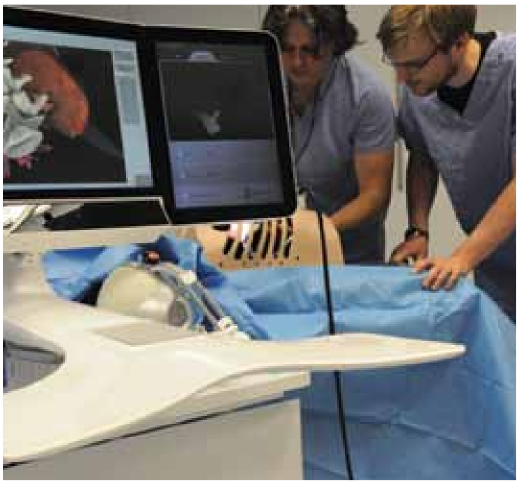
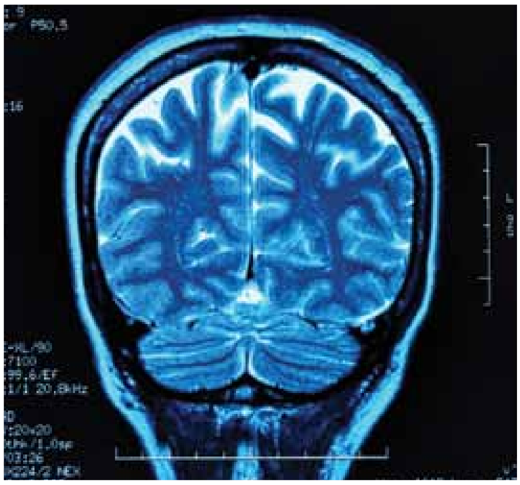
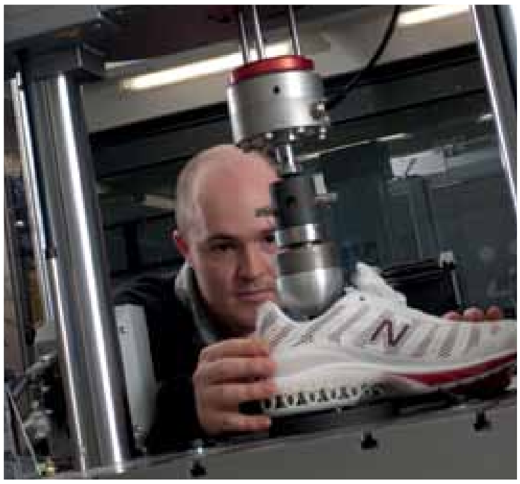


The Universe of Engineering
A call to action





Engineering the Future

The action forum for engineering

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Acknowledgements

This work was commissioned by Engineering the Future, the alliance of the 36 professional engineering institutions, EngineeringUK, the Engineering Council and the Royal Academy of Engineering.

The review was led by a steering group of senior engineers from across the engineering profession. Fifteen years on from the original *Universe of Engineering* report, which highlighted the importance of engineering and engineers to the UK, many of its messages and concerns remain poorly addressed. This report makes strong, practical recommendations with identified leads, the progress of which will be tracked and monitored by the profession through the Engineering the Future committee.

The steering group during the review process July 2013 – May 2014 were:

Chair:

Dame Sue Ion DBE FIMMM FREng	Royal Academy of Engineering

Members:

Professor Liz Bacon FBCS CEng CSci CITP	Vice President, BCS the Chartered Institute for IT
Professor Jon Binner FIMMM CEng	President, Institute of Materials, Minerals and Mining
Barry Brooks FIET CEng	President, Institution of Engineering and Technology
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Dr Paul Golby CBE FREng	Chairman, EngineeringUK
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Judith Hackitt CBE FREng	President, Institution of Chemical Engineers
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Patrick Kniveton FIMechE CEng	President, Institution of Mechanical Engineers

This report was written on behalf of the steering group by Dr Rhys Morgan, Director, Engineering and Education at the Royal Academy of Engineering. All comments should be made to rhys.morgan@raeng.org.uk

Contents

Image courtesy of NASA

1. Executive summary

This review was carried out by a panel of senior members from across the engineering community. It highlights just how important UK engineering and engineers are to the UK economy and its prospects for growth, to the health and wellbeing of UK society and to addressing global challenges. In this report, we aim to:

- draw attention to the size and scope of the world of engineering;
- support the profession in its ambition to meet the needs of the whole universe of engineering.

The universe of engineering is continually expanding and evolving. In many ways, engineering activity undertaken in the UK today has been transformed from that of even 15 years ago. Technology and our understanding of materials and processes have changed dramatically. The Internet, World Wide Web and advances in computing have revolutionised what we can do and the way we do it. The things we used to make, we now make better, stronger and more quickly, but through advances in engineering and technology we also make things we could not have made 15 years ago. But engineering is not just about making things. At its heart, engineering is a creative activity that seeks to solve technical problems to improve our well-being and to tackle society's challenges. However, fifteen years on from the original *Universe of Engineering* report, the central role of engineering in society is still not evident to the public at large. This lack of awareness of the real nature of engineering has a serious consequence – young people and their influencers have outdated views of engineering, and as such are not pursuing careers in our profession. In addition, a serious engineering skills gap is emerging that is reaching critical levels for our industries. In publishing this report we wish to convey two key sets of messages:

To policymakers: the contribution of engineering to the UK is much greater than is immediately apparent, both to the UK economy and through its global reach. Engineering is a practice carried out by a profession; it is not, as it is sometimes presented, a group of industrial sectors. Engineering activity occurs not just in the traditional industrial sectors but across the whole economy, and engineers are pervasive throughout it. The UK's engineering profession sets standards that are used and adhered to by engineers across the world, both by engineers from the UK working overseas and by indigenous engineers from other parts of the world. This global reach is a demonstration of the worldwide influence of UK engineering.

To our professional engineering community: the profession needs to evolve to attract new people to the profession and meet the needs of those working in engineering who are currently beyond its reach. It must seek to be relevant not only to individuals engaging in core engineering activity but also to those at the interface with other disciplines and in newly emerging fields. It must reinforce the system of self-regulation through professional review to sustain public confidence, and it needs to develop a clear and inspiring message to convey to the public the nature and extent of engineering.These two key sets of messages lead to some important recommendations that are presented in the report. We believe the engineering profession should take a strong lead, working in partnership with government, to achieve these recommendations. It is for this reason that we recommend that the *Universe of Engineering* should be owned and its actions delivered by the professional engineering community, through Engineering the Future.

