Chemical Engineering Matters

IChemE's technical strategy – scope, applications and implications
2nd Edition

IChemE ADVANCING CHEMICAL ENGINEERING WORLDWIDE

Contents

Why chemical engineering matters

I am indebted to those Council colleagues who laid the foundations upon which the *Chemical Engineering Matters* initiative has been built. In particular, Bill Wakeham who introduced the chemical engineering matters model in his 2011 presidential address. Also, Ed Daniels from Shell, whose technical leadership was the driving force behind the publication of the first report in 2013.

Chemical Engineering Matters is intended to be thought provoking. It draws together many of the strands that make up our profession in the 21st century. I had no hesitation in making this a core theme for my presidential year and I have been greatly encouraged by the willingness of IChemE members all over the world to engage with the topics addressed in this report.

The "vistas" have proved to be a valuable mechanism for member engagement and we are using them to catalyse debate amongst IChemE's regional member groups and special interest groups. I would like to thank Jon-Paul Sherlock from AstraZeneca for his enthusiastic leadership and participation in this work.

Initially, *Chemical Engineering Matters* has focussed on member engagement. IChemE is determined to ensure that its technical positioning reflects the views of professional chemical engineers. This work has generated a wealth of ideas, case studies and new contacts across the broad landscape of chemical engineering. We are now assessing ways to organise, mine and capitalise on this information to highlight the valuable contribution made by chemical engineers across our global community. The output will inform a productive dialogue with external stakeholders, including policy makers and the media. I want this dialogue to generate positive outcomes that highlight the role of chemical engineering as a vital part of the jigsaw that is 21st century living.

Chemical Engineering Matters informs every aspect of IChemE's work and sits at the heart of the Institution's forward planning. This report has been updated to reflect member input and the actions for IChemE have been further developed to give an indication of work completed so far and objectives for 2014–2015.

I have always believed in the positive difference that chemical engineering can make in the world. That's why I chose to become a chemical engineer. Today, more than ever before, I am determined to work with IChemE members and all those involved in delivering solutions based on chemistry to spread the message that chemical engineering matters. This report provides a framework for our ambition.

Judith Hackitt OBE

President, April 2014

In October 2011 the world welcomed its seven billionth citizen and with five more people born every second, the global population may exceed nine billion by 2050. The majority of this growth will be driven by the developing world, where rapid improvements in living standards are evident – thanks significantly to the application of chemical engineering.

People are living longer and they aspire to lifestyles that have been enjoyed in Western Europe and North America since the 1950s. Social and economic progress on this scale presents a major challenge. The burgeoning middle classes of the 'BRIC' nations are driving consumer demand at an unprecedented rate.

The International Energy Agency has estimated that US$38tn in infrastructure investment will be needed to meet projected world energy demand to 2035 alone. The threat of climate change continues and we are witnessing increased stress on our energy, water and food resources.

In the developed world, ageing populations pose an additional challenge. Demands on health and social care services are increasing rapidly. New patterns of consumption and spending associated with this changing demographic are impacting on the global economy. Manufacturers in Asia are refocussing on local markets. Today, China continues to report economic growth in excess of 7% even though much of the world is still emerging from deep recession.

The future is challenging and uncertain. The puzzle is complex, but chemical engineering remains central to the delivery of sustainable energy, water, food and wellbeing in all parts of the world.

IChemE is dedicated to advancing chemical engineering worldwide; and this new report restates our intention to support chemical and process engineers in their mission to improve quality of life. Chemical engineering matters.

Ed Daniels

Technical vice president, February 2013

Executive summary

It was clear from the outset that the detailed thinking set out in IChemE's *Roadmap for 21st Century Chemical Engineering* would need to be the subject of ongoing review. Nonetheless, a member consultation in 2011 revealed continuing support for the roadmap and the position statements that it embraced.

Further dialogue with members in the first part of 2012 refined the institution's thinking on technical strategy matters. A new focus on potential chemical engineering solutions in four key challenge areas – energy, water, food and nutrition, and health and wellbeing – was agreed, coupled with a stronger emphasis on external influences, including the wider economy and public attitudes to science. The conversation attempted to prioritise key points of influence and intervention for IChemE, but this proved more difficult than anticipated. The report that has emerged is, as a result, different.

Chemical Engineering Matters has moved away from the classical roadmap approach in favour of a more open-ended look at the options for progress. This report is an exploration of possibilities and a vivid illustration of the versatility and wide-ranging application of chemical process solutions to human challenges. It positions the discipline as a vital piece of the jigsaw that is the quest for sustainable living in the 21st century.

At the core of the report, the reader will find four vista diagrams – one for each challenge area. The diagrams attempt to capture the current status and some specific challenges under each heading and propose some options for action by chemical engineers and others. External factors are also addressed in the context of the challenges. The vistas represent the beginning of a process, rather than an end. They are intended to provoke debate and stimulate target setting.

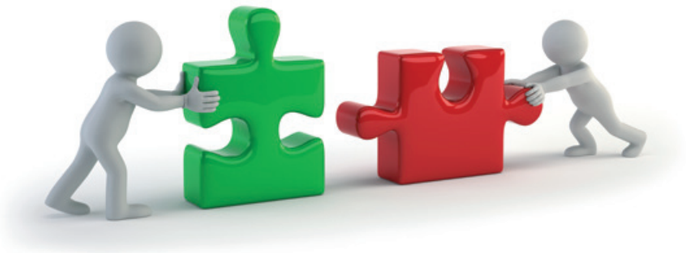
Through the vistas, *Chemical Engineering Matters* has identified a clear set of global challenges that can be addressed by the application of sound chemical engineering principles. The solutions and work programmes for the institution will vary in different locations and will require versatile partnerships with other stakeholders to secure delivery in developed, emerging and nascent economies around the world.

In addition to the vistas, the report also describes IChemE's current thinking in three fundamental underpinning areas: safety and risk, education and training, and research and development. Readers will also find a discussion on the external influences that shape the environment in which the modern chemical engineer must operate.

Some key conclusions are reached and these are set out on pages 25 and 26 in the form of eight areas of action for IChemE's leadership and staff team to pursue. These actions span the four challenge areas along with the fundamental issues and the externalities. Broad in scope, the actions will guide policy development and work programmes in the years ahead.

Over the course of modern history, chemical engineering has never stood still and chemical engineers are not noted for inaction. This proactive, problem-solving approach will continue in the future. Given the scale of the challenges facing humanity, IChemE clearly recognises that doing nothing is not an option.

Preliminary conversations around the vistas have highlighted the inter-dependencies between water, energy and food production. These relationships are summarised in the "nexus" concept developed by the Stockholm Environmental Institute in 2011. IChemE is working to improve understanding of these interactions with its international partners, including the AIChE.



Beyond the Roadmap for 21st Century Chemical Engineering

In 2007 IChemE set out the scope and scale of the challenges facing society and proposed roles for chemical engineers in delivering sustainable process solutions.

Initiated by Ian Shott, the institution's technical vice president at that time, the report *A Roadmap for 21st Century Chemical Engineering* addressed the question:

"What does society need; what are the desirable outcomes and how can chemical engineers work in partnership with others to make it happen?"

The report acknowledged that this was a tough question. Nonetheless, it asserted that chemical engineers must offer credible answers if the profession is to be taken seriously by decision makers, opinion formers and an informed and increasingly demanding public. At the roadmap's core were 20 position statements, underpinned by a series of action plans describing an extensive range of projects and initiatives that required IChemE support. The sustainability challenge was clearly stated and the work also acknowledged that there was no one-size-fits-all solution. A commitment was given to allocate resources to support the action plans and to publish regular updates. The roadmap was re-evaluated and IChemE is working with members around the world to demonstrate that chemical engineering matters.

Uncertain future

The roadmap was written before the onset of the global financial crisis. Iraq was still under military occupation and the Arab Spring lay around the corner. The events at Fukushima and in the Gulf of Mexico were yet to unfold. The potential of shale gas (and other unconventional fossil fuel assets) was still not fully understood and concerns around access to rare earth metals and other strategically-important resources had not materialised. Trying to predict the future is a risky business, but despite the uncertainties of geopolitics and its impact on the world of chemical engineering, the institution has made progress since 2007 and a good deal of the ambition set out in the roadmap has been realised.

Progress and growth

Members are the institution's greatest asset and numbers have grown by more than 10,000 since 2007. Collaborations in pursuit of roadmap goals have been sealed worldwide in Canada, South Africa, India, New Zealand, Singapore and the US. The creation of the new international vice president role in 2008 accelerated this process. IChemE journals reach a bigger audience, ensuring that new technical knowledge is widely shared. The institution's Awards for Innovation and Excellence have gone global. A Nuclear Technology Special Interest Group has been formed in direct response to a key energy challenge identified in the roadmap. IChemE has contributed to significant works on global water security, sustainable food production, biofuels and more. A model code of risk has been published and in 2013 the *Hazards* process safety symposium was staged in Australasia for the first time. So, despite the resource constraints posed by an uncertain economic climate, IChemE remains committed to the ideas that spawned the roadmap and will continue to support technical activities that advance the cause of chemical engineering worldwide.

