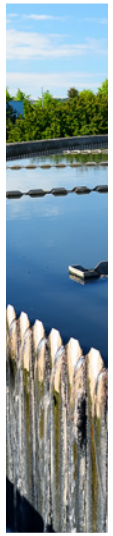
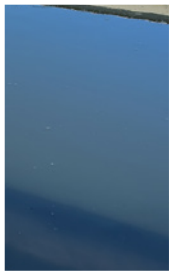
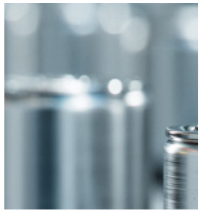
IChemE

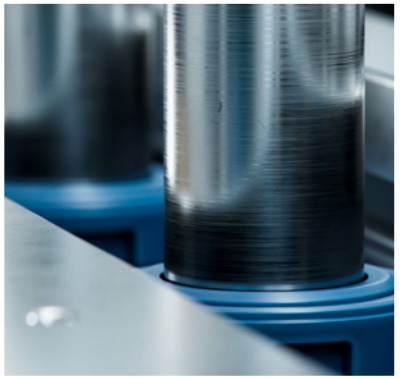
Engineering a Sustainable World

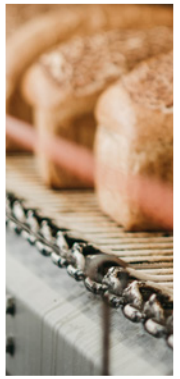
The Chemical Engineering Challenge











May 2024

Introduction

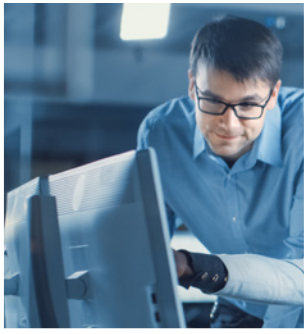
It is my great pleasure to present *Engineering a Sustainable World – the Chemical Engineering Challenge*. It represents a comprehensive review of the challenges the world faces, and distils the views of IChemE members as to the role of chemical and process engineers in addressing these.

My sincere thanks to the many members and staff who have contributed. It is your input and hard work that has enabled this vision to be developed – the first fresh look at the engineering challenges and IChemE's contribution to their solution for 15 years.

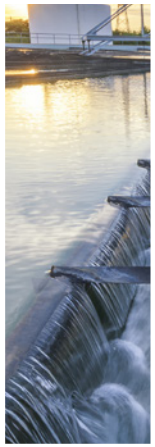
I hope you find it inspiring, engaging and useful with your own networks be they formal or informal. Working together and with others, chemical and process engineers are fundamental to addressing the major challenges facing the world. Let's be the change.

Thanks.

Nigel Hirst CEng FIChemE
President







Contents

Foreword

I am excited to introduce *Engineering a Sustainable World – the Chemical Engineering Challenge*.

Chemical and process engineers are key to engineering a sustainable world. We apply professional expertise to support society's needs and address challenges for sustainable development – climate change, circular economy solutions and securing green and affordable energy, water, food, and health. Chemical engineers use science-based expertise, systems thinking and digital tools to do this safely, economically and ethically, to maximise beneficial impacts on the environment and society. We collaborate with others, globally and locally, to deliver strategy and projects, solve challenges, and improve quality of life.

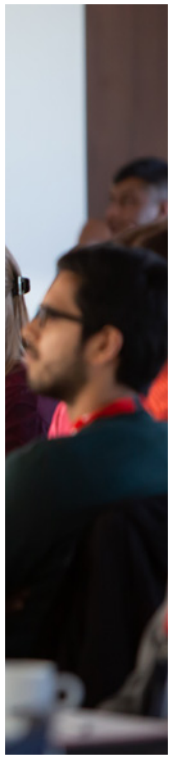
Our world continues to grow rapidly, with frequent disruption and change. There are new and accelerating trends and issues – especially while managing environmental and societal impact, security and technology. To develop a forward view about the profession, we consulted our 30,000 worldwide members to understand the perspectives of chemical engineers about the technical problems we are facing, and the role of chemical engineers in addressing them.

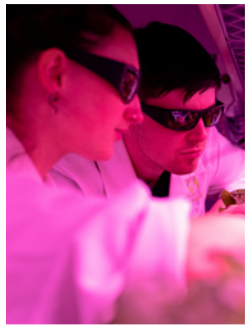
The report aims to inform chemical engineers at all career stages and in all sectors about how they can create societal benefits and help meet the challenges of the United Nations' Sustainable Development Goals (SDGs). It will also guide IChemE's engagement externally, with policymakers, career advisors, university academics, and business decision-makers.

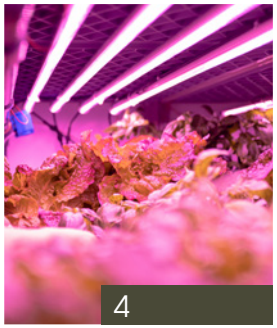
I thank everyone involved. I encourage you to read, share, and discuss. Let's continue our work to engineer a sustainable world.

Alexandra Meldrum

Honorary Associate Professor Alexandra Meldrum FIChemE FAICD
Vice-president, Learned Society and Member of the Board of Trustees







Summary and recommendations

We need to engineer a sustainable world if society, the economy, and the natural world are to endure. It is the vision of IChemE, as set out in Strategy 2028+, and central to our being as chemical and process engineers. Sustainability must be at the heart of all chemical engineering thinking and practice in the 21st century, embedded in everything we do alongside process safety and conducting ourselves in an ethical way.