There are 10 further key points we wish to highlight:

- the extraordinary breadth of engineering: from nano-structures to mega-structures; from advances in nanotechnology to major tunnelling projects; and in applications as diverse as cancer fighting drug delivery systems and the next generation of smartphone technology
- the number and diversity of highly skilled jobs associated with engineering across the whole of the economy
- the number of companies dependent on engineering and engineers for their success
- the rapidly and continually changing nature of engineering industries and the structure of the sector in the 21st century
- concerns about diversity and the need to improve opportunities across engineering for women and those from ethnic minorities and non-typical backgrounds
- the weaknesses in the essential foundations laid in our schools in preparing young people for engineering careers
- the need to improve the understanding of engineering and to promote the key role that engineers play in our country's health, wealth and happiness
- the importance of providing professional development for individuals taking Apprenticeships and other vocationally based training routes through to Engineering Technician, and Incorporated or Chartered Engineer registration.
- the importance of college and university education in delivering the core skills required by the main engineering disciplines while enabling students to succeed in the increasing interdisciplinarity of the real world and meeting the needs of a diverse range of employers
- the need to concentrate and focus the multiplicity of initiatives aimed at improving the image of engineers and engineering in order to maximise impact and improve effectiveness.

Find out more about the extraordinary examples of 21st century engineering at: www.engineeringthefuture.org.uk

2. Recommendations

Recommendation 1:

The engineering community needs to develop a dynamic, inspiring, continually evolving set of images and messaging for a wide audience.

Action:

EngineeringUK and the Royal Academy of Engineering, with the support of the professional engineering institutions through Engineering the Future

Recommendation 2:

The Engineering Council and the professional engineering institutions must cast the net wider in terms of identifying and including as members of the profession people who already have engineering skills. The institutions need to adapt and broaden their reach, develop an appropriate offer at all levels from apprentice to Chartered Engineer, share best practice, and more fully represent the current universe of engineering.

Action:

Engineering the Future

Recommendation 3:

Current national statistics are not adequate to provide a true picture of the contribution of engineering to the UK economy. The Standard Industrial Classification (SIC) and Standard Occupational Classification (SOC) Codes measures of economic activity tend to conceal a more complex and pervasive use of engineering skills across the UK economy. The profession should work with government to develop the use of measures of economic activity that reflect more properly the role of engineering.

Action:

Engineering Council and EngineeringUK

Recommendation 4:

The profession should work with government to ensure the appropriate measures are in place to drive improvement in careers guidance, to monitor progress and focus initiatives. EngineeringUK will lead with respect to providing careers inspiration and appropriate advice and guidance including the use of industrially experienced engineers in schools and CPD for teachers.

Action:

Engineering the Future – careers guidance policy
EngineeringUK – careers inspiration

Recommendation 5:

The Royal Academy of Engineering will lead in partnership with government, schools, universities, employers, and other stakeholders to increase the number of women in engineering and those from underrepresented social and ethnic groups.

Action:
Royal Academy of Engineering

Recommendation 6:

The professional engineering institutions should prepare for the impending increases in Apprenticeships and vocational training packages in engineering, and be ready to provide seamless registration and progression pathway opportunities for future generations.

Action:
Engineering the Future

Recommendation 7:

The professional engineering institutions should work with the further education and higher education sectors to ensure that industrially experienced engineers are used to provide contextualised learning. In HE, this improvement should be driven through the course accreditation process.

Action:
Engineering the Future

Recommendation 8:

The engineering expertise within government needs to be further improved, and all government departments should recognise the value that can be gained from greater use of the independent engineering advice from the professional engineering community. As a major employer, government should also lead by example in ensuring the engineers it employs are registered.

Action:
Engineering the Future

3. The nature of the engineering universe

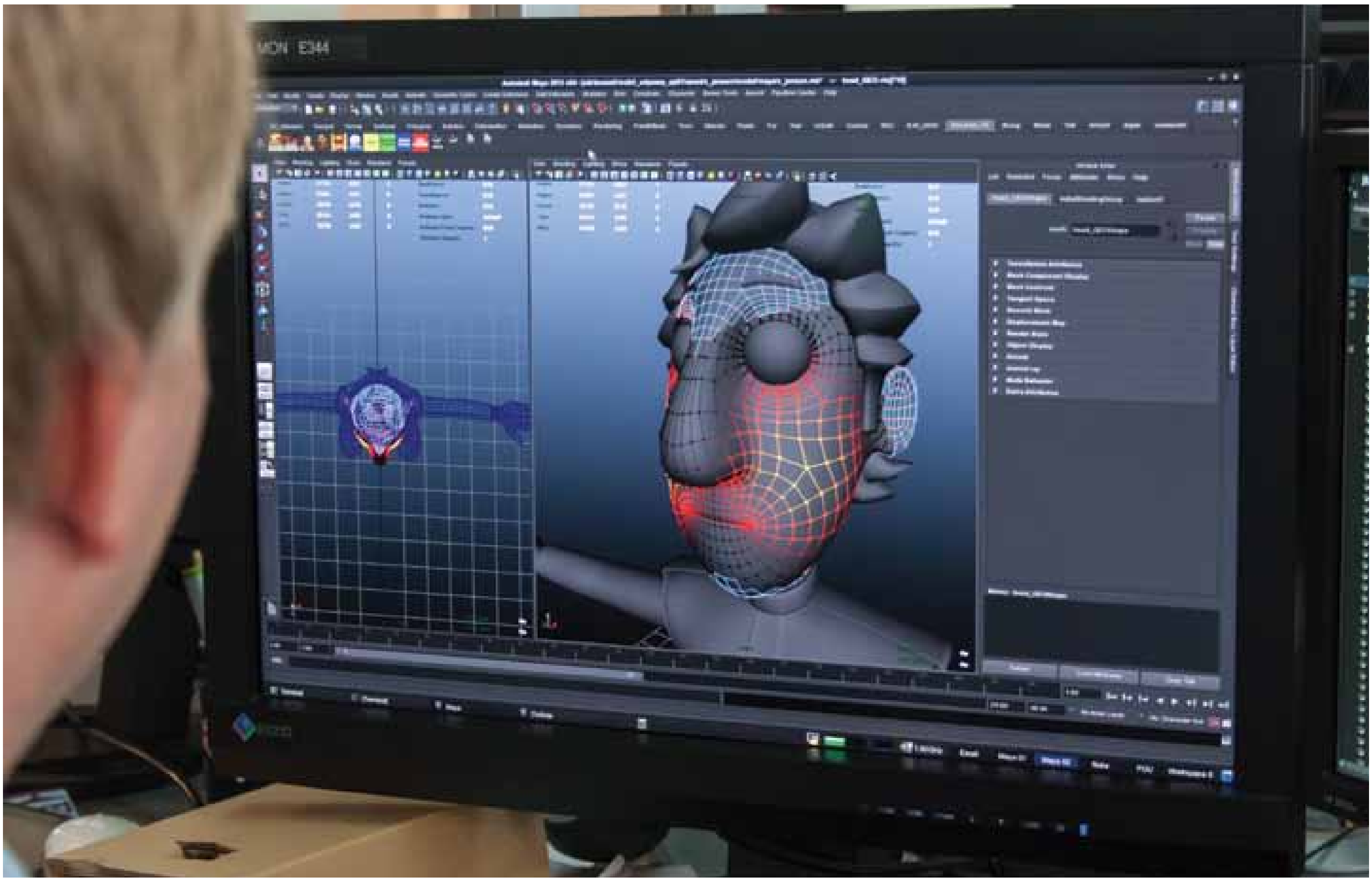
Engineering is a creative, practical activity. It is underpinned by design and uses computing and technological advances to solve increasingly challenging problems. It is inherently innovative and is often highly creative.