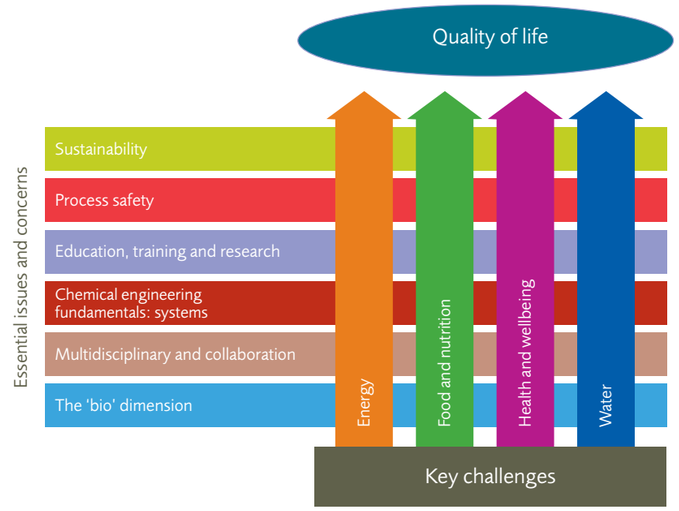


Figure 1: The *Chemical Engineering Matters* model

Quality of life

Predictably, shortcomings in the original roadmap were identified. The report did not give sufficient prominence to wealth creation. The food and bioprocess sections were less well developed than those addressing energy and process safety. Some stakeholders saw the delivery grids as too narrow or too vague. The role of fundamental chemical engineering science and systems thinking lacked clarity and the document was considered overly long. Notwithstanding this critique, the report continues to guide the institution's work; and a survey conducted in 2011 revealed that a clear majority of members still supported all 20 technical position statements.

Central to IChemE's approach to the review lies the question, "*Why does chemical engineering matter?*" The answer is clear. Without chemical engineering much of human progress would have been impossible. In the challenge areas – water, energy, food, health and wellbeing – chemical engineering plays a key role in creating, improving and maintaining quality of life. In 2012 IChemE members and selected stakeholders from the wider chemical engineering community were consulted on each of the four challenge areas. Contributors were asked to consider each challenge in the context of issues and concerns that command the attention of the chemical engineer. The overall approach is shown in Figure 1 and this model underpins *the Chemical Engineering Matters* approach.

The cross-cutting issues impact on every chemical engineering solution. The ideas that underpin collaborative, multidisciplinary R&D activity depend on a sound grasp of biology, chemistry, maths and physics. This activity adds to the body of knowledge that constitutes our fundamental understanding of chemical engineering science. In turn, this knowledge is the foundation upon which modern chemical engineering education and training are based. With this knowledge, chemical engineers adopt a solution-based approach to design, build, operate and manage safe and sustainable processes that deliver the products and services which people need. They also educate and train the next generation. This concept is depicted in Figure 2.

IChemE is a diverse, international technical community. The four challenges – and their solutions – require different approaches depending upon local circumstances. This report, based on the findings of the consultation, identifies a range of chemical engineering solutions that will meet the needs of developed, emerging and nascent economies.

Four vistas

Chemical engineering solutions in each of the four challenge areas are presented as 'vista diagrams'. The vistas present solutions that are available now, in the near term or that are on the horizon. These diagrams will be the subject of animated discussion; they are incomplete and open to constant revision. Indeed, IChemE recognises that step changes can occur and that the vista can alter dramatically. Readers should not be overly concerned at this. The rich variety of solutions suggested is a compelling illustration of the possibilities offered by the profession. The institution encourages chemical engineers from all sectors around the world to identify the areas of the vistas that align with their activity.

IChemE recognises that the capability to deliver process solutions that maintain or improve quality of life is shaped by factors beyond science and technology. In most parts of the world, free market orthodoxy dictates that little progress can be made unless the economic conditions are right. Governments set – and often change – policy in order to stimulate (or discourage) economic activity, and the sectors where chemical engineers work are heavily influenced by these political choices. Furthermore, prevailing public attitudes also determine the viability of a particular solution. These externalities are discussed along with the need to engage with opinion formers from a position of influence based on sound science and best engineering practice.

This report puts forward a clear-cut plan in the form of eight tangible actions that IChemE will pursue. These actions will support the international chemical engineering community as it strives to deliver safe and sustainable process solutions. *Chemical Engineering Matters* will provoke debate, arouse interest and alert people to the power of a discipline that has shaped, and continues to shape, the world in which we live.

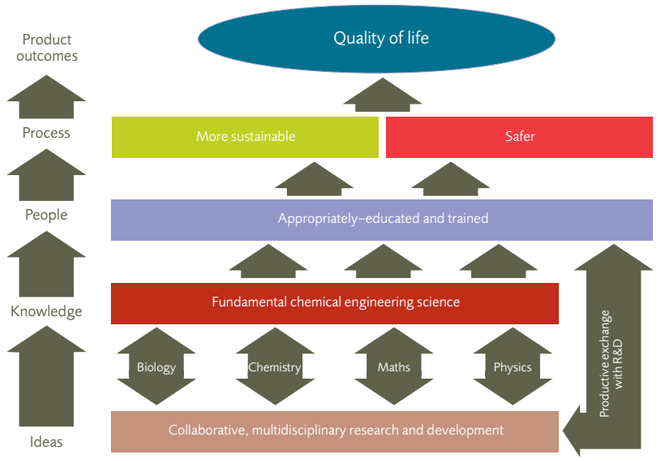


Figure 2: Chemical engineering and quality of life

The fundamentals: safety and risk

The *Roadmap for 21st Century Chemical Engineering* committed IChemE to work with government, regulators and other stakeholders to build a common understanding of risk issues.

The roadmap also emphasised the importance of closer engagement with business leaders, regulators and other professional bodies with the aim of developing cultures that deliver real improvements in safety, health and environmental performance. These objectives remain key to our future work programmes. Safety and risk management are fundamental core values, which chemical engineers must apply in every aspect of their work, irrespective of the sector. Continued promotion of a wider understanding of process safety is central to this ambition.

Good regulation, which is enabling in nature and strikes a balance of what is reasonable and practical to reduce risk, is important for all process industries. IChemE supports a non-prescriptive, goal-based approach to process industry regulation where the legal duty lies squarely with the organisation that creates risk and benefits from it. In the high-hazard industries effective regulation also plays an important role in establishing and maintaining public confidence.

Everyone employed in the process industries must play their part in managing risk, but the chemical engineer's role is particularly important in relation to process safety. Failing to manage process safety risks has led to major catastrophes in process industries around the world. In 2008 IChemE launched a new training offer addressing the fundamentals of process safety and also developed a comprehensive professional development programme concentrating on human factors in process safety. A proactive approach to sharing lessons learned from process safety failure, and success, is a key part of IChemE's work. The *Hazards* symposium remains an important fixture in the institution's event calendar and is now becoming a recognised and well-supported international event, having been held in both Malaysia and Australia. A new partnership with the Mary K. O'Connor Process Safety Center, based at Texas A&M University, will provide further international exposure for the *Hazards* brand. The *Loss Prevention Bulletin* has been updated to become the key publication for sharing learning and good practice among those who are engaged in process safety.

In 2012, the Organisation for Economic Co-operation and Development (OECD) published new guidance on corporate governance. Leadership on process safety from the very top of organisations is essential for successful and sustainable business performance and IChemE will work to support the adoption and implementation of the guidance across the global process industries.

To underline the fundamental nature of process safety competence within chemical engineering, IChemE has developed a new qualification for process safety professionals. The associated registration 'Professional Process Safety Engineer' will provide practitioners with a recognised, respected qualification at the same professional level as Chartered Engineer or Professional Engineer. IChemE is proceeding with a phased roll out of its international safety centre, which will provide the overarching framework for all of the institution's safety and risk activities. The IChemE Safety Centre (ISC) will offer a forum for knowledge exchange and the promotion of best practice, whilst at the same time bringing a stronger level of cohesion to all of the institution's safety activities and programmes.

IChemE will work to develop new competences in risk communication. Risk assessment tools provide effective means to measure and manage risks and to communicate with other engineers. Given the importance of the solutions which engineers provide to society, meaningful and comprehensive dialogue with stakeholders is essential. The institution will develop meaningful engagement about how we manage and reduce, but never eliminate, risk in order to deliver sustainable solutions.

The fundamentals: education, training and skills

IChemE accredits Masters and Bachelors degree programmes at 54 universities in 14 countries around the world.

The accreditation process is not prescriptive; rather it specifies the learning outcomes required of today's chemical engineering graduate. The profession continues to evolve rapidly and nowhere is the need to take account of change more important than in academic and professional formation. New graduates must acquire the skills to perform in a wide variety of roles across the four challenge areas. Industry requires graduates who are equipped with the knowledge, skills and personal attributes to function at a high level and make a difference early in their employment. Graduates must demonstrate a high-quality academic grounding in chemical engineering principles. IChemE's accreditation guidelines are reviewed regularly in response to changing international trends. This flexible and adaptable stance will continue.

Accredited degrees provide graduates with a clear pathway to qualification as a Chartered Chemical Engineer (CEng). Chartered status remains the gold standard of IChemE membership, bringing with it international recognition and respect. In 2014 there are over 11,800 Chartered Chemical Engineers worldwide.