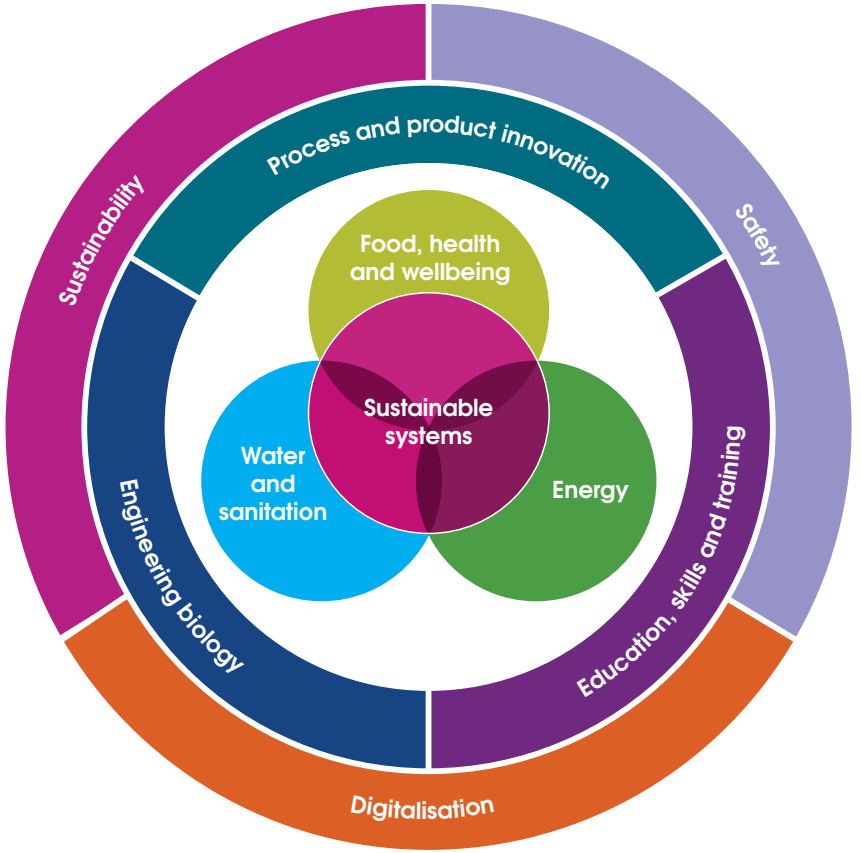
The great challenges that the world faces will only be addressed by many professions and sectors working together. Chemical engineers will be crucial to that success, with our knowledge, skills, creativity, and systems thinking. All are vital, if collectively we are to achieve a sustainable world. The 17 United Nations SDGs encapsulate the enormous challenges ahead. Chemical and process engineers have a role to play in meeting them all, but particularly sit at the heart of:

- Zero Hunger (SDG 2)
- Good Health and Wellbeing (SDG3)
- Clean Water and Sanitation (SDG 6)
- Affordable and Clean Energy (SDG 7)
- Industry, Innovation and Infrastructure (SDG 9)
- Responsible Consumption and Production (SDG 12)
- Climate Action (SDG 13)

The report explores the contribution that chemical and process engineering can, and must, make.

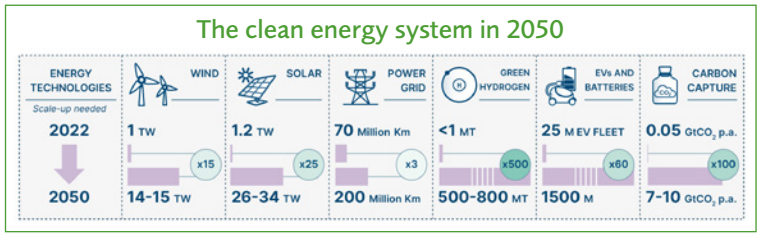
A model for success

Reimagining our world with sustainable systems at its core must be the single biggest step to success. Chemical engineers are uniquely placed to design, develop, implement, understand, and manage complex systems, using them to drive a circular economy where resources and materials are reused many times instead of being extracted, used, and discarded. Systems include essential functions in society such as education, management, regulation, process safety, insurance, and government. Systems-thinking approaches enable increased productivity, efficiency, and effectiveness, reduced use of new resources, and minimum waste. Innovations will arise from cutting-edge science, and chemical engineers will provide the necessary translation into effective, sustainable, and viable solutions.



SUSTAINABLE DEVELOPMENT GOALS

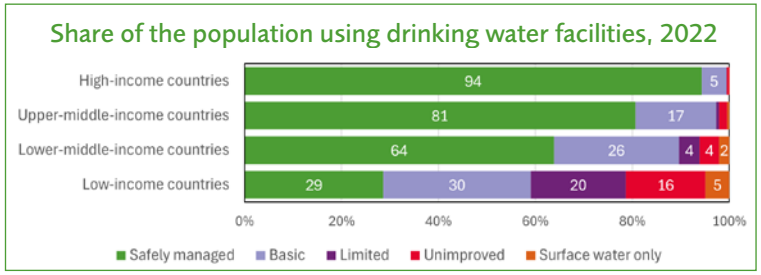
The energy sector has been, and always will be, dependent on the skills of chemical engineers – now even more so as the focus shifts towards a low emissions future, requiring a significant scale up of decarbonisation technologies and renewables. Chemical engineers are key to this, by improving processes to reduce energy consumption, capturing and using or storing carbon dioxide, developing more sustainable mining practices, engineering better batteries and storage systems for renewable energies, and placing sustainability at the core of all processes. Updating and upskilling of the existing workforce may be required, along with new ideas and innovations as the energy mix changes.



ETC (2023), Material and Resource Requirements for the Energy Transition, page 9.
Available at: www.energy-transitions.org/publications/material-and-resource-energy-transition/

Food, health, and wellbeing are fundamental needs for all – the key to prosperity and peace. Making agriculture and food manufacture more sustainable at scale requires new approaches and an ability to master hugely complex systems. Chemical and process engineers are critical. For example, in food production, they work on alternative protein sources such as fungi and insects, and develop more sustainable packaging using smart, multifunctional, and biodegradable materials. With increasing demands for improved health and wellbeing solutions, including innovative healthcare, improved nutrition and pharmaceuticals and consumer goods, particularly in the post-COVID-19 era, they will be central in rapid innovation and scaleup.