Like other developed countries, the UK is entirely dependent on engineering for society and the economy to function, including supplying power and water, maintaining and improving our buildings, and for our transportation and communication systems.

Engineering also drives the UK's manufacturing, chemical and process industries. It takes many guises across the economy, from vast civil engineering projects such as Crossrail to nanotechnology research at the cutting edge of electronics.

As engineering evolves, engineers and technicians are using their skills in an increasingly diverse range of businesses and activities. Its pervasiveness extends into areas such as medicine, the arts, media and entertainment, finance, fashion and clothing, sports, and the digital economy.

Engineers are central to the revolution in IT, including the internet and mobile communications, which have completely changed the way we



Blockbuster movies are now routinely augmented by computer-generated imagery – created by software engineers
(Image courtesy of Framestore and McLaren)

go about our lives. Engineering is increasingly interdisciplinary, and traditional definitions and boundaries within engineering have become much less relevant.

Yet the UK is facing an unprecedented skills crisis. Analysis by the Royal Academy of Engineering suggests the UK will need over a million engineers and technicians by 2020 and EngineeringUK research shows this will require a doubling of annual engineering graduates and apprentices. This will require a step change in the effort to attract young people into engineering and it must start with coordinated, inspiring messaging to the public that truly captures the real nature and breadth of engineering in the 21st century.

Although many definitions or descriptors exist, some of which are presented in Annex 1, we have found that few, if any, capture the multiplicity of engineering and the creativity and excitement of engineering activity.

In fact, attempts to define engineering usually serve to limit the true nature of the activity. Engineering is well-recognised in industries such as aerospace, automotive and rail, but in medicine, the media, sport, the environment and many other areas of our lives its role is less well understood. Case studies are a valuable way of illustrating the variety of engineering activity and examples of some leading-edge engineering across a broad range of disciplines can be found in Annex 2. A variety of further examples of cutting-edge engineering can be found through the Engineering the Future website: www.engineeringthefuture.org.uk

These case studies illustrate the variety of work that practicing

Engineers play a key role in elite sports to improve the performance of athletes and the products they use
(Image ©Engineering for Growth)

engineers are involved in and how engineering evolves to serve the needs of society as new fields of endeavour emerge, some driven by scientific advance. They also highlight the extent to which engineering activity has become multi- and interdisciplinary, and the impact that this has on the knowledge, skills and experience of engineers.

While almost every business in the UK is indirectly supported by engineering, for example through power, transport and communications, a significant proportion is directly dependent upon engineering and engineers for their success. The UK has, in the recent past, been described as a *post-industrial* nation. It is not. There are over 565,000 engineering companies in the UK employing over 5.4 million people across all employment functions[1]. Mature engineering sectors such as manufacturing and construction are thriving and new high-tech digital industries are being developed with innovative engineering at their heart. Engineering enterprises now account for a quarter of turnover of all businesses in the UK and contribute to over 30% of the GVA of the economy[2]. More detail on engineering enterprises in the UK is provided in Annex 3.

There are a great many small to medium-sized enterprises (SMEs) in engineering sectors and 95% of engineering companies across all sectors employ fewer than 20 people. Yet despite the significant number of SMEs, large companies with over 250 employees provide a high share, 43%, of employment across the engineering sectors (noting that this is across all functions, not just engineering).

The structure of engineering businesses in the UK has been rapidly and continually changing over the last 20 years. Major, vertically integrated organisations continue to be replaced by leaner and more agile networks of supply chain-based enterprises. This shift away from vertical integration to a flatter supply chain model is likely to continue, driven by globalisation and specialisation at all levels. Within UK manufacturing, there is evidence of an increasing and welcome trend of *re-shoring*, where companies are returning production to the UK from overseas manufacturers, driven by a need for reduced production lead times, the increasing cost of shipping and the economies made possible by advanced manufacturing technologies[3]. This trend suggests that many UK manufacturing businesses, with engineering at their heart, are innovative, and capable of competing successfully on a global stage.

However, engineering is not confined to manufacturing. The construction sector has over 155,000 businesses and the IT sector has 150,000 enterprises and is growing rapidly. There are yet more engineering businesses outside the well-understood engineering footprint identified by the standard industry classifications and many enterprises are working at the intersection of engineering and other sectors such as manufacturing and healthcare, and IT and entertainment. There are also many engineering consultancies hidden in industry sectors such as the business services sector.

Despite its ubiquity and presence across much of the economy and despite our engineering heritage, there is a surprisingly low level of knowledge and a high level of misperception of engineering in the UK. Traditional engineering sectors and the role of engineers within them provide the stereotypes of engineers in the mind of the public, which dwell on outdated and narrow images that are very different from the current reality.

We believe that the engineering community needs to talk about itself differently and lead the drive to change public perceptions and attitudes towards engineering. This is essential if we are to encourage new generations to become future engineers.

As the engineering community builds on the public engagement initiatives that are in progress, it should work collectively to improve the image of engineering. It should develop a coordinated set of messages and draw on its many positive aspects, such as design and creative problem-solving, to make it more attractive to young people and their influencers as a future career option.

Recommendation 1:

The engineering community needs to develop a dynamic, inspiring, continually evolving set of images and messaging for a wide audience.

Action:

EngineeringUK and the Royal Academy of Engineering, with the support of the professional engineering institutions through Engineering the Future

4. Engineering skills and professional institutions

The contribution that engineers make to the wider economy is greater than indicated by the statistics on the engineering sectors mentioned in the previous chapter. The reasons for this are because government statistics focus on sector output rather than professional or occupational output. Engineering enterprises and engineers working outside the engineering sectors identified by the standard industry classification are therefore not included in the contribution of engineering and engineering skills to the economy.