In addition to its higher education work, IChemE supports employers and trainers across the talent pipeline. Its *whynotchemeng* campaign has seen considerable success with applications to study chemical engineering first degrees in the UK having more than doubled since 2007. The campaign has raised the profile of chemical engineering in different industries. The UK intake has reached record levels and *whynotchemeng* materials are also used to promote chemical engineering in Australia and South East Asia. The campaign will be refocussed in response to the skills demand in different countries and sectors and with a new emphasis on retention. IChemE will work to keep the best chemical engineers in the chemical engineering profession.

IChemE is strongly committed to diversity in the engineering professions and strives to avoid stereotyping. Today, more than a quarter of chemical engineering undergraduates are female. Men and women enjoy similar success rates in the application process for Chartered membership.

IChemE is dedicated to securing a steady flow of highly-skilled and motivated chemical engineering graduates and postgraduates. In addition, industry also requires highly-skilled and competent technicians. IChemE offers two categories of technician membership and it will continue to work closely with other science and engineering bodies to raise the profile of these key individuals. The institution also works to ensure that the labour force is continually up-skilled, re-skilled or able to maintain knowledge so as to remain at the cutting edge of technology in a fast-moving landscape. The institution supports accredited company training schemes at over 70 global employers alongside a diverse offer of more than 80 training courses in both technical topics and transferable skills. IChemE will continue to provide high-quality professional development, training, and support for the chemical engineering community in response to the challenges and potential solutions described in the four vistas.

IChemE has also identified a need to support and develop future academic leaders, thereby ensuring world-class undergraduate tuition and productive engagement in collaborative, multidisciplinary research.

Building on progress to date, in 2014 IChemE has started to develop a global, professional learning community by enhancing its accreditation, qualification, initial professional development and continuing professional development offer.

The fundamentals: chemical engineering research

Chemical and process engineering will be at the forefront of tackling many of the world's tough challenges. On an international scale the need is clear.

The European Union's 'Horizon 2020' programme, for example, highlights a set of societal challenges that include secure, clean and efficient energy; food security and the bio-economy; smart, green transport; and resource efficiency – along with key enabling technologies such as advanced manufacturing and processing, biotechnology, and smart materials. All of these require chemical engineers' skills and chemical engineering tools. IChemE will help ensure they are applied.

Like other disciplines, chemical engineering is being subjected to huge changes. Process technology, transport processes and the classical unit operations will remain at the core, but chemical engineers must pay more attention to molecular transformations along with biological systems and concepts, while fully exploiting new tools like molecular modelling, quantum chemistry and synthetic biology. The concepts of systems thinking will provide a broad integrating framework. The boundaries between research and implementation and science and engineering will become increasingly blurred. Chemical engineers manipulate molecules, as well as scaling up processes and optimising economic and environmental performance.

Above all, chemical engineers understand processes. This understanding brings benefits in many fields; from traditional chemical processing and design, to business, financial and other processes – from the nanoscale to the level of the global ecosystem. Chemical engineers are found in many walks of life, but they also operate in a multidisciplinary context. IChemE will encourage the application of innovative thinking to diverse fields, nurture closer links with other disciplines and celebrate success across the spectrum. Chemical engineering excellence can transform businesses and IChemE will publicise and advocate transfer of best practice across industries and organisations. Process innovation must be of equal importance to product innovation.

This places big demands on practising chemical engineers, and on those who educate them. Undergraduate courses and postgraduate training need to cover a wide range of topics, while ensuring that the fundamentals of the subject are solidly embedded and that research and teaching are linked for mutual benefit. The discipline must adopt new concepts and integrate them into curricula, so that finally, innovative and more sustainable processes will break through into industry. IChemE will press for adequate investment in the university base, for recognition and incentives for first-rate teaching as well as first-rate research, and work to foster more productive, multifaceted and effective relationships between the research base and industry.

The number of young people wishing to enter the discipline is growing. This presents a new challenge. Finding the right people to teach them will be tough. In industry, chemical engineers are often very well paid. Pursuing a career in chemical engineering education and research is viewed as a passion, rather than a path to a large salary and material wealth. IChemE will work with universities to persuade some of the brightest and best young chemical engineers to consider the academic world for part of their careers. The institution continues to support the dissemination of academic research at conferences such as *ChemEngDayUK*, *Chemeca* and the *Symposium of Malaysian Chemical Engineers*.

IChemE also recognises that in an era when much of the world is emerging from the severest economic downturn since the 1930s, public and private funding for chemical engineering research will be harder to obtain. In the face of this challenge a new mood of optimism is required along with a willingness to publicise and promote the profession and the difference that it can make, more consistently and more compellingly than ever before.

This report has identified a huge range of possibilities where chemical engineers can shape the future. IChemE will work to identify shining examples of chemical engineering research that offer real potential to change lives. It will act as a broker between the researchers, funding bodies and industry to build a confident and outward-looking international chemical engineering community that will play its part fully in building a more sustainable future.

In 2014, IChemE continues to support work being carried out by past president Sir Bill Wakeham, benchmarking chemical engineering research.

The sustainable **water vista**

Water is fundamental to life, but it is a limited resource. Ensuring that people have access to clean water is a major global challenge.

More than a billion people have inadequate access to a clean, safe, treated water supply. Population growth and industrialisation are putting increasing pressure on water supplies. Water scarcity is being aggravated by interrelated factors including environmental problems – eg desertification, salination and pollution and climate change – as well as over-extraction and large-scale national and international water diversion. Traditionally the water industry has relied on civil engineering to solve its challenges, but chemical engineers are being increasingly relied upon to provide advanced technology solutions. There are opportunities to improve the sustainability of municipal and industrial water supplies.

Recycling and reusing water

Chemical engineers have an essential role to play in resolving the challenges associated with recycling wastewater and reusing 'grey water' in industrial and chemical processes. Cost-effective and robust technologies are needed that recycle water and treat and dispose of associated byproducts, such as concentrated saline.

In the near- to mid-term, chemical engineers will also be able to support the development and implementation of technology and strategies that facilitate access to clean municipal water supplies, that lead to improved water conservation, and that process water in more energy-efficient ways.

Producing clean, safe water, making it readily available and improving sanitation and human waste management are significant global public health challenges. Sustainable desalination to provide clean, safe water will feature increasingly in some regions and chemical engineers will play a key role in the development of more energy-efficient desalination processes.

Chemical engineers will also play a vital role in reducing water losses by improving infrastructure, processes and process technology in a variety of settings, ranging from agriculture, oil and gas extraction and mining to process industries and the provision and distribution of potable water. IChemE will work to highlight the importance of sustainable chemical engineering in the water sector.

Policy, social awareness and understanding

The public needs to be educated to understand the pressures that are placing reliable water supplies at risk. Improved awareness of concepts such as a water footprint and virtual water will aid understanding and will, in turn, lead to more responsible use of water. Different countries have different needs, demands and challenges, however, so there must be support to facilitate understanding, as well as a sharing of best practice and new ideas, at global, regional and local levels. Some regions may choose to introduce universal metering and adopt pricing policies that promote responsible water use.

IChemE will work to highlight the importance of sustainable chemical engineering in the water sector.

Chemical engineers can support growth by engaging with decision makers to ensure there is a strategy to implement improved process technology and practices. More effective use of process audit and control will identify weaknesses and focus improvements. IChemE will proactively communicate progress in this area.

Maximising the value of waste

The amount of municipal and industrial wastewater is increasing. Domestic sewage is a growing problem in rapidly-expanding urban areas; and industrial wastewater may contain harmful contaminants as well as valuable chemicals. Dealing with wastewater is costly but, where not addressed properly, it can have a significant impact on the environment.

Using specialist technology in the treatment, reuse and recycling of water can offer significant cost savings in terms of the quantity of water used, reduced waste discharge and other cost benefits. Water treatment technologies can be used to extract commodities, including nitrates, phosphates and biogas from sewage sludge and to recover valuable substances, such as trace metals, salts, organic acids and rare earth elements from industrial effluent. Demand for recovered materials will increase as global demand continues to drive up commodity prices.

There will be a greater adoption and development of technologies to recycle process water in industrial plants. Advanced digestion, granular treatment processes, fixed-film biomass reactors, anaerobic ammonium oxidation processes and membrane bioreactors all have important roles to play in effluent treatment.

The energy and water industries are likely to become more integrated and there will be greater multi-disciplinary working and collaboration. Electricity is already produced from the co-digestion of sewage, industrial effluent and domestic waste. Biofuel cells may give access to electricity generation from wastewater, and low-grade heat from power plants and solar power may be used in desalination, for example, using membrane distillation.

Process safety and efficiency

There is a need to ensure process and product safety throughout the water network. Industrial processes, ranging from mining and hydraulic fracturing to manufacturing all carry inherent, but manageable risks. These may be environmental risks in the case of unexpected/uncontrolled release, but they may also be related to the processes and systems, for example, high energy and high pressure. Chemical engineers will play an essential role in a wider deployment of advanced, intelligent systems for in-line monitoring throughout entire systems and networks. Chemical engineers will play a role in all of these areas, working to design and implement processes; however, appropriate regulation is essential.

Improved industry practice, supported by innovative chemical process technology and greater public engagement, will drive stronger performance in water management with a renewed focus on the environmental aspects of water on our planet, protecting catchments, sustaining rivers and working towards rehabilitation and remediation of ecosystems.