Water and sanitation are two of the most basic human needs and essential if we are to achieve an equitable as well as sustainable world. Climate change and a growing population make access to clean water and sanitation more challenging than ever. We also need to focus on managing better the scarce water resources that we have – reducing losses, improving efficiency, and removing increasingly complex contaminants such as hormones and pharmaceuticals in a safe and sustainable way. Chemical and process engineering skills are vital to ensure we can meet these challenges, especially at scale.



WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) (2024) – with major processing by Our World in Data (Last updated 6 January 2024).

In a world where we need to reduce energy consumption, use less resources and increase yields, the emerging field of engineering biology, which applies engineering principles to the design and fabrication of biological components and includes biochemical engineering, offers huge possibilities and opportunities. Many biological processes occur at ambient temperature and in relatively mild conditions, meaning they require less energy while producing high-quality food, healthcare, chemicals, and materials. Working with highly selective engineered enzymes and biological systems can deliver high yields and improved results. Chemical and process engineers have the skills to scale up processes in this emerging area while ensuring appropriate management of risk and managing a range of diverse stakeholders.

Process and product innovation, intensification and simplification will be a key enabler to making sustainability a reality. Combined with cutting-edge technologies, this has the potential to drive radical change in products and processes. Chemical and process engineers are crucial to doing this safely, effectively, and economically, combining a broad range of skills (including digital tools and knowledge in materials science) with deep technical understanding. They take new research to higher levels of technical and commercial readiness using their abilities to evaluate options critically and systematically, scrutinise risks, sell ideas, and collaborate.

To achieve any of this, chemical and process engineering must attract and retain significant numbers of capable and diverse people across the world, with access to high quality education, skills, and training throughout their careers. They must be taught a broad range of knowledge and skills, including fundamental principles and practice, and how to apply them to emerging technologies in a safe and sustainable way. Chemical and process engineers must be committed to lifelong learning, including embracing new knowledge and skills where they are needed. Digitalisation, including artificial intelligence (AI) and big data, will help to alleviate growing demand for skills by enabling efficient work processes and analysis.

Chemical and process engineers are key to achieving the transition to a sustainable world in ways which are safe and equitable across geographies, societies, sectors, and socio-economic groups. We must build new technologies and ways of working which are inclusive and accessible, drawing on skills and talents of people from all backgrounds, ages, and situations. The skills requirements of the transition alone mean that globally we must significantly increase the number and diversity of people pursuing chemical, process and other forms of engineering education and careers. Widening access to engineers from a more diverse range of backgrounds will be an important part of the solution. By attracting more school leavers and improving access for under-represented demographics, we will provide opportunities to share the rewards of innovation and new ways of working widely and generously, as well as ensuring a fair distribution of the costs.

Be the change – the role of chemical and process engineers and IChemE

The challenges to achieving a sustainable world are significant and diverse. Individual chemical and process engineers must play their part alongside employers, whether in industry or academia. Professional bodies, including IChemE, have a major role in motivating, enabling, and guiding the change. Governments, policymakers, influencers, and civic institutions must lead and support through their actions as well as their words.

Individual chemical and process engineers should:

- prioritise their lifelong learning, working to recognise their development needs, seeking out the skills they require and engaging with training and support throughout their careers;
- anticipate future training and development requirements, seeking out guidance as appropriate, so giving themselves time to re- or upskill, and gain additional qualifications and/or experience, which allows them to take advantage of emerging opportunities;
- raise awareness about sustainability and use their skills to advance progress towards meeting UN SDGs;
- engage with IChemE to learn from and share knowledge and experience with others, in the same sector and beyond, supporting the profession's move towards a safe and sustainable future;
- engage with local communities, educational establishments, family, and friends to help them understand the importance of being part of the change to a more sustainable world and the pivotal role of chemical and process engineers in achieving it.

Employers should:

- require all those working in chemical and process engineering roles to continuously update and upgrade their knowledge and skills, providing practical and moral support to engage in meaningful professional development;
- work with IChemE to provide an assured framework for career-long professional recognition and progression to all those working in chemical and process engineering roles, including access to appropriate professional development, training, and mentoring;
- prioritise training and development budgets to provide individuals and teams with the skills and knowledge they require to move to more sustainable technologies and products. Similarly, prioritise research and development spending to underpin sustainable systems, including rapid scaleup of key alternative technologies;
- be open to new business models and engineering processes;
- engage with local, national, and international communities to raise awareness of the move to more sustainable technologies, including honest discussions around benefits and costs.

IChemE will:

- use this report, the thinking that has led to it and other relevent frameworks to guide the way in which we prioritise efforts and target our resources, in Learned Society activities, collaborations with others, and above all in supporting our members;
- actively engage with governments, industry, and policymakers to communicate the breadth and scale of the changes needed if the world is to achieve a more sustainable future, and to highlight the pivotal role of chemical and process engineers;
- further improve and develop the ways in which chemical and process engineering professionals from different sectors, employers, career stages, and geographies can come together and pool their expertise for the benefit of themselves and society. It will enhance how members and non-members can share best practice, develop guidance materials, and create the networks to exchange knowledge and ideas;
- continue to support and shape the training and skills of chemical engineers to meet the challenges of the future by determining the requirements for accrediting courses, qualifying members, and ongoing professional development;
- relaunch Professional Process Safety Engineer registration, allowing safety professionals from a broad range of backgrounds to join and enrich the wider IChemE community, so increasing our voice and raising standards in this crucial area;
- place engineering ethics front and centre for all our members, collaborators, and supporters. We will continue to embed ethics as part of chemical engineering through accreditation and training, and promoting responsible use of resources, production and technologies including AI – to avoid unintended social and environmental consequences;
- continue to raise the profile and importance of meeting the global challenges discussed in this report – across the chemical and process engineering community, the public, politicians, and opinion-formers. We will continue to support individual engineers in their efforts to deliver a sustainable world as well as business, universities, and governments.