Another issue is the *identification* of engineers and individuals using their engineering skills working in the economy. The 2012/13 Annual Population Survey (APS) shows that 2.7 million individuals working in the UK declare themselves as engineers, with around half of these working in technician level engineering roles. These *self-declared* engineers constitute around 10% of the workforce. However, the currently available workforce statistics belie the actual number of engineers working in the economy. This is because the

3D Printing developed by manufacturing and materials engineers is revolutionising the way we make things
(Image courtesy of EPSRC Centre for Innovative Manufacturing in Additive Manufacturing)

statistical methods only allow a primary occupation or sector to be identified; many individuals with engineering qualifications, and therefore using their engineering knowledge and skills, are not declaring themselves as engineers. Our analysis of the APS suggests that the number of people with engineering skills at all levels working across the whole economy is significantly higher. We estimate that the number of people working in engineering could be as high as 4.3 million[4]. A summary of the more detailed analysis of the deployment of engineering skills in the economy can be found in Annex 4.

The 36 professional engineering institutions (PEIs), the Engineering Council, EngineeringUK and the Royal Academy of Engineering, collectively the professional engineering community, have the important role in the UK of ensuring that professional standards are maintained by a system of peer review and by ensuring that practising engineers remain up to date with their knowledge through a process of continual professional development (CPD). Professional engineers demonstrate their competency by means of a system of professional review against a defined standard. The UK Standard for Professional Engineering Competence (UK-SPEC) is published and maintained by the Engineering Council on behalf of the profession[5]. This regulation of professionalism is critical in maintaining a commitment to both a professional code of conduct and to CPD, both of which help to underpin public

Engineering is now found in almost every aspect of medicine – from diagnostics and surgical procedures to post-operative recovery systems and telemedicine

Advances in engineering are creating an invisible world of micro-mechanical systems used in applications from air bag deployment sensors in cars to optical micro-switches for the internet and other networks

(Image courtesy of Eos)

confidence in engineering. As most engineering occupations have a significant impact on society, it is important that as many engineers and technicians as possible are professionally registered. This would help to ensure the highest standards of professional conduct.

Despite the significant numbers of engineers in the economy, there are only around 232,000 registered engineers in the UK. Engineers are registered across four types and three levels of registration; Engineering Technician (EngTech), ICT Technician (ICT*Tech*), Incorporated Engineer (IEng) and Chartered Engineer (CEng). The profession has been built through membership and registration of engineers and technicians working in well-understood occupations. As engineers have become more pervasive across other sectors of the economy, the profession has broadened its offer to more specialised engineers and sectors. However, as the trend towards engineers and technicians working in more diverse parts of the economy continues, the system of self-regulation and professionalism of engineers must be applied in these new fields in order to maintain the necessary professional standards and public confidence. A better understanding of where engineers are practising is important, as the principle of self-regulation depends on sufficient numbers of engineers choosing to become professionally registered and agreeing to the professional code of conduct.

The UK's engineering profession is also global. Approximately 18% of the total registrants are non-UK engineers. This enhances the reach of UK standards, methods and regulation across the globe. The UK engineering profession's global reach is achieved through UK engineers working in UK businesses on export projects, through engineers educated and registered in the UK working in international or overseas businesses and through engineers from other countries adopting UK standards. The PEIs also set explicit engineering standards that are developed in the UK and adhered to in other countries. Overseas companies and governments often exert a strong global pull to adopt UK standards. This global reach is an excellent example of how the UK exerts influence or *soft power* across the world.

We have concern over the huge mismatch between the total number of people with engineering skills working in the UK and the number who are registered with the Engineering Council and are members of a professional body. In part, this is because the profession has traditionally appealed mostly to those at Chartered Engineer level, but even then the proportion registered is low. The profession needs to substantially increase its work to encourage greater registration.

As the breadth of engineering increases and engineers and technicians work in new and evolving fields, professional bodies must evolve in parallel. The PEIs and the Engineering Council must adapt and broaden their reach to ensure standards are relevant across new domains. In reaching out to a wider membership, the engineering profession must develop an appropriate and compelling offer for all those in traditional and non-traditional roles, and disciplines not previously thought of as engineering. That offer must include CPD relevant to their professional competencies and professional development. There is also an opportunity for professional institutions to work together to recognise interdisciplinary skills and to develop interdisciplinary CPD programmes and training. The following recommendation is to the profession, though it should be noted that work has already begun and where there is excellent and successful practice, this should be shared among the PEIs. We also recommend that the engineering profession works with government to find a way to more accurately reflect the contribution of engineers to the economy.

Recommendation 2:

The Engineering Council and the professional engineering institutions must cast the net wider in terms of identifying and including as members of the profession people who already have engineering skills. The institutions need to adapt and broaden their reach, develop an appropriate offer at all levels from apprentice to Chartered Engineer, share best practice, and more fully represent the current universe of engineering.

Action:
Engineering the Future

Recommendation 3:

Current national statistics are not adequate to provide a true picture of the contribution of engineering to the UK economy. The Standard Industrial Classification (SIC) and Standard Occupational Classification (SOC) Codes measures of economic activity tend to conceal a more complex and pervasive use of engineering skills across the UK economy. The profession should work with government to develop the use of measures of economic activity that reflect more properly the role of engineering.

Action:
Engineering Council and EngineeringUK

5. The role of the education system

There is now compelling evidence of a shortage of engineers in the economy[6]. It is also clear that high-level technician skills are in particularly short supply and that future workers in engineering will require higher-level technical skills[7]. The 2013 *Review of Engineering Skills*[8] by Professor John Perkins FREng, Chief Scientific Adviser to the Department of Business, Innovation and Skills, has highlighted the complex skills pipeline into engineering jobs and access to, and progression through, the professional engineering qualifications. Key statistics on the education system with respect to engineering are shown in Annex 5.

In a typical year cohort in England, 40% do not achieve a C grade or above in mathematics GCSE. Beyond compulsory education at age 16, the number of students choosing qualifications that lead to engineering careers plummets. The reasons for this are numerous, and include inadequate knowledge of engineering and poor perceptions and attitudes towards it, the perceived difficulty of subjects leading to engineering, the lack of specialist teachers in physics, mathematics and computing and the pressures of performance tables for schools.

Entrepreneurial engineers are combining innovation and design to apply emerging technologies in new ways (Image courtesy of QEPrize)

Engineers shape the world around us and create beautiful structures such as the Falkirk wheel connecting the Union canal with the Forth and Clyde canal in Scotland (Image © Peter Sandground)

In engineering higher education, the number of UK-domiciled students who achieved engineering degrees has effectively remained static over the last eight years, with 12,900 students in 2004 and 13,700 in 2012. By comparison, non-EU international engineering students completing engineering degrees in the UK have increased by 70% over the same period, from 3,200 to 5,500. In postgraduate education, non-EU international students make up three quarters of postgraduate engineering degrees achieved (excluding PhD and PGCSE students). Many engineering MSc courses are entirely dependent on non-EU international students for their continued existence. Only 35% of PhDs awarded in 2012 in UK engineering departments were awarded to UK-domiciled students. This reliance on non-EU international students is a cause for concern, and UK industry is missing out on advanced research skills of UK PhD students.