The water vista diagram sets out the opportunities for chemical engineers in securing sustainable water supplies and will be used as a framework for further discussion and priority setting.

The sustainable energy vista

Society needs fuel for heating, cooking and transport. Electricity is required to power industry and commerce, operate equipment and light our lives. Demand is increasing rapidly. Not only is the world's population inexorably rising, but global development and industrialisation is making that population more affluent and, as a result, more energy hungry.

Meeting this dramatic rise in demand presents a crucial challenge in the decades ahead. The main energy sources on which humanity has relied to date are finite and often susceptible to geopolitical flux. On top of this comes the climate change challenge and the need to drastically reduce emissions of greenhouse gases, chiefly generated by burning fossil fuels. Future energy solutions must be sustainable with regard to their impact on the environment and consumption of resources, as well as financially affordable. This is a challenge for all of society to confront, including chemical engineers and the process industries.

There is intense competition for mineral and biological resources. This challenge requires urgent attention and it is imperative that a long-term view is taken when assessing the options available and their environmental impacts. Short-term thinking is no longer acceptable. Scientists and engineers must rise to the challenge, working in integrated teams to improve current energy systems and processes while developing new innovations.

IChemE recognises the need to promote greater energy efficiency with step-change improvements in existing processes. In practical terms, this demands the development of advanced manufacturing processes that use resources as efficiently as possible while reducing energy consumption to a minimum. Linked to this is the need for smarter energy management, with a flexible grid that delivers energy to where it's needed, when it's needed and new and effective ways to store energy when we have a surplus – this is particularly important as the reliance on intermittent renewable energy sources such as wind and solar increases.

Sustainability – people, perceptions and processes

Humanity cannot continue to consume finite resources and generate waste at current rates. The sustainability challenge of living within the limits of planet Earth without compromising future development must be solved. This requires a paradigm-shift in lifestyles, both in terms of behavioural and practical changes. How will this be achieved? What role will technology play? And how can chemical engineering make a difference?

As well as contributing to tomorrow's solutions, chemical engineers must make the case for greater and more proactive action to counter the impact of ever-increasing resource demand.

IChemE recognises the need to promote greater energy efficiency with step-change improvements in existing processes.

Role and needs of policy and society

A sustainable energy strategy must benefit the economy and the population at large as well as the environment. The pace of change will vary from nation to nation. Developed countries, which have already capitalised on the use of previously-abundant natural resources, must take the lead using their established knowledge and infrastructure to drive change. IChemE will support and encourage sustainable progress, avoiding and learning from past mistakes. Making this happen requires international consensus that often proves elusive. Nevertheless, we can act today to reduce the impact on the planet and address the uncertainties and instabilities that have the potential to spark global conflict. IChemE will work with kindred bodies around the world to demonstrate the value of sustainable chemical engineering.

The future energy mix

Ultimately, to uphold and improve quality of life in a sustainable way we need widely-available carbon-free or ultra-low carbon energy. This will eventually entail using solar energy to power our homes and industries, distributed internationally and stored in advanced energy storage systems to give the system resilience.

There is a seemingly unstoppable enthusiasm for personal mobility, while the movement of globally-traded goods remains an economic necessity. Since we cannot reduce the energy needed for personal and commercial transport, we must decarbonise it. This may be achieved using a mix of electric and fuel-cell propulsion and fuels derived from biomass (food and agricultural wastes) and cellulosic crops grown on marginal land. Making the transition to a low-carbon economy will involve implementing a raft of interim solutions. Fossil fuel use remains unavoidable in the short- to medium-term, but the impact can be greatly reduced by implementing carbon capture and storage (CCS) technology. In some parts of the world new nuclear power plants, including next-generation technologies based on the thorium fuel cycle and eventually fusion, will provide a major component of the energy solution. Greater use of renewables including wind, wave and tidal power presents new challenges. The variable, yet forecastable, nature of renewables will drive new thinking of both demand- and supply-side power management.

Carbon capture, storage and use

Carbon capture is proven technology, but in 2014 there is no large-scale commercial CCS activity in the power generation sector. CCS can reduce carbon emissions, but it reduces operational efficiency, often to the detriment of the economics of the process overall. Carbon capture and utilisation (CCU) may also play a role, using CO_2 as a feedstock for chemical processes, microalgae or plant growth and mineral carbonation. Careful attention must be directed towards energy balances and rigorous life cycle analysis for new processes. IChemE acknowledges that these technologies offer a short- to medium-term solution that will support ongoing fossil fuel use, but their adoption depends heavily on carbon pricing and government intervention. Equal effort must be directed towards the development and widespread deployment of truly sustainable and commercially-viable processes based on renewable energy.

Tight gas and other 'unconventional' assets

Tight gas, including shale gas and coal bed methane, has attracted considerable attention since 2007 and these assets offer improved energy security, with a lower carbon footprint and new routes to petrochemicals. IChemE believes that health, safety and environmental risks can be managed effectively via operational best practice and appropriate regulation. The sustainability of tight gas exploitation is a matter of animated debate amongst IChemE members and it has been argued that global carbon targets cannot be met if new build of unabated gas-fired power generation is allowed to proceed unchecked. The role of government policy is pivotal here and IChemE will continue to stimulate informed debate amongst its membership and more widely.

Energy storage and distribution

The transition to a low-carbon economy brings new challenges in the storage and distribution of energy. Solving the puzzle is likely to involve a combination of advanced batteries and super capacitors for stationary and mobile applications in domestic and commercial settings. Effective energy storage on a large scale can

smoothe the peaks and troughs in supply and demand and improve predictability. In many parts of the world this will require major upgrades to transmission infrastructure and distribution networks. Surplus energy can be used to generate hydrogen through multi-cell electrolysis. Where local geography permits, pumped storage and air compression reservoirs can also be used to store power. Batteries also offer significant potential and IChemE will encourage the development of improved battery technology, mindful of the limited availability of some metals and minerals through genuine scarcity or geopolitics.

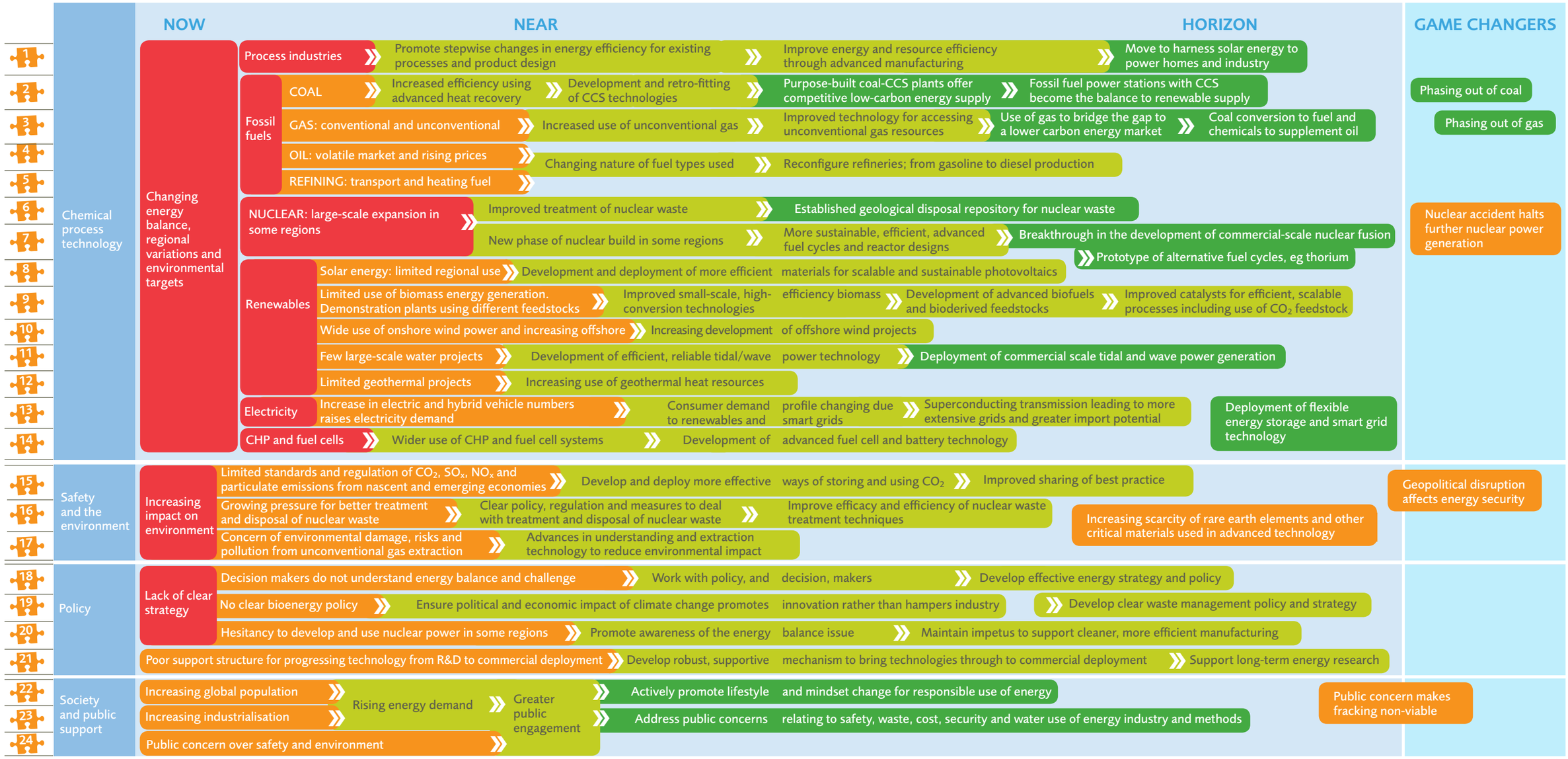
Safer, more efficient processes

Existing processes can be rendered sustainable by making them more energy, and resource, efficient and by further improving the front-end efficiency of electricity generation. Better use can be made of waste heat. Further short-term gains can be achieved through process integration and more integrated supply chains. IChemE will continue to stimulate debate and promote sharing of best practice in these areas. It will work with industry and policy makers to secure a shift towards cleaner, more efficient manufacturing. Support for forward thinking needs to come from all levels, embracing systems thinking and life cycle analysis.