In return, we call on governments and policymakers to:

- publicly recognise the pivotal role of chemical and process engineers, and chemical and process engineering in achieving a sustainable world and in the transition towards this;
- designate chemical and process engineering as subjects of national strategic importance, alongside explicit references to chemical and process engineering in relevant discussions, documents, and legislation;
- prioritise funding for research into key chemical and process engineering-related topics, including:
  - rapid process intensification and scaleup;
  - decarbonisation of energy generation;
  - engineering biology scaleup and industrialisation;
  - energy storage system technology;
- prioritise chemical and process engineering education and training at all levels – supporting significant expansions in technical and apprenticeship, undergraduate and postgraduate, and post-doctoral routes as well as reinstatement of 'National Engineering Scholarships', designed to encourage and enable young people from currently under-represented groups to engage.

Sustainability is and will remain at the very heart of everything IChemE does. We will continue to embed the principles and practice of sustainability across our activities, standards, and performance measures. In doing so, IChemE and our members will maximise our impact for the benefit of economies and societies, reinforcing the role and importance of our profession at the very centre of a sustainable world.

Engineering a sustainable world

The world is changing – sustainable chemical and process engineering is central

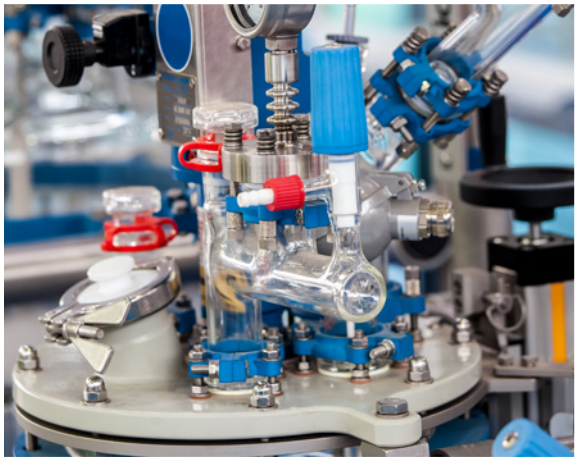
The industrial landscape is changing as we collectively increase efforts to minimise and mitigate waste, adapt to climate change, decarbonise industries, and support a safe, fair and sustainable energy transition. While some industries are reducing in size, reach and impact, others are rapidly emerging.

Supply chains are under pressure. Shifting demographics, jobs, and workforce mean labour markets are changing and everyone must adapt. These are all significant challenges for investment, productivity, and growth. Many changes occur at pace, and the economic gap between developed and developing nations is widening.

The United Nations set out its 17 SDGs in 2015. It reported in 2023 that progress had been so slow that attaining them is now considered to be 'in peril'. COVID-19, conflict, climate change, and widening inequalities compound the issues. Meanwhile, greenhouse gas emissions continue to rise, according to the World Meteorological Organization in 2023.

We see rapid technological change, economic uncertainty, a warming planet, and local conflicts, with ongoing shifts in the concentration and sources of geopolitical power. In the near and medium term, environmental risks are expected to dominate, while technological acceleration, including artificial intelligence (AI), introduces both new opportunities and new threats. With economic strains on low/middle-income earners – including the costs of net zero itself – and countries' populations increasing, risks, including involuntary migration, social polarisation and unrest, are likely to grow.

Chemical and process engineering and the people who work in these professions have never been more important in an uncertain, volatile, and often fragmented world. They are central in meeting the global challenges of energy, food, health, and water. Chemical and process engineers will help the world address these and other challenges in effective, efficient, and equitable ways.



Engineering responsibly – professional ethics at our core

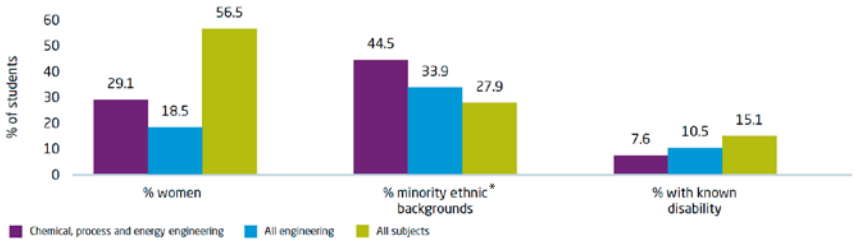
Acting ethically must be at the heart of everything that chemical and process engineers do, weighing up societal, environmental, and technical dimensions to achieve the best solution to a problem or challenge.

IChemE is a signatory to the ethical principles set out in 2005 by the UK Royal Academy of Engineering, specifically:

- **honesty and integrity;**
- **respect for life, law, the environment and public good;**
- **accuracy and rigour;**
- **leadership and communication.**

Through our Code of Conduct, we require all of our members to follow these principles, always working to high ethical standards and in the public interest. As we address the big challenges before us, the implementation of ethical approaches is increasingly important, integral to sustainability, safety, health, and the environment. Engineers are also expected to act in ways which enable and promote equality, diversity, and inclusion. The example from UK undergraduates shows that there is room for improvement, especially with regards to gender and disabilities – though diversity data will differ in other countries.

Characteristics of first year undergraduate entrants, example from UK 2020/21



EngineeringUK analysis of HESA student record 2020/21.
www.engineeringuk.com/research-policy/educational-pathways-into-engineering/higher-education/

* ethnicity is only recorded for UK students, others are excluded from the analysis.

Ethical behaviour builds trust in the profession. It requires commitment from individuals throughout their careers, and support from organisations of all sizes and sectors. It requires self-regulation and professional behaviour at all times, where appropriate, going beyond compliance with external regulations and legal requirements. In terms of working environments, it also requires companies and individuals to build a culture where individuals are able to raise concerns about danger, risk, malpractice, or wrongdoing that could cause significant harm.