Careers inspiration and guidance

The professional engineering community supports careers inspiration activities to students in schools through the Tomorrow's Engineers programme delivered by EngineeringUK. There is also significant effort through the voluntary support from members of engineering institutions. Through initiatives such as the Big Bang Fair and Tomorrow's Engineers, hundreds of thousands of students have had interactions with practising engineers. In addition, STEMNET, a Government-funded charitable organisation, delivers programmes to inspire young people. The STEM Ambassadors programme run by STEMNET has 28,000 volunteers from business and industry who give their time to enthuse young people in STEM and show the benefits of a STEM career. A recent independent evaluation of the impact of the programme on young people and schools has highlighted that 40% of the Ambassadors are female and 60% are under the age of 35.

Role models are essential for inspiring young people about engineering. They are also well placed to provide accurate information about engineering jobs across all sectors of the economy. However, we believe the current use of volunteer effort is not effective enough. Despite all the effort over many years, there has been limited success in increasing the number of young people pursuing engineering qualifications beyond compulsory education as shown by the statistics in the previous section. Professor Perkins highlighted in his review of engineering skills the need for more coordination across the engineering community to increase its reach and to improve its effectiveness. We reiterate that message here.

The engineering profession should seek to focus and consolidate the multiplicity of existing initiatives, and have an emphasis on the Tomorrow's Engineers programme as the main engagement initiative for engineering in schools. It should also work more closely with STEMNET to support engineers visiting schools to improve the consistency of messaging to young people through the STEM Ambassador network.

However, careers inspiration alone will not provide young people with the necessary guidance in choosing their future careers.

The policies of successive governments towards careers guidance in schools have done little to help young people's understanding of the world of work. The engineering community must work with the government to improve careers guidance for young people.

Recommendation 4:

The profession should work with government to ensure the appropriate measures are in place to drive improvement in careers guidance, to monitor progress and focus initiatives. EngineeringUK will lead with respect to providing careers inspiration and appropriate advice and guidance including the use of industrially experienced engineers in schools and CPD for teachers.

Action:

Engineering the Future – careers guidance policy
EngineeringUK – careers inspiration

Diversity

Professor Perkins' *Review of Engineering Skills* highlighted the serious lack of diversity in the engineering profession. The UK professional engineering workforce has the lowest percentage of female engineers in Europe, with women accounting for only 8%. Given the shortage of engineering skills faced by industry, the current situation with respect to women and underrepresented groups is critical. The engineering community must significantly step up its efforts to make an impact to attract these groups into engineering.

By the end of compulsory education at age 16, only around six thousand young women, from an annual cohort of approximately 300,000, will choose to take A-level physics. The number of young women taking vocational engineering qualifications and engineering Apprenticeships is even lower. Girls' perceptions of engineering careers and the attitudes of key influencers such as parents, teachers and peers play a very important part. The issue of women in the profession is only one aspect of the problem of diversity within engineering. The low level of participation of minority ethnic groups in engineering, both in education and employment, is also a cause for concern[9,10].

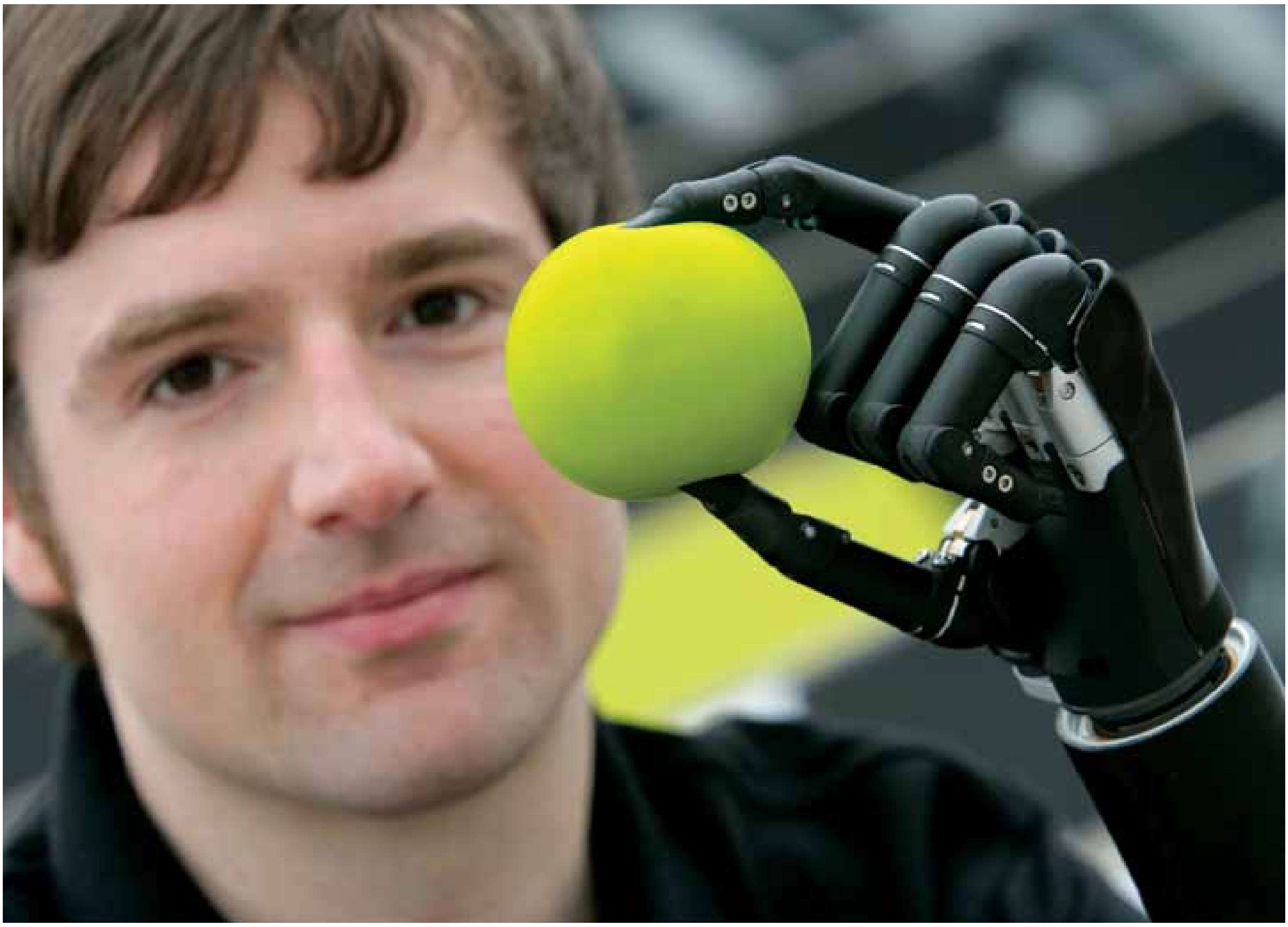
A diverse engineering workforce can meet the needs of a diverse society. There is an imperative to improve opportunities for women and people from certain social and ethnic groups. However, it is not a problem that the engineering profession can solve on its own. Widening diversity is more than simply a question of improving perceptions. The issues are complex and cultural, involving schools, employers, the profession and other key stakeholders, all of whom will need to engage if the problem is to be solved.