Continuous improvements in safety and environmental protection standards are required. The tragic events following the 2011 earthquake and tsunami in Japan and the explosions at the Fukushima Daiichi plant graphically illustrated how far-reaching the consequences of an accident can be. IChemE will work to secure outstanding safety performance in the energy sector.

The R&D landscape

All over the world people need secure and affordable energy supplies. IChemE asserts that these supplies must also be sustainable. In 2014 this puzzle does not have an obvious solution. Energy strategies require vision and long-term thinking supported by a vibrant research base. The institution will work to secure adequate funding for energy research programmes from public and private sector sources. However, success also depends on the capability to translate research into innovation. IChemE will continue to encourage the evolution of effective mechanisms that move innovative energy technologies from the research phase through demonstration to application and commercial deployment. The energy vista diagram gives an indication of the diverse possibilities for chemical engineers in the energy space, and will be used as a framework for further discussion and priority-setting.



The sustainable food vista

Major improvements in farming during the latter half of the 20th century have ensured that, to date, global food production has kept pace with population growth. However, the combined pressures of a growing population and improved living standards in the developing world mean that there is a demand for more food and for protein-rich foods that are water, and land, intensive.

Land and water are finite resources with competing demands upon them. Furthermore, climate change may impact negatively on traditional food production methods and on land and water availability.

Population pressure and the demand for more food has led to a greater awareness of the challenges faced and to an application of scientific and engineering solutions to food production. It is possible to meet demand without increasing energy, water or land use, as well as minimising waste production and safeguarding the ecological landscape. There are opportunities for chemical engineers and other disciplines to work with the agricultural industry to solve problems throughout the global food chain.

Minimising environmental impact

Food production is an energy- and resource-intensive process and modern agriculture accounts for 30% of greenhouse emissions.

In future, it will be necessary to ensure that the land and water from which food is obtained maintains the right qualities to produce food sustainably. Appropriate fertilisers will need to be used. Environmental pollution will need to be minimised and the impact of plant and animal diseases taken into account.

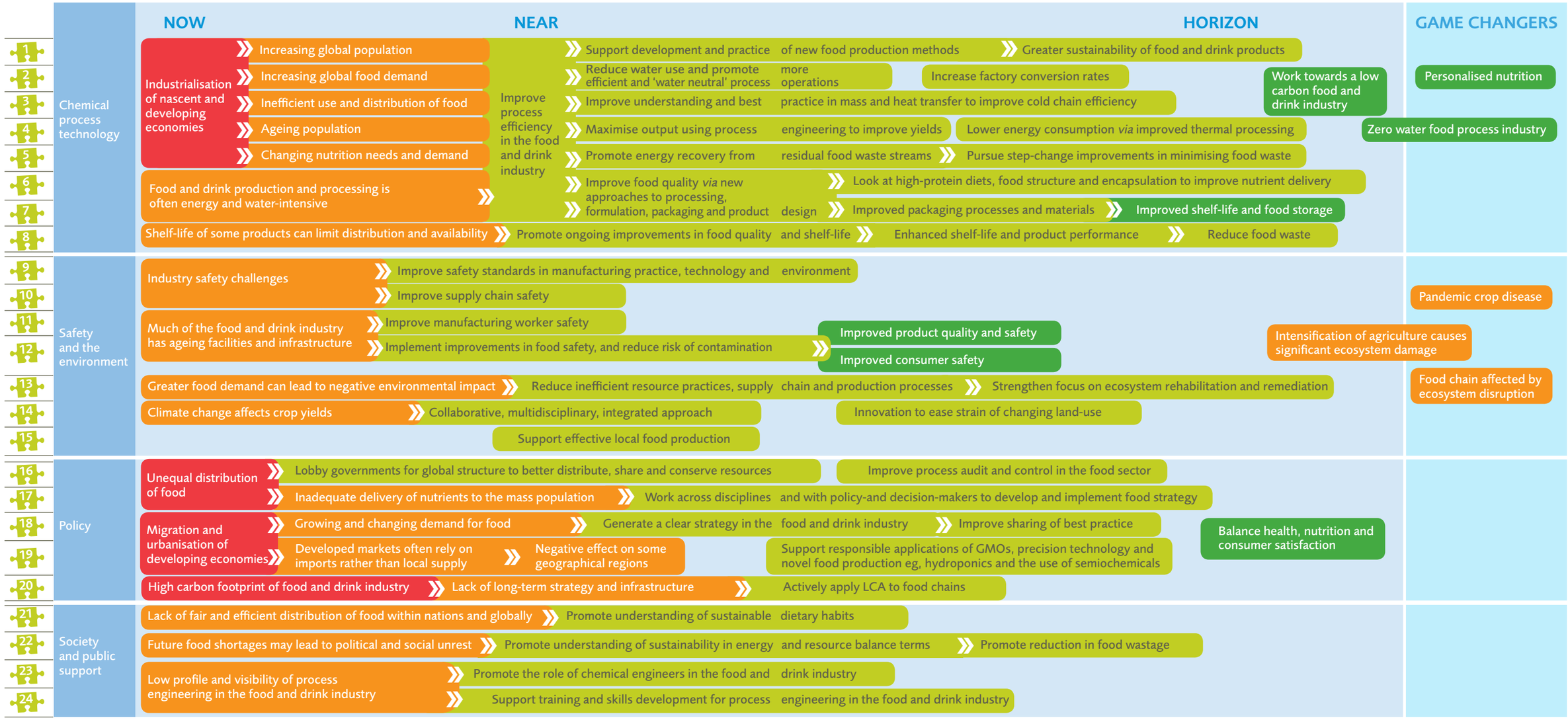
Chemical engineers can help to meet the growing and changing demands for food by supporting the development and implementation of novel, low-impact agricultural methods that use less energy, water or land, such as hydroponics, greenhouses that are CO_2-enriched, and through the use of semiochemicals.

In considering life cycle analysis and overall environmental impact of food, the public and the food production industry have a responsibility to consider factors such as energy and water use.

Efficiency and waste

Waste in the food supply chain, from field to consumer, is significant – approximately 30–50% of all food grown worldwide is lost, either before or after it reaches the consumer. In the move towards greater resource efficiency, both agriculture and the food and drink manufacturing industries must improve the efficiency of production.

Waste should be minimised as far as possible, but waste that is created should be re-used or recycled, through composting. Where this is not feasible, energy recovery from food waste through incineration, anaerobic digestion, pyrolysis,



IChemE supports the development and application of new processes and technologies to minimise the generation of waste.

gasification or production of fuels and chemicals through fermentation is preferable to landfill.

Strategies to make more effective use of food waste, include using waste materials to generate energy, need to be developed. In particular, strategies need to be developed to manage the large quantities of wastewater that are generated during processing.

IChemE supports the development and application of new processes and technologies to minimise the generation of waste and to maximise the use of the waste that is produced. New research strategies are needed to optimise the use and reuse of waste streams.

Food security

Global inequalities in food availability exist and there are regions of significant population density that cannot be supported by the land around them, often due to climate and political unrest. More effective transportation and storage of food and drink is a partial solution to this challenge, but more could also be done to enhance local production. Where feasible, chemical engineers can play a role in establishing local water supplies for drinking and irrigation.

Whilst ensuring that food is delivered to where it is needed is the responsibility of decision makers at national and international level, the food industry can help in identifying where sufficient food has been distributed. Greater transparency will assist in improving access to food for all. As food storage and shelf-life improves this should also improve consistent access to vital food and nutrition for the population as well as reducing waste caused by spoilage.

Non-food crops offer significant potential for new raw materials with applications in the areas of energy, construction, fibres, packaging, pharmaceuticals and speciality chemicals but this diversification must be balanced against the need for land use to grow food. Chemical engineers should work with the farming industry and other science and engineering disciplines to optimise agricultural output while working to reduce escalating energy consumption and environmental degradation.

Food and agriculture industries will increasingly need to work alongside key decision makers on regional- and global-level strategies to increase innovation in food production. These strategies will complement regional models to optimise efficient and effective agriculture. Some governments already have policies in place to ensure food security, with initiatives to support local food production. This is particularly important, for example, in Australia where agriculture is a major part of the economy. Australia is largely self-sufficient in its own food production. It is also a significant exporter to the growing Asian markets.

Process and product safety

Product safety is achieved by applying best practice, process safety and making appropriate environmental considerations throughout the supply chain. Some of these areas are not process safety issues in the traditional sense, but there should be awareness and understanding of all of these issues within the chemical engineering community.