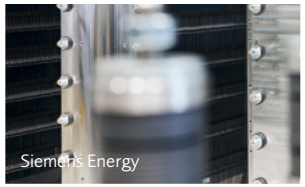
Engineering ethics is key to our success as a profession – attracting new talent and helping engineers develop and put in place effective long-term solutions. Ethical behaviour will underpin success – assisting in the development of innovations which improve the quality of life for all, while protecting our natural environment.

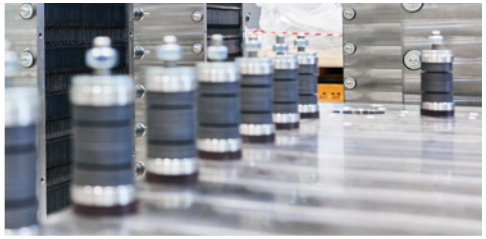
Engineering a sustainable world – where we can impact most

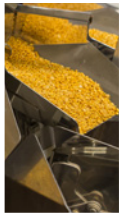
Chemical engineering has a considerable part to play in contributing to a future sustainable society. Given the scale of change required to achieve sustainability, we cannot succeed unless we proactively collaborate with others, including engineering institutions, government, and regulatory bodies.

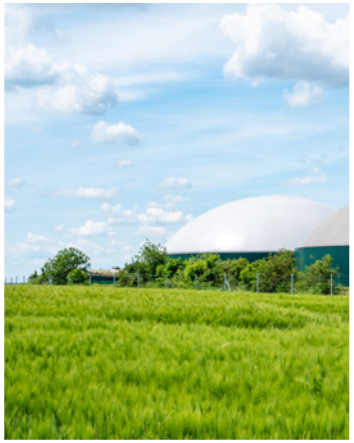
The SDGs are a powerful framework and IChemE can use them to best orientate and explain our positive societal impact. We have identified the SDGs that are either led by chemical engineers or require substantial contributions by chemical engineers to succeed.

The following sections set out the areas where chemical engineers are pivotal to success, the main technical challenges they need to overcome, and the likely solutions identified by IChemE members. To succeed, chemical engineers will also require some new tools and enablers, which will drive success across all sections.


Siemens Energy







Sustainable systems

Chemical and process engineers serve complex business systems and value chains that link food, materials, energy, water, and waste, and interface with society, the economy, and the environment. Sustainable development demands responsible consumption of resources and drives the circular economy, where resources are recycled and reused to 'keep molecules in use for longer'. Benefits of the circular economy are numerous – more efficient use of resources leads to reduced extraction of virgin resources, decreased waste generation, and fewer negative environmental impacts.

Key technical challenges

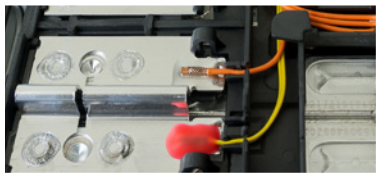
Sustainable systems target recyclable products. Recycling involves collecting and sorting used products, dismantling them, manufacturing products with non-virgin inputs, and breaking materials down to chemicals that can then be reused to produce products.

Likely solutions

Circular business models encourage products, components and materials that are easy to repair, dismantle, recycle, reuse, or reprocess. For example, batteries should be designed so they are easy to disassemble, and polymer formulations should enable recycling or depolymerisation. Life cycle analysis frameworks will need to be systematically applied, and the underlying datasets require continuous improvement.

Greater efficiency will reduce waste at source but require systems thinking, careful planning and detailed understanding of production processes within integrated industrial networks.

Efficient, integrated systems for generating, storing, and transmitting electrical and thermal energy can avoid greenhouse gas emissions. Decarbonised, cost-effective thermal energy technologies are expected to play an important role.



Energy

Chemical and process engineers play a pivotal role in driving a just transition to affordable, clean energy, and developing resilient manufacturing processes that are better adapted to a changing climate.

Key technical challenges

Reaching net zero requires decarbonisation – achieved through efficiency improvements, replacing fossil fuels with renewable or climate-neutral alternatives wherever possible, and abating carbon emissions where this is not feasible.

It also requires drastic changes to chemicals and materials manufacturing. Many processes that make the building blocks of modern life (cement, glass, ceramics, metals, and bulk chemicals) are incredibly energy intensive.

Chemical engineers are key to developing safe, sustainable and cost-effective alternatives which require less energy and can replace traditional processes.

Likely solutions

Chemical engineers help reduce energy demand and carbon emissions. They design and manage processes for capturing, using, and storing carbon dioxide from burning fossil fuels and from the atmosphere. They work on technologies to produce and store electricity from renewable (but variable) sources safely and efficiently.

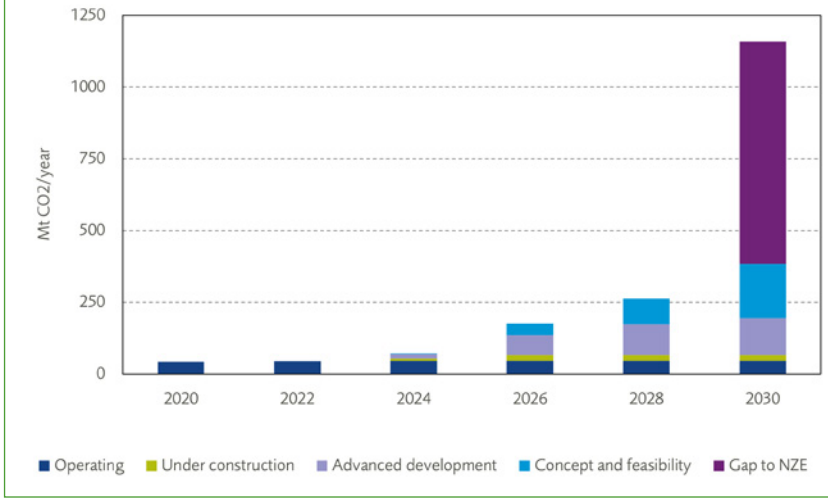
By applying systems thinking, chemical engineers develop renewable energy technologies, including:

- cheap, safe batteries for storing renewably generated electricity, designed so that 'critical minerals' and other components can be recovered and reused;
- efficient systems to store and release thermal energy;
- future fuels, including synthetic fuels, hydrogen, and biofuels;
- more sustainable methods and energy sources for mining and processing critical minerals;
- light, durable, low-cost solar cells and recyclable blades for wind turbines.

