomas Graham House
Science Park, Milton Road
Cambridge CB4 0WF, UK
T +44 (0)1223 420066

Burlington House
Piccadilly, London
W1J 0BA , UK
T +44 (0)20 7437 8656

International offices
Beijing, China
Shanghai, China
Berlin, Germany
Bangalore, India
Tokyo, Japan
Philadelphia, USA
Washington, USA

www.rsc.org/new-perspectives

@RoyalSocietyofChemistry
@RoySocChem
@roysocchem
@wwwRSCorg
linkedin.com/company/roysocchem

Registered charity number: 207890