Challenges to the farming industry include better understanding and acceptance of the role that GM crops can play in meeting global food demand, and an understanding of the impact of disease outbreaks within crops and livestock on yield. Greater food production will not be achieved by simply intensifying current agricultural processes, as intensification can lead to larger or more frequent outbreaks of disease and although vaccination, fungicides and other treatments may increase in use, so does nature's resistance to them.

The policy dimension

The role of science and engineering in food production will grow in order to satisfy and manage demand within the limited land, water, energy and raw materials available. This will involve improving current strategies and developing new technologies. In parallel with these developments, chemical engineers must engage with key decision makers and other scientists/engineers in order to apply strategies and technologies appropriately, and to learn about challenges, strengths and pitfalls of these approaches in practice. Promoting awareness of resource limitations and efficiency is essential to meeting demand sustainably.

Although there has been significant resistance from the general public towards genetically-modified crops, there has been some acceptance from farmers of their role and potential. With climate challenges and the demand for more food, genetic modification may play an increasing role in the future of food production. In these circumstances, consideration of the environment, ecosystem and product safety is essential. IChemE will encourage this debate.

The food vista sets out the range of possibilities for chemical engineering in all of these areas and will be used as a framework for discussion and priority-setting.

The sustainable **wellbeing vista**

According to the World Health Organization, 'health' is defined as a state of complete physical, mental and social 'wellbeing' and not merely an absence of disease or infirmity.

Social wellbeing comprises many elements, including living in an environment that is healthy and promotes physical and mental harmony. Chemical engineering plays a fundamental role in facilitating health and social wellbeing and enabling people to live healthy and fulfilled lives. Chemical engineering processes support the design and manufacture of a wide range of materials that make durable and safe homes, consumer goods and other lifestyle products.

In the future, chemical engineers will play an important role in developing and refining the engineering and manufacturing solutions that will help a growing and increasingly affluent and acquisitive population to achieve health and wellbeing, while at the same time optimising energy and resource consumption to safeguard the environmental wellbeing of our planet.

Chemical engineers, members of other technical disciplines, and industry managers have a responsibility to inform the general public of the fundamental sustainability principles, risk and process safety. Effective engagement and good communication is essential to success in the years ahead.

Sustainable lifestyles

The world's population is becoming urbanised and more people now live in towns and cities than in rural areas. In areas where urban growth is rapid, development is often haphazard and can have a detrimental impact on the environment. Furthermore, the requirements of the population for a satisfactory living space, good social amenities and effective transport networks can conflict with the demands of commerce and industry. The future must involve realising the concept of the 'sustainable city'. Urban spaces should be designed and built in ways that will make best use of construction materials. They should be sustainable in production and application, protect the environment, and flexible enough to respond to changes in use or environmental extremes.

Efficient use of energy and resources is fundamental in helping to achieve sustainable lifestyles; and progress to reduce inequality of resource use is necessary to ensure future generations are healthy and enjoy a good quality of life. Developed nations must lead the way by making fundamental shifts in consumption.

By applying the principles of 'green engineering', chemical engineers can help to safeguard the environment and facilitate healthy lifestyles. They should endeavour to apply these principles at the earliest stages in the design of a process or product.

Sustainable industrial design

Industrial design needs to evolve sustainably so that efficiency is improved, ecological footprints are reduced and local needs are met. There is increasing pressure on all chemistry-using industries to improve material and energy efficiency. IChemE believes that chemical engineers should work together and with other science and engineering disciplines to improve the efficiency of processes – for example, by reducing raw material use and/or by designing products from which components can be safely and efficiently recovered, reused or recycled at the end of their useful lives. These approaches will be particularly important where resources are already limited.

In some cases, it will be preferable to identify alternative materials. There is already a growing demand for new products with enhanced properties and such demand will only be met by developing manufacturing processes with greater atom efficiency, reduced ecological footprints, or that use novel feedstocks, including biomass.

By working together, engineers, scientists and manufacturers will be able to learn from successes and failures in order to minimise energy use and resource waste. Life cycle analysis (LCA) is an increasingly useful tool and there are opportunities to further develop its application to map energy, water and resource use. The leadership and systems thinking that chemical engineers bring will be invaluable in realising lasting, sustainable improvements.

Novel approaches in pharma and healthcare

People are living longer, thanks in no small part to developments in healthcare in recent decades. Longevity and the associated demographic shift experienced by all developed nations brings with it new challenges, including how to ensure physical and mental wellbeing into old age, and how to enable a shrinking workforce to support and pay for the needs of older people.

In developed economies, pharmaceuticals have been used effectively to improve public health. In particular, many infectious diseases that were common in previous generations have largely been eradicated. Now, the high-mortality, high-cost illnesses in developed countries are neurodegenerative conditions, cancers, and ailments often attributed to more affluent lifestyles – eg heart disease and type II diabetes.

However, managing infectious diseases remains a challenge. While the health of people in developing countries is progressively improving, large sectors of society are often unable to access basic sanitation and clean water. In addition, antimicrobial resistance is a significant global challenge, and while this problem has long been acknowledged, some infectious agents are now resistant to most current treatments as a result of inappropriate drug use in people and animals and to poor infection control. These challenges mean we need to identify and develop new treatment strategies and regimens.

IChemE will actively promote the development of biological engineering as a professional discipline.

The pharmaceutical industry is in a state of flux and there is a shift away from reactive treatment of disease and towards prevention-based medicine and healthcare. There are significant cost pressures associated with new products to market, and responding to changing legislation is a constant challenge for the healthcare industry. The pharmaceutical pipeline is long, expensive and has high attrition rates. Failure to bring new active pharmaceutical ingredients (APIs) to market reduces revenues as other products come off patent and there is less money to invest in research and development. Chemical engineering expertise will help reduce the complexity of API manufacturing processes and make them easier to scale up and control. Chemical engineers can also improve cost effectiveness in a whole range of areas from vaccine manufacture and oral dosage formulation to validation and the determination of overall equipment effectiveness. IChemE will maintain effective support for chemical engineers in the pharma industry.

The growth of biological and biochemical engineering

Many chemical engineers have yet to recognise the possibilities that exist in the bio domain, but biological and biochemical engineering offer great health and wellbeing potential. Systems thinking to bridge the gap between biology and process engineering will facilitate the development of personalised medicine, and more targeted, cost-effective medicines and therapies. In the future there will be greater use of biosensors, and engineering will play an important role in the growth of biological materials for transplant organs, tissues and bone.

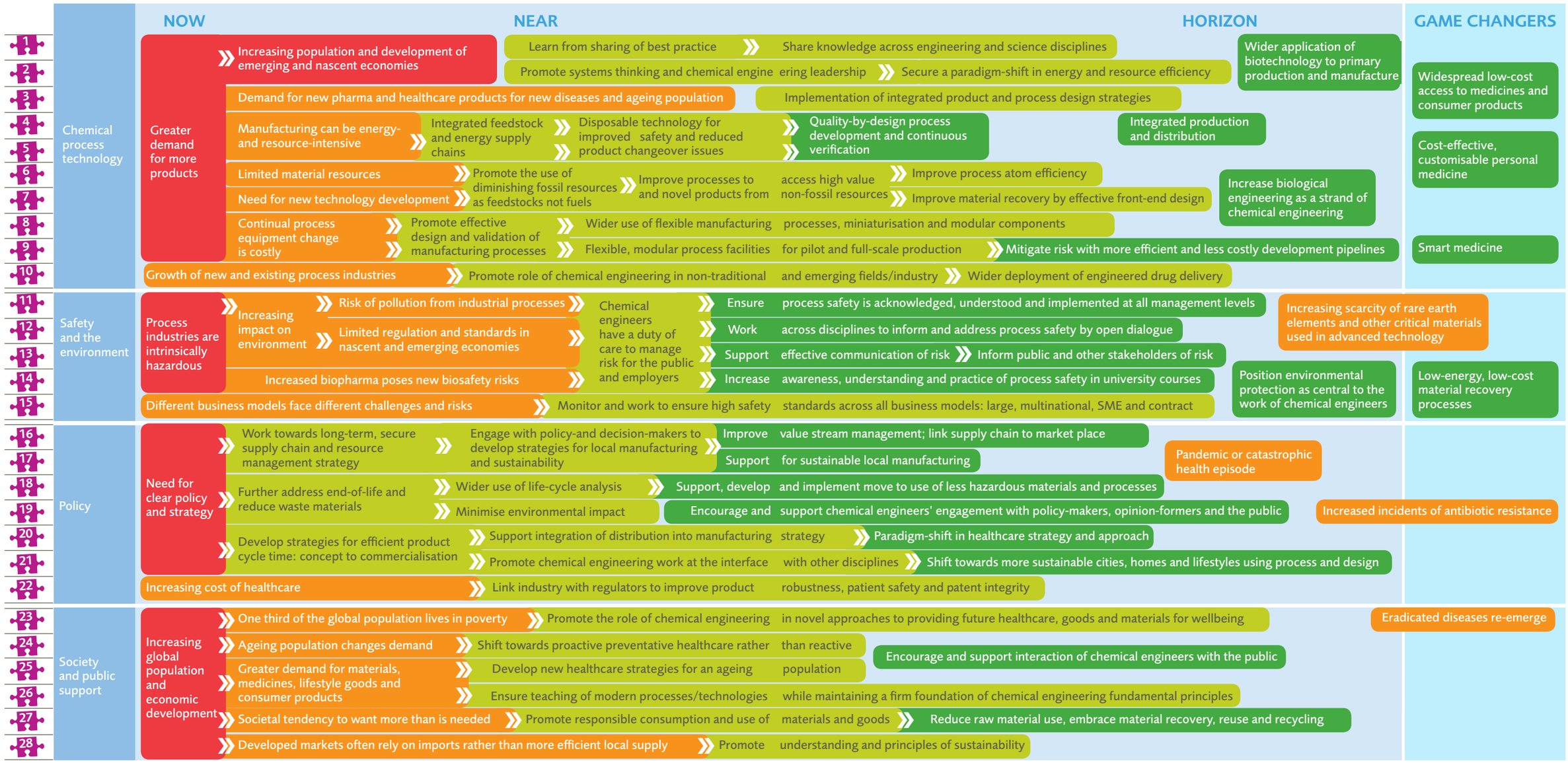
Biochemical engineering has considerable potential for application in manufacturing processes that will use more sustainable feedstocks and generate novel products. However, there is still considerable work to be done to develop and grow the area of biological and biochemical engineering. IChemE will actively promote the development of biological engineering as a professional discipline in its entirety and facilitate interaction between all scientists and engineers involved in this diverse field.