Chemical engineers help develop low-carbon ways of manufacturing glass, cement, steel, chemicals, and hydrogen, and next-generation nuclear technologies that are safer, cheaper, and produce less waste. Chemical engineers apply systems thinking to develop circular solutions for equipment, components, and supply chains that are designed to maximise recovery and reuse of resources.

Chemical engineers aim to ensure their activities, from design through operation and onto decommissioning, are safe, efficient, flexible, and have low environmental impact. They work towards providing effective plant automation and control, and responsive and resilient supply chains. Process safety remains paramount and, by transferring lessons learnt from mature industries to emerging sectors in the energy space, it is strengthened and encouraged.

Capacity of current and planned large-scale CO2 capture projects vs. the net zero scenario, 2020-2030 (worldwide)



IEA, www.iea.org/energy-system/carbon-capture-utilisation-and-storage#tracking

Food, health, and wellbeing

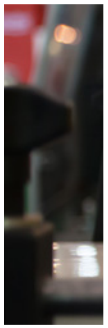
Food, drink, pharmaceuticals, and fast-moving consumer goods (FMCG) are essential to human life. Across these sectors, chemical and process engineers develop, design, and operate sustainable, efficient, and safe production facilities and supply chains. They produce nutritious food and effective agrichemicals, packaging, personal hygiene, medical products, and bulk and specialised pharmaceuticals.

Key technical challenges

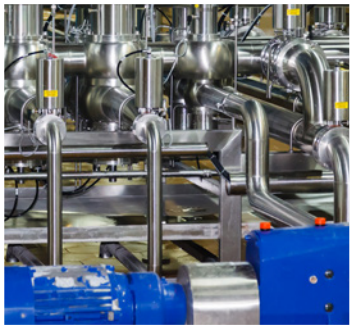
Agriculture and food production, especially meat, are a significant source of greenhouses gases which needs to be addressed. Reducing food waste will require supply chain improvements and more sustainable packaging. We also need to improve land use and the nitrogen cycle to provide nitrogen for plant growth without generating nitrogen-rich wastewater. In the pharmaceuticals sector, single-use technologies have reduced contamination and increased safety, to the detriment of sustainability, while the ongoing use of batch and small-scale operations presents efficiency challenges. Waste from single-use technologies needs to be reduced.

Likely solutions

Chemical engineers work to minimise and manage food waste and reduce negative impacts of packaging, for example by using smart, multifunctional, and biodegradable materials. Food from alternative protein sources, such as fungi and insects, is being explored. Process improvements and novel types and formulations of pharmaceuticals and biopharmaceuticals create personalised medicines that can be more effective and stable, and produced efficiently and cost-effectively. Site-specific drug delivery and minimised dosage will increase efficiency and reduce side effects.








Water and sanitation

Access to clean water and sanitation is fundamental to human wellbeing and productivity. However, climate change and growing populations mean that lack of access to sanitation and safe drinking water affects billions of people globally.

Key technical challenges

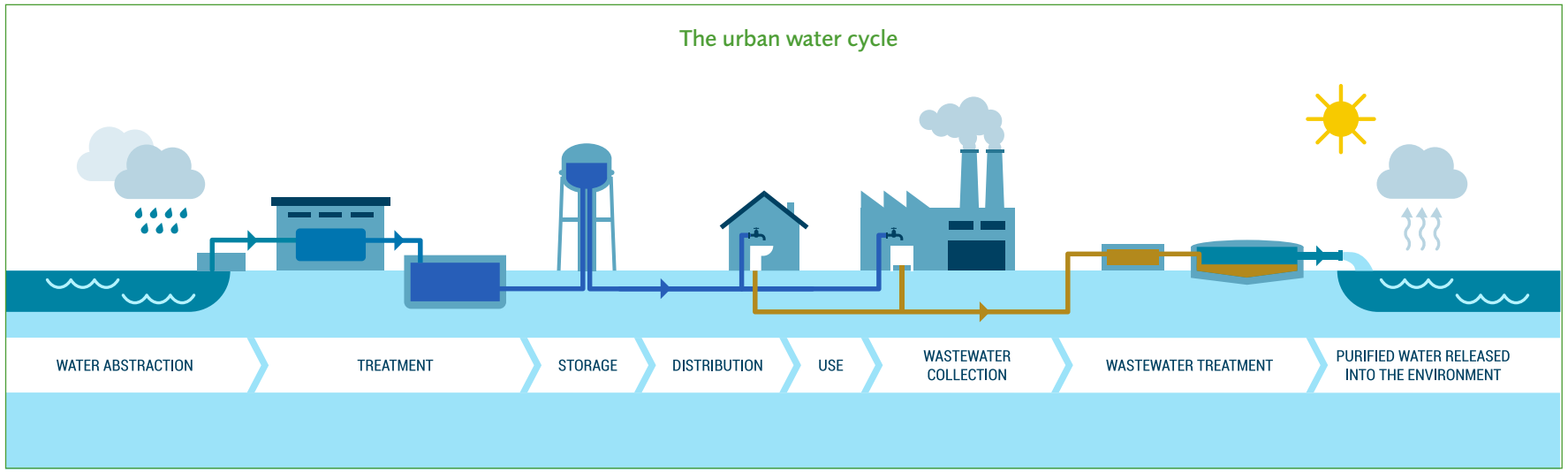
Supplying sufficient fresh water for drinking, industry, agriculture, and sanitation will be a huge challenge, especially in parts of the world that are becoming more arid. The projected ramp-up of electrolytic hydrogen will further add to freshwater demand. Desalination can supply fresh water but is highly energy intensive. Meanwhile, the water supply suffers significant losses as the relatively low cost of water does not incentivise water conservation and investment in infrastructure. The removal of complex contaminants such as hormones and pharmaceuticals as well as microplastics from drinking water presents further challenges.