Recommendation 5:

The Royal Academy of Engineering will lead in partnership with government, schools, universities, employers, and other stakeholders to increase the number of women in engineering and those from underrepresented social and ethnic groups.

Action:

Royal Academy of Engineering



Bionic prosthetics limbs developed by engineers have transformed lives for thousands of people (Image courtesy of Touch Bionics)

Further education

The further education (FE) system in the UK serves many purposes but has not received the attention and funding it needs, given its importance in providing technical skills in engineering and other disciplines.

The FE sector is large. Some 6.67 million qualifications were achieved in 2012, with a quarter of those in STEM subjects (1.65 million). However, the overwhelming issue for the sector is that the majority of STEM qualifications, particularly for engineering and technology, are achieved at Level 2 – equivalent to GCSE. There is limited progression to the higher-level qualifications and skills needed by industry.

The rejuvenation of Apprenticeships is a welcome development. However, again the majority of these are taken at the intermediate rather than the advanced level. There is also a significant demand for Apprenticeship vacancies with, on average, five applications for every Apprenticeship offered. Also, the number of Apprenticeships started by 16-18 year olds was a small fraction of the total number of starts, which suggests that school leavers are either not aware of this as an option or young people are being overlooked by employers who are favouring older applicants.

The good news is that there has been substantial recent reform of the FE sector and Apprenticeships which we hope will improve progression to higher skills. In particular we support the recent reforms to Apprenticeships that will enable more apprentices who complete their training to become professionally registered as Engineering or ICT Technicians (EngTech or ICT*Tech*). Professional registration of technicians will enable easier transferability of skills for the individuals and will improve their social mobility. Higher Apprenticeships are increasing in number; completion of these may enable apprentices to register as Incorporated Engineers (IEng).

However, the current process of registration for technicians varies between PEIs. We would like to see an integrated, seamless and easily navigable registration process for technicians, regardless of institution membership. This should also demonstrate the pathways towards the higher professional titles of Incorporated Engineer and Chartered Engineer should the applicant wish to pursue higher professional qualifications. This work is underway in some of the institutions and best practice needs to be identified and expanded.

Recommendation 6:

The professional engineering institutions should prepare for the impending increases in Apprenticeships and vocational training packages in engineering, and be ready to provide seamless registration and progression pathway opportunities for future generations.

Action:

Engineering the Future

Higher education

The 2000 *Universe of Engineering* report highlighted the need for greater attention to be paid to the 'engineering process'[11] within higher education (HE) and the profession rather than a focus on engineering knowledge. There is still too much lecture-based teaching, though significant advances have been made. In particular, the four-year integrated masters programme includes significant design, build and test project activity in the final year with students working in multidisciplinary teams and gaining experience of applying the engineering process to real problems. However, more effort could still be made by HE academics to ensure a better balance of lectures, practicals and laboratory based work[12].

Both the original report and this latest review have highlighted the increasing multi- and interdisciplinary nature of modern engineering. Many engineering degree programmes provide a broader curriculum offer than the course title might suggest. Despite this, more could be done to improve the multidisciplinarity of engineering courses and the PEIs could provide incentives to encourage this through their accreditation processes.

HE appointments are often driven by a need to improve the research profile of an institution and many academics are recruited on their research track record. The result is that fewer lecturers in UK universities will have significant industrial experience. Previous research by the engineering profession has shown that this does not produce the best graduates[13]. The use of more visiting lecturers and visiting professors from industry to provide contextualised learning and real examples of engineering problems facing industry today should be encouraged.

Recommendation 7:

The professional engineering institutions should work with the further education and higher education sectors to ensure that industrially experienced engineers are used to provide contextualised learning. In HE this improvement should be driven through the course accreditation process.

Action:

Engineering the Future

Agriculture is highly dependent on engineering to ensure a sustainable global food supply chain (©Pixinoo/Shutterstock)

6. Engineering in government

The *Perkins' Review* epitomised the value of having engineers in important roles in the civil service. While some departments are increasing the number of engineers in official or advisory roles, (for example, the Department of Energy and Climate Change), there is a strong case for increasing this further. With engineering playing such a critical role in society, it follows that engineers should have a greater role in policy-making. Engineers themselves should seek roles in public life.

Engineering expertise should be available much more readily across all government departments, both internally through greater recruitment of engineers into the civil service and externally, through the advice of the many organisations within the engineering community. Engineering the Future and Education for Engineering (E4E) are two alliances across the professional engineering community that have been established to enable the profession to provide advice from the engineering community to government on aspects of engineering and education. These two bodies have provided valuable advice to government such as the very recently demonstrated need for climate change mitigation and adaptation in many parts of the UK and independent advice on future energy sources, healthcare, transport, culture and media and all aspects of the new information and communication age, such as the increasing impact of cybercrime and cyberterrorism. We acknowledge the support from government for the creation of Engineering the Future and E4E and would welcome government departments make more use of their independent advice.

Recommendation 8:

The engineering expertise within government needs to be further improved, and all government departments should recognise the value that can be gained from greater use of the independent engineering advice from the professional engineering community. As a major employer, government should also lead by example in ensuring the engineers it employs are registered.

Action:

Engineering the Future

Annex 1: definitions and descriptions of engineering

"Engineers help build the world around us. They use science to solve problems."

Nina and the Neurons: Go Engineering. BBC Cbeebies
Television programme aimed at primary school children. 2014

"Engineering is the knowledge required, and the process applied, to conceive, design, make, build, operate, sustain, recycle or retire, something of significant technical content for a specified purpose; – a concept, a model, a product, a device, a process, a system, a technology."

Sir Robert Malpas. *The Universe of Engineering: A UK Perspective*. 2000[14]

"The application of science to the design, building and use of machines, constructions, etc."

Oxford English Dictionary. UK

"Engineering is concerned with developing, providing and maintaining infrastructure, products, processes and services for society. Engineering addresses the complete lifecycle of a product, process or service, from conception, through design and manufacture, to decommissioning and disposal, within the constraints imposed by economic, legal, social, cultural and environmental considerations."

Quality Assurance Agency for Higher Education (QAA) Engineering Subject Benchmark Statement. 2010

"Engineering is all around us, satisfying everything from our basic needs to our more complex dreams and ambitions. The engineers and technicians who make this possible enjoy contributing to teams through technical endeavour to sustain and improve lives. They possess an incredible range of creative talent that is underpinned by their enquiring minds and balanced by their intellect and judgement."