Process safety – people and the environment

Maintaining good health is not only about providing healthcare and material goods. It is also about having healthy and safe living environments. It is essential, therefore, that the concepts of process safety and environmental responsibility and risk are communicated by chemical engineers to wider groups, including the public, policy and decision makers and non-governmental organisations (NGOs).

Process safety is improved by learning from accidents, near-misses and disasters, as well as by sharing and learning from successes. It is essential that process safety accountability is defined and championed at board level.

IChemE will seek, in conjunction with other relevant professional bodies, to exert a greater influence on the process sector, regulators and academia to develop and use new ways for cost-effective and sustainable risk reduction. The health and wellbeing vista diagram suggests the areas of intervention and will be used as a framework for further discussion and priority-setting.



External influences: politics

IChemE members often express frustration at a perceived lack of scientific understanding and engineering knowledge amongst politicians.

However, the institution counsels against the adoption of antagonistic positions in preference to a programme of constructive engagement based on sound science, good engineering practice and the pursuit of clear policy outcomes.

The work of government is not easy and engineers who seek to influence policy making must recognise the short-termism that is a consequence of electoral cycles. A majority of politicians, regardless of ideology, pursue power to bring about change, and most embark on this course with noble intentions. This necessitates fighting and winning elections, placing them at the mercy of an increasingly-discerning electorate and also the factions and power bases within their own parties. Politicians must win the popular vote, thus they need to be 'popular'. Many of the outcomes that scientists and engineers advocate (eg nuclear power, wastewater reprocessing or the adoption of genetically modified organisms for food crop protection) are not 'popular' and it helps if this paradox is understood from the outset. IChemE will help chemical engineers and their employers to articulate the positive benefits of their work.

IChemE will urge governments to make better use of the professional engineering community.

Advocacy and engagement

Huge sums of money and political influence are traded in order to secure preferred policy outcomes. *The New York Times* reported that funds raised by presidential candidates, their respective parties and supporters in the 2012 US elections topped US$1.6bn. In 2014 the world's largest public relations firm, Edelman, has 4,800 employees worldwide with a global turnover in excess of US$741m. Trade bodies and other lobby groups, including engineering institutions, also work to influence political decisions, with the aim of shaping policy to favour the development of one or more technology solutions; but the resources deployed are tiny in comparison. IChemE continues to support limited programmes of advocacy and engagement with policymakers. These must be based on clear objectives and requests for specific policy goals.

Evidence-based policy making is a much-repeated mantra, but there are also instances where policy is implemented based on carefully-selected evidence. The credibility of any given body of evidence is of paramount importance and IChemE is well placed to comment and advise on the basis of its independence and rigorous professional standards. However, the institution is not alone. Historically, this area has seen conflict between different engineering disciplines and sometimes between subsets of a single discipline – chemical engineers included. This should be avoided wherever possible, and IChemE supports broad alliances bringing together different groups from across the science, technology, engineering and mathematics (STEM) spectrum in pursuit of policy outcomes that are supported by the STEM community as a whole and in the wider public interest.

Systems thinking

The delivery of much public policy has an engineering dimension that needs to be considered at the start of the policy-making process. Policy-making can benefit from the contribution of chemical engineers, who bring systems thinking to bear on policy challenges. IChemE will urge governments to make better use of the professional engineering community and encourage the professional registration of engineers within the civil service. Where appropriate, chief engineering advisors should also be recruited to government departments in addition to, or instead of, chief scientific advisors.

Finally, it is worth noting that chemical engineers are generally voters too, and some, albeit a minority, are engaged in the political process at a personal level. It is often said that politics is too important to be left to politicians and IChemE will support and encourage those members who seek to connect with their elected representatives and/or work within their local or national political systems. Chemical engineering needs good politics and politics needs good chemical engineers.

External influences: the economy

The energy and chemical process industries are undergoing huge changes worldwide.

After falling 1.5% between 2008 and 2009, global oil consumption recovered to reach an all-time high of 90.4m barrels in 2013. One third of this growth came from China, which now uses more than 11% of the world's oil. Global natural gas consumption has rebounded reaching a record 117tn ft^3 in 2013. In a new development unforeseen at the time of IChemE's 2007 roadmap, the International Energy Agency has suggested that there may be as much recoverable gas in unconventional formations as there are in conventional ones. Elsewhere on the energy landscape, the number of new-build nuclear power plants started in 2010 reached the highest level since 1980 and global wind power capacity exceeded 318,000 MW in 2013.

In 2012 the top 30 chemical-producing countries had a combined turnover exceeding US$3,800bn. For the first decade of the 21st century the EU was the clear leader in world chemical sales, but the region has lost ground and today 12 of the 30 are in Asia, accounting for 50% of world chemical sales. This has prompted calls for new regional manufacturing strategies based on indigenous resources in Australia and the US.

Concern over climate change has driven the emergence of emissions trading schemes (ETS) – a political attempt to internalise the environmental costs of greenhouse gas emissions. In 2013, the traded volume of the global carbon market was 10.1 Gt, down slightly from the 2012 record high of 10.7 Gt. The value of the world carbon market dropped for a third consecutive year in 2013 to US$56bn. Europe, with the most advanced carbon market has seen prices fall to €5 per tonne in January 2014, although this is forecast to rise. Carbon pricing continues to prove controversial in many regions, particularly in the US where moves to secure a cap-and-trade bill stalled in 2010. Japan has pulled back from plans to implement a mandatory ETS in 2013 and South Korea is also wavering. Australia launched a carbon tax in 2012 at some political cost to the minority government, a pledge to repeal by mid-2014 was made by a new government at the end of 2013. The likelihood of a universal international carbon trading framework seems remote. Nonetheless, IChemE continues to support the principle of emissions trading and remains convinced that the internalisation of carbon costs is required to secure progress in the delivery of low-carbon technologies.

The global labour force reached 4.3bn in 2013, after 17% growth in the preceding decade. The potential labour pool has tripled since 1950 and people of working age (15–64) now account for two thirds of the world's population. Supply and demand are not balanced and the labour force is growing at divergent rates in different regions. For example, one quarter of the world's labour force lives in South Asia but the region's share of the global economy is just over 3%. When combined with differing approaches to higher education and the number of trained chemical engineers in the labour force, it is clear that the demographics of global and regional potential labour forces will have important implications for the process industries. IChemE is committed to the principle of free trade and the free movement of talent and it will work with governments in all parts of the world to ensure that the pipeline of chemical engineers continues to flow for industry, for educators and for the research community.

Chemical engineers must operate in the context of the wider global economy. They cannot change market trends but they can make a difference. IChemE will support and promote efforts by chemical engineers to drive efficiency improvements, particularly in the sphere of energy saving and waste reduction. The economic outlook remains uncertain and the signals are mixed. The US shale gas boom has aided recovery in some regions although security of supply and geopolitical uncertainty continue. In 2013 the US chemical industry reported the first growth in jobs for a decade but globally, ageing assets pose challenges for the future. Cost pressures led Dow Chemical and DuPont to announce major site closures and global job cuts in October 2012 whilst BASF remained upbeat in its analysis. The optimistic mood around Australia's resources sector has waned, with several projects shelved in the face of falling prices and increased construction costs. Uncertainty is the new norm.

External influences: public acceptance

In the developed world the public was hugely supportive towards technology in the period after the Second World War and this upbeat mood endured into the 1970s.

This positive mindset coincided with a period in history that is viewed by many as the zenith of chemical engineering in Europe and North America. In the 1980s enthusiasm gave way to disappointment and sometimes to outright hostility. More recently, the prevailing viewpoint might best be described as ambivalent.