Likely solutions

Chemical engineers help provide water purification and wastewater treatment systems that prevent water losses, reduce energy requirements, and remove more complex contaminants. Recovering nutrients, biosolids used in agriculture, and methane-rich biogas from wastewater contribute to the circular economy.

Likely solutions include membranes, nanomaterial-based adsorbents and catalysts, and enzymes for bioremediation. Digital tools help to sense, monitor, and control water quality and flow rate, and can assist in dealing with malfunctions and optimising plant operation for quality and efficiency. To respond to climate change, chemical engineers apply risk assessments and appropriate technologies, and design resilient infrastructure, helped by models and digital tools.

The urban water cycle



Tools and enablers

Engineering biology

Engineering biology is an emerging area of technology that applies engineering principles to biological systems, and which encompasses biochemical engineering. The Royal Academy of Engineering identifies engineering biology as a priority for growth, noting that "harnessing the capabilities of organisms, processes and mechanisms that exist in nature, and combining this with the incredible advances in areas such as processing power and machine learning presents solutions to problems of all scales – most pertinently in the need for sustainability and reducing emissions".

As a tool, engineering biology promises significant improvements in all the sectors identified above, including remediation of land and water, and products that provide food, healthcare, chemicals, materials, and energy.

Biochemical engineers develop and operate biological and chemical processes using engineered and optimised enzymes, genes, or cells. They can deliver products with superior properties, such as heat-stable vaccines, more effective pesticides, and biodegradable polymers, through processes that are more sustainable and more specific and selective than existing alternatives. Examples include lab-grown meat, protein-rich foods made from fermented fungi, and the extraction of valuable products from organic wastes through anaerobic digestion.

Digital tools are used to model biological processes and design the biological components along with the required processing equipment and controls. Further innovations will be needed to address the limitations of biological processes, such as dilute products and short-lived organisms.

Engineering biology has significant potential. Responsible innovation, advocacy, knowledge sharing, government support and funding, along with appropriate regulatory and ethical frameworks, can help maximise its impact. Safety and public discourse are critical given the reliance on genetically engineered organisms.

Engineering biology technologies and application areas

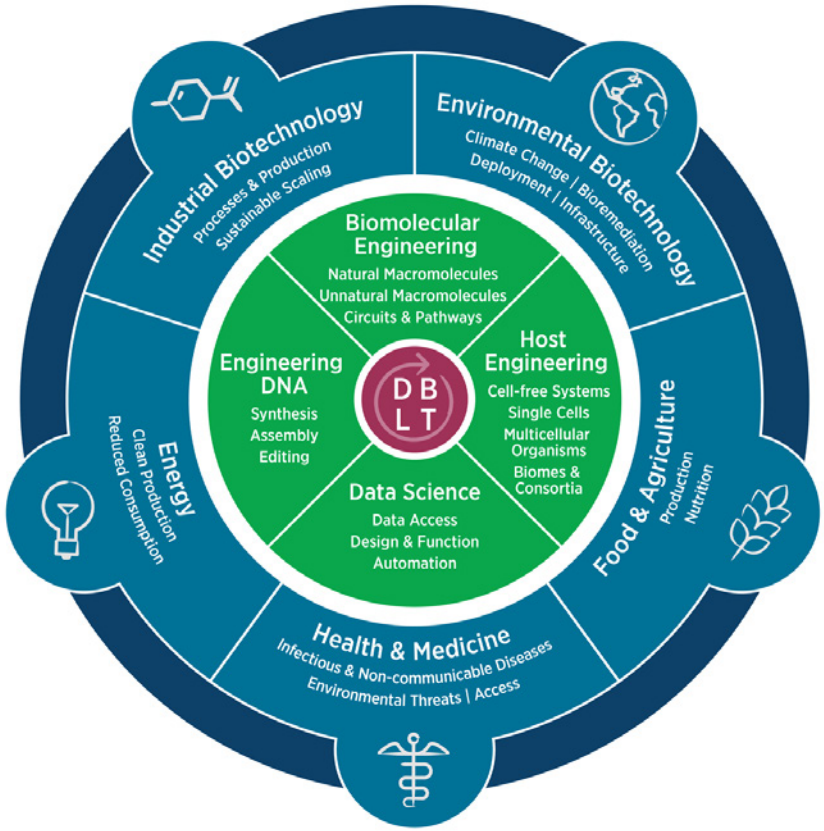


Figure used with permission, from Engineering Biology: A Research Roadmap for the Next-Generation Bioeconomy, Engineering Biology Research Consortium (2019). Available at https://roadmap.ebrc.org/2019-roadmap/

DBTL = design-build-test-learn.

Process and product innovation

The world needs new products that are socially and environmentally sustainable and contribute to the circular economy. Developing the circular economy requires innovators who bring a systems view of innovation that considers the sustainability of the whole system and value chain – from cradle to grave or cradle to cradle – from the outset. It will also require novel business models to support the added complexity.

Innovation needs to consider environmental impact, risks, hazards, ethics, costs, timelines, intellectual property rights, and stakeholder engagement across full product lifecycles, and sometimes also extensive supply chains.

Chemical engineers invent efficient, effective equipment and technologies, in terms of resource consumption, yield, waste generation, cost, and safety. Innovations in materials science, molecular engineering, nanotechnology, transformation pathways, and 3D printing benefit a spectrum of products, including heavy industry, bio-based, nano, and customised products.

They are assisted by digital tools for process automation, modelling, optimisation, and operation. Quantum computing and AI are exciting new developments but the risks of employing them must be assessed and managed.