Engineering Council. *UK Standard for Professional Engineering Competence (UKSPEC)*. 2014

"No profession unleashes the spirit of innovation like engineering. From research to real-world applications, engineers constantly discover how to improve our lives by creating bold new solutions that connect science to life in unexpected, forward-thinking ways. Few professions turn so many ideas into so many realities. Few have such a direct and positive effect on people's everyday lives. We are counting on engineers and their imaginations to help us meet the needs of the 21st century."

National Academy of Engineering, USA.
Changing the Conversation: Messages for improving public understanding of engineering. 2008

Annex 2: case studies of leading-edge engineering

This annex provides a snapshot of the breadth of activity that engineers undertake. The case studies below show engineers operating at the very edge of our current understanding of what engineering is or at the edge of current capability. The case studies show a variety of applications, from well-understood major civil engineering projects such as Crossrail to cutting-edge applications in medicine, performance clothing and security and counterterrorism. More examples of extraordinary engineering can be found at www.engineeringthefuture.co.uk

Drug delivery systems engineering

Medicine has made significant advances in recent years because of technological developments, particularly around medical diagnostics and imaging. A recent development emerging from research laboratories at Oxford University could take the use of ultrasound imaging to new areas of medicine. Dr Eleanor Stride, a mechanical engineer, and her team are pioneering the use of ultrasound in combination with magnetic fields to achieve targeted release of therapeutic agents from stimulus-responsive drug carriers. Specifically, they use combinations of gas filled micro-bubbles and liquid nanodroplets as drug carriers, that can be tracked around the body under real-time ultrasound imaging to a target location where the drugs are released by increasing the ultrasound intensity. By functionalising the bubbles with magnetic nanoparticles, excellent targeting can be achieved using an external magnetic field. The research is truly interdisciplinary engineering, bringing together technology and expertise from fluid dynamics, nanotechnology and pharmacology to clinical medicine.

Performance sportswear

Sports clothing companies are constantly improving their fabrics with respect to the athlete's performance and comfort. Engineers are using their knowledge of materials to be at the forefront of the latest developments. MMT Textiles Limited is one such company devising cutting-edge fabrics for performance athletes. MMT began as a spin-off from university research into biomimetic textile technology. The company's founder, Dr Veronika Kapsali, developed INOTEK™ fabric, which draws its inspiration from nature. Dr Kapsali started her career as a fashion designer, working with the UK's best designers during London Fashion Week. After many years as a designer, Dr Kapsali's interest turned to the functional aspects of the fabrics she used. Dr Kapsali left the fashion world and began researching new fabrics using biomimetics; an approach to design that draws ideas from the natural world and uses engineering to introduce them into industrial products. By examining the way pine cones open and close in different levels of humidity, MMT Textiles developed a synthetic-fibre material that mimicked this behaviour to change the permeability of the weave in the fabrics so as to increase air flow to the athlete's body for improved cooling. The research is an excellent example of the interdisciplinary nature of biomimetics, fusing together engineering and biology for increased functionality.

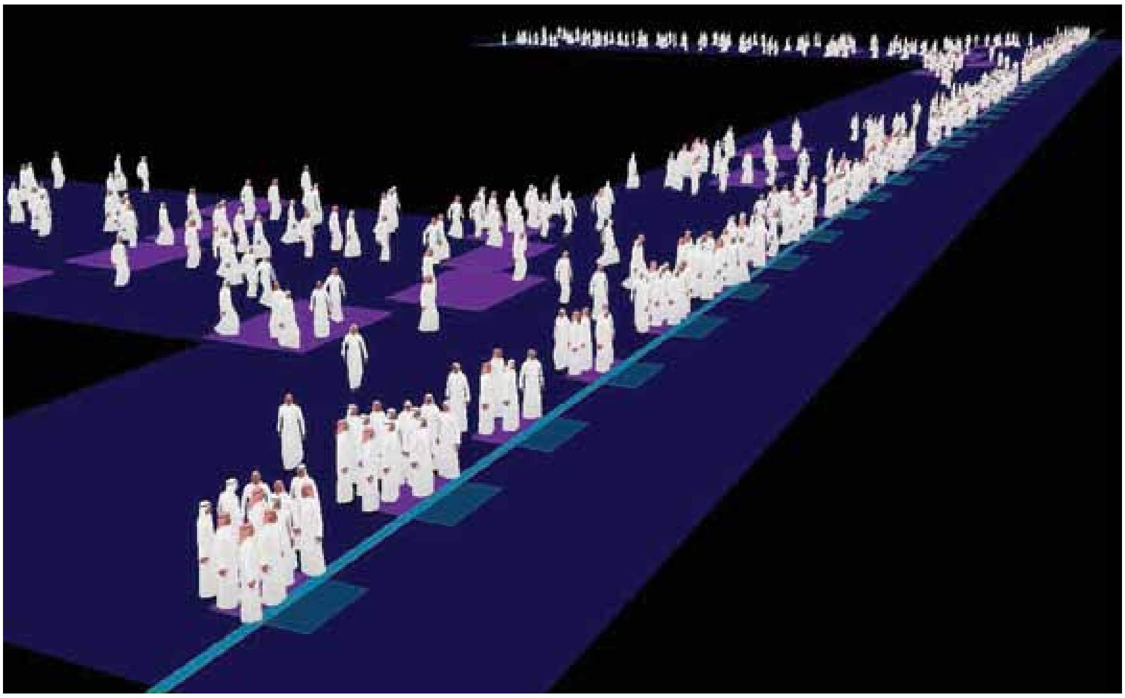
Counterterrorism

The MacRobert award, the UK's most prestigious engineering award, this year went to an engineering company that has created a new device to support airport security in identifying liquid explosives. Cobalt Light Systems has developed a means of analysing the composition of chemicals sealed within any non-metallic container without opening it, providing detailed and exceptionally reliable results in just five seconds. The machine shines a laser at the container, and the spectrum of light returned is then cross-checked against those collated in a library of threats. Having initially used this technique to help pharmaceutical companies verify the quality of medicines, Cobalt has now developed it into a security machine, the Insight100, which will enable airports to remove the existing hand-luggage liquid ban through phased implementation over the next few years, in line with pending EU regulations. While previous plans to remove the liquid restrictions have been delayed due to concerns about the robustness of technology available at the time, the introduction of the new Insight100 has proven a game-changer. It has recently been deployed in eight of the top 10 EU airports including Heathrow and Gatwick, and a total of 65 airports in Europe have introduced the system since January 2014.

Crowd management

Engineers in recent years have turned their knowledge of modeling of physical systems to simulate pedestrian flows for major events and transport hubs. Crowd Dynamics International, a UK-based company, is a world-leading expert on crowd movements. Using proprietary software, its engineers develop simulations based on years of research and a deep understanding of the psychology of crowds. Their software uses thousands of 'agents', individual entities, each of which are given artificial intelligence. The agents interact with each other as they navigate their way through a simulated environment, reflecting the movements of real crowds.