Over the last 30 years these public mood swings have driven a tendency amongst scientists to retreat into their laboratories. Meanwhile, engineers of all descriptions have never really excelled at promoting their efforts and explaining the value of the work to the person in the street. Chemical engineers have found themselves in a particularly difficult place. The absence of historical heroes with the visibility of Brunel, Faraday or Watt has confined the discipline to relative obscurity. Given the upstream nature that characterises much of the chemical engineer's work, it is hardly surprising that public polling carried out by IChemE has consistently revealed that it is generally unclear, even to the educated observer, exactly what chemical engineering is all about. IChemE members frequently express dismay at this state of affairs because, as this report clearly illustrates, chemical engineering is fundamental to progress in the key challenge areas of energy, water, food and nutrition, and health and wellbeing.

One unhappy area where chemical engineering has been catapulted into the public eye is the sequence of high-profile process safety incidents, from Flixborough, through Bhopal and to more recent episodes at Texas City and Buncefield. Failures in chemical process systems were identified as causal factors in all of these catastrophic events, but interestingly the profession largely escaped the public anger that followed. The operating companies were less fortunate and the reputation of the chemical industry suffered accordingly. Risk is an inescapable consequence of high-hazard process activity; nonetheless accidents can be avoided. IChemE will help chemical engineers to get better at communicating risk to non-experts in a language that can be understood.

Around the turn of the century, STEM communities around the world finally woke up to the image problem and the term 'public understanding of science' entered the lexicon. Scientists were reminded that they had a formal obligation to communicate with the public, and engineers were not immune from a new trend towards greater transparency and openness. At the same time, the concept of corporate social responsibility also became more widely recognised with many global companies publishing sustainability indicators in their annual reports for the first time. These developments were welcomed and actively supported by IChemE.

In 2014 science enjoys wide coverage in the popular media and in literature in most parts of the world. There has never been a better time to raise public awareness of chemical engineering and IChemE will use this report in pursuit of that goal. It will work with the wider chemical engineering community to identify compelling examples of the positive benefits of chemical engineering. At the same time, it will support and train those members who wish to engage with the media or to communicate the benefits of their work to the public at large. The institution will also encourage companies to be more forthright about the value that chemical engineering adds to their business.

IChemE believes that chemical engineering is a force for good. Chemical process technology has delivered massive improvements in quality of life for many centuries and that work continues in all parts of the world. This requires public acceptance and support. IChemE will work to secure public confidence in the profession and tirelessly promote the message: chemical engineering matters.

IChemE will work to secure public confidence in the profession.

Putting the pieces together: eight actions for IChemE

1 Safety

Competence in process safety lies at the heart of the chemical engineering skill set. IChemE will promote a thorough understanding of hazard, risk and risk reduction at all stages in the process life cycle, from design and construction, through operational management and leadership to decommissioning. The crucial role of human factors in process safety will also shape the institution's approach.

IChemE has introduced the new Professional Process Safety Engineer registration which has attracted strong interest from industry. It will continue to develop the IChemE Safety Centre and promote the highest standards in corporate governance for process safety.

The goal of professional chemical engineers is never to put anyone in harm's way as a result of the processes they design and operate.

2 Education, training and skills

Sustaining the chemical engineering talent pipeline is fundamental to IChemE's mission. In order to advance chemical engineering worldwide, the institution must support the supply of appropriately-trained chemical engineers. Through the international review led by Professor Colin Webb, IChemE will review its course accreditation guidelines to ensure that industry, academia and all those who depend on competent and capable chemical engineers have access to the right talent.

IChemE will support a global professional learning community via a new, integrated training and professional development offer, supporting skills development at all levels.

3 Research

Chemical engineering is changing and the challenges the profession must address are becoming more complex. A sharp focus on core chemical engineering concepts and fundamental systems thinking must be maintained. IChemE will work to encourage multidisciplinary working and the effective exchange of knowledge and ideas between the research base and teaching. The interface with industry is equally important.

IChemE will press for investment in applied research at a level commensurate with the excellence of the underlying science. The institution will also work to promote outstanding research that can change lives by supporting and organising technical conferences and events worldwide.

4 Water

Water is essential to life on earth. It is a natural resource, which enables the production of food and energy, provides hygiene and sanitation and operates as the primary link between humanity, climate systems and the environment. Population growth, industrialisation and urbanisation are placing increasing pressure on the water economy.

IChemE will provide additional suport to chemical engineers in the water community and explore new ways of promoting process technology in securing viable industrial and municipal water supplies.

The institution will publish a series of Green Papers setting out the role of chemical engineering in delivering sustainable water solutions and work to raise the profile of the discipline in the sector.

Putting the pieces together: **eight actions for IChemE**

5 Energy

Meeting growth in global energy demand presents a crucial challenge in the decades ahead but there is no universal solution. Fossil-fuels will maintain a central position in the world's energy economy for several decades. However, these resources are finite and the challenge presented by climate change dictates that a paradigm-shift towards decarbonisation and sustainable energy use is needed. IChemE recognises that the contribution from renewables will increase and whilst the institution welcomes this development, it will argue for robust life cycle analysis and promote the fullest understanding of thermodynamics and energy balances for all proposed solutions.

IChemE supports chemical engineers in all parts of the energy economy and the new Energy Centre will develop a platform for the coherent policy positions based on the full range of expertise within the membership.

6 Food and nutrition

The typical human requires around 2,300 kcal/d to support normal healthy living. The chemical engineer's understanding of mass and energy balances suggests that this is manageable in light of current global population projections, but food inequalities are a growing challenge. Distribution and societal factors lie beyond the control of chemical engineers. Nonetheless the profession can exert significant influence over the development of processes and technologies that can reduce waste and optimise the food supply.

IChemE will publish a series of Green Papers highlighting the role of chemical engineering and the positive contribution made by chemicals in sustainable food production and supply from farm to fork.

7 Health and wellbeing

In developed economies the concept of wellbeing is tied to consumption and much of the developing world is racing to imitate this lifestyle. Chemical processes have fed the demand for consumer products for more than a century, and the health of the chemical engineering profession has traditionally been linked to global consumption. Human health and life expectancy are improving as a result of better sanitation, diet, housing and developments in healthcare, but sustainability is a pressing concern.

IChemE will promote the role of chemical engineers in delivering more healthy and sustainable lifestyles. The institution will work to secure better integration between the consumer product and pharmaceutical industries and academe by conducting a review of the challenges and potential solutions in the health and wellbeing space.

8 External influences

IChemE is politically neutral and will adopt an independent position on issues that are viewed as partisan. However, the institution recognises that political decisions, should be evidence based and supported by the strongest possible input from the engineering community. The chemical economy is changing rapidly with the emergence of the BRIC nations and Middle Eastern countries as chemical manufacturers, for domestic consumption and for export. This dictates that different policy solutions will be needed in different parts of the world. IChemE recognises the need to respond to public concerns and engage productively in lifestyle conversations about the impact of chemical processes and products.

IChemE will work with its member groups and local leaderships around the world to develop coherent policy goals that will form the basis of engagement with opinion-formers and policy-makers.

The institution will continue to highlight the role of chemical engineers in improving process efficiency and reducing costs to deliver cheaper and more sustainable products by developing its press office function and social media presence with active member input. The *ChemEng365* blog launched in May 2014 plays a key role in this.

Where do I fit in?

Based on the findings of the roadmap review, *Chemical Engineering Matters* reflects the diverse opinions of IChemE's international membership. Particular emphasis has been placed on areas where chemical engineering has a significant global impact. The report has identified a series of strategic challenges and puts forward ideas on possible directions of travel for IChemE and the wider chemical engineering community in the years ahead. Readers can engage in the next stage of the conversation in several different ways:

- IChemE values feedback from its members on any of the issues raised in this report, but more importantly we urge you take advantage of free membership of our special interest groups (SIGs). The SIGs cover the wide range of topics found in *Chemical Engineering Matters* and provide a regular forum for technical discussion. They can also provide a platform for sharing new research thinking and the latest developments in industry. Please use this report to spark new ideas and set new priorities
- If you are an employer, IChemE can connect you to a wide range of expertise related to many of the process solutions identified in this report. Chemical engineers can help you grow your business.
- **Chemical engineers do not have a monopoly on wisdom and this report will be used as a catalyst for discussion and co-operation with other disciplines. Proposals for collaboration around any of the topics raised are welcomed. Other engineers and scientists are invited to submit ideas for joint meetings and projects.**
- If you work in the government policy-making space at local, national or international level or in the media, you will see that IChemE is an advocate for solutions that will support a safer and more sustainable world. If you think that our members can be a useful addition to your contact book please get in touch.
- Since its launch, reference lines have been introduced onto the vistas and ***tce*** feature articles are referenced to where they fit on the vistas. IChemE encourages all chemicals engineers to identify the areas of the vistas that they can relate to and share this.
- Better still, contact IChemE's policy and communications team to arrange a local workshop to discuss any of the four vistas.

To continue the conversation you can engage with us in different ways:

email: chemengmatters@icheme.org

twitter: @ChemEngMatters and #chemengmatters

or call any of the numbers listed on the back of this report.

Acknowledgements

This report was researched and prepared following consultation with IChemE's global membership, kindred bodies and other stakeholders, in 2012. It has been fully reviewed in 2014, producing this second edition. IChemE is grateful to all those who spared the time to share expert opinion, in particular, members of the special interest group community who were involved with the project.

IChemE would also like to thank all individuals and organisations who engaged with the initiative since its launch and those who continue to embrace the belief that chemical engineering matters.

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