Education, skills, and training

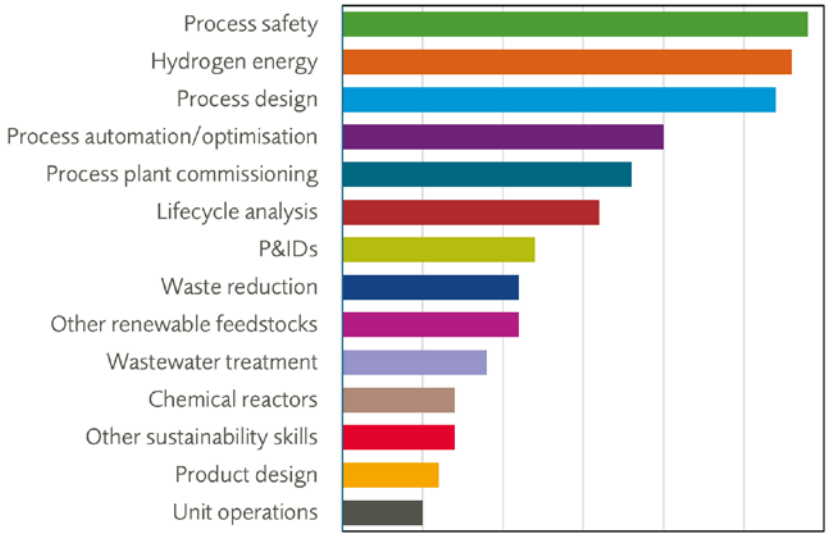
Chemical and process engineers play a crucial role in addressing SDGs and various challenges outlined in the report. Ensuring they are educated and continue to work to agreed competency standards underpins public confidence in the profession. Attracting a diverse pool of students and trainees into scientific and engineering career paths is essential for maintaining a robust talent pipeline. Policies supporting engineering studies, especially for school-leavers, help build capacity.

Teaching materials need to be continually reviewed, and where appropriate, updated, to ensure that chemical engineering fundamentals are taught using examples that are relevant to the world of tomorrow – for example fuel cell and fermenter designs, distillation of non-ideal mixtures, and membrane separations. Increasing electrification will mean that electrochemical engineering will move from a niche area to mainstream.

Chemical engineering principles, knowledge, process safety and ethical thinking can be applied to emerging technologies, complemented by interdisciplinary and specialist expertise. As chemical engineers increasingly engage in diverse arenas and non-traditional career paths, a culture of lifelong learning is essential.

This can be supported by greater collaboration between academia and industry, specialist degrees aligned with specific sectors, and various modes of lifelong learning. As the pace of change increases, lifelong learning is essential for professional chemical engineers.

Which technical / engineering skills do you think you need to develop your career within the next 12 months?



IChemE Salary Survey 2024

Which employability skills do you think you need to develop your career within the next 12 months?

IChemE Salary Survey 2024

Conclusion

Engineering a sustainable world will require change at a scale and pace that is beyond the capability of any one profession, institution, or country to deliver. Chemical engineers bring skills that are vital to success, but they can only reach these goals by collaborating with others.

Delivering this change will require concerted efforts, as set out on pages 6-7. It will require individual chemical and process engineers, employers, IChemE, and governments and policymakers to be aligned to a single vision.

For individuals, this means a lifelong commitment to training and development. Our world, the challenges it poses, and the technologies needed to address those challenges are changing at an unprecedented rate. Only by keeping abreast of these changes and possessing skills honed to the latest standards can chemical engineers deliver the change that is required. It also means engaging with individuals and communities to help them understand the importance of the task and what they can do to achieve it.

For employers, it means driving and enabling staff to continuously update their skills throughout their careers, using the framework for continuing professional development (CPD) and training options provided by IChemE and others. Enhancing sustainability and the rapid scaleup of improved technologies need to be at the forefront of investment decisions.

For IChemE, this means prioritising efforts, developing resources, training materials, standards, and opportunities for professional recognition to support the priorities and sectors set out in this report.

We will use our reach and convening power to communicate the breadth and scale of the required change with governments, industry, and policymakers. We will also find new and better ways to help chemical engineers pool their expertise, share best practice, and collaborate with others to deliver the change, guided by professional ethics.

At the same time, IChemE will push policymakers and governments to recognise the role chemical and process engineers play in delivering a sustainable world, and to prioritise research funding into key technologies that will help bring about the step change in sustainability we require, along with training at all levels, from apprenticeships to post-doctoral research.

Sustainability is and will remain at the very heart of everything IChemE does. With our members and partners, we **will** engineer a sustainable world.

Appendix: detailed assessment of the technical challenge areas

Consulting IChemE's 30,000 members worldwide has resulted in rich feedback covering the core technical topics addressed in this report. While the summary outputs are covered here, significantly more detail is available online.

For each of the topics, we set out the context, the key technologies and areas of activity, the challenges and constraints, the contributions chemical engineers bring to the table, and the skills they require.

The links below give you access to these reports. We hope that they will help and inspire you to make the changes that are needed to ensure a sustainable future for all.

Sustainable systems

Energy

Food, health, and wellbeing

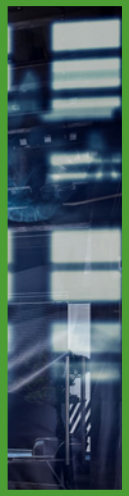
Water and sanitation

Engineering biology

Process and product innovation

Education, skills and training

Glossary



Contact us for further information

UK

+44 (0)1788 578214
membersupport@icheme.org

Australia

+61 (0)3 9642 4494
austmembers@icheme.org

Malaysia

malaysianmembers@icheme.org

New Zealand

+64 (0)4 473 4398
nzmembers@icheme.org

Acknowledgements

Engineering a Sustainable World – The Chemical Engineering Challenge was published in 2024 following consultation with IChemE's global membership, with broad and detailed contributions from many subject matter experts. The Institution is grateful to all those who spared the time to share expert opinion, in particular, members of the Learned Society Committee and other volunteer groups who helped to develop the report.

www.icheme.org

LC 0018_24