The analysis can also reflect the interactions that people have with traffic and other modes of transport, such as trams and trains. These simulations provide architects, urban designers, event organisers and security services with accurate models of crowd movements identifying densities, risks, delays, actions and reactions that large groups of people can generate. The team at Crowd Dynamics has provided the police and authorities with real-time information for the London New Year's Eve celebrations, to enable the operational team to make informed decisions on the night. Their work also contributes to developing transportation infrastructure and architectural planning across the world. For a number of years they have been working with authorities in Mecca for some of the world's largest crowds during religious pilgrimages and celebrations. Most recently, they have pushed the limits of crowd simulation to be able to forecast crowd movements in mass building evacuations in real-time, guiding crowds along the most optimal routes.



Next generation telescopes

Many of the latest advances in astronomy are attributed only to science. But is is the role of engineering that make it possible. One such example is the production of mirrors for next generation telescopes. A team of scientists and engineers at Glyndŵr University's OpTIC Centre in St Asaph, home to the UK's National Facility for Ultra Precision Surfaces, are currently polishing prototype mirrors for the European Southern Observatory's European Extremely Large Telescope (E-ELT). At 39 metres in diameter, the completed telescope will be the largest optical and near-infrared telescope in the world and will be built in Cerro Armazones in Chile in 2023. But it is the quality of the mirror finish that is extraordinary.

Each of the 1.2metre hexagonal mirrors that make up the array has extraordinary surface finish demands. Surface roughness needs to be less than 2 nanometres RMS, while the full 1.2 metre surface is less than 10 nanometres RMS. These tolerances make these complex shape mirrors the most demanding surfaces ever produced. When finalised, the E-ELT primary mirror will represent the world's most sophisticated active optical system ever created.

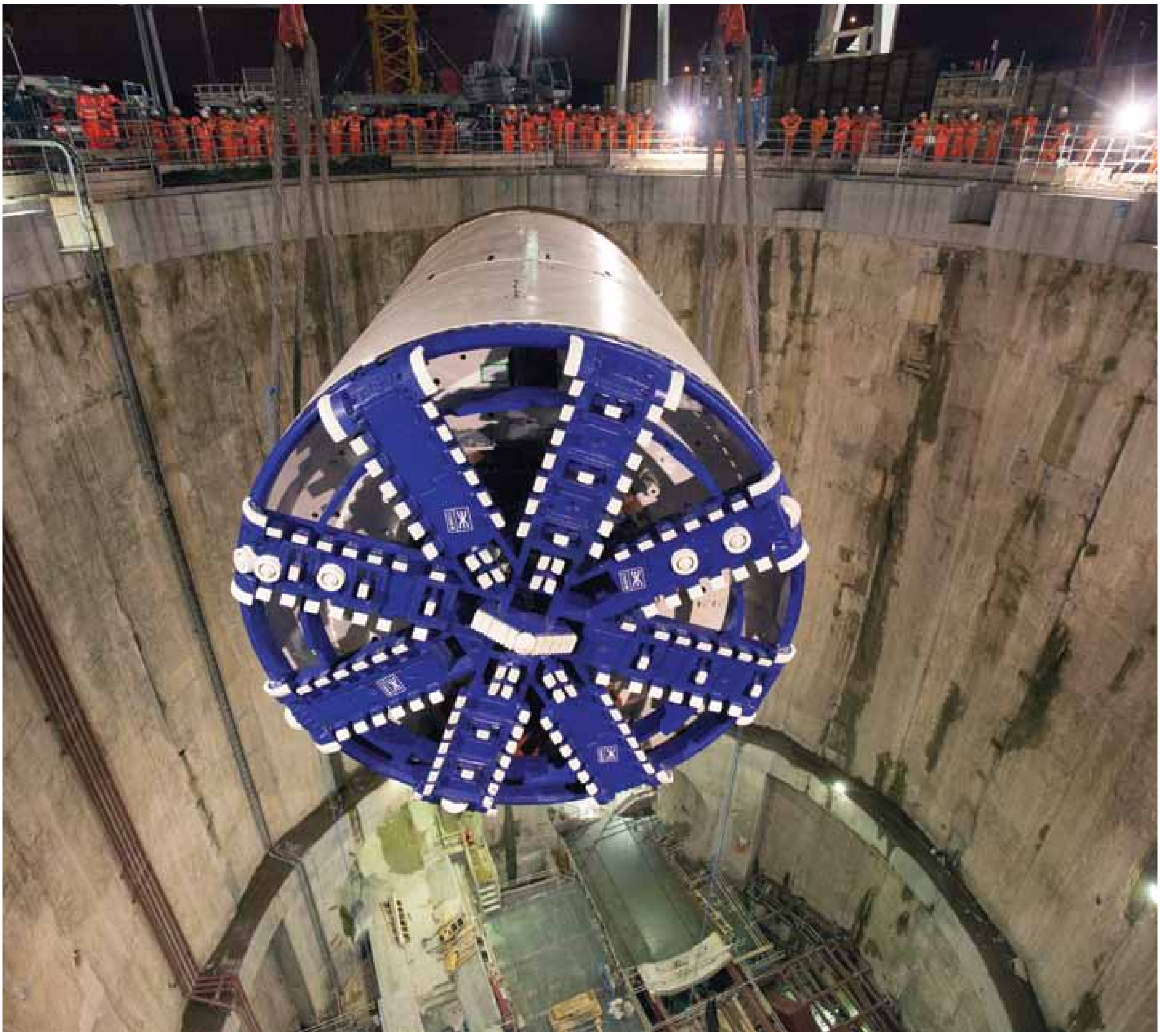
Environmental fashion

Designer Helen Storey has teamed up with chemist Tony Ryan on a fascinating interdisciplinary project to develop clothing which will help reduce pollutants in the atmosphere. Working together at the interfaces of their disciplines, they have developed Catalytic Clothing. This clothing uses a photocatalyst in the material to break down airborne pollutants from automotive exhaust. The photocatalyst is delivered to the surface of the clothing during a normal washing cycle, just like when adding conditioner to clothes. When sunlight shines on the fabric, electrons in the photocatalyst rearrange and react with water in the air to break the photocatalyst apart into free radicals. These highly reactive molecules then react with the pollutants in the air near the person wearing the clothing and cause them to break down into non-harmful chemicals. The Catalytic Clothing technology is designed to break down the pollutants straight away, but if any pollutants are attached to the fabric without being broken down, they can be washed off during subsequent laundering, which already happens with normal clothing.

An estimate of the required level of uptake for the Catalytic Clothing indicates that a significant reduction in the level of airborne pollutants in a large city such as London could be achieved if, for every metre of pavement width, 30 people wearing Catalytic Clothes walked past each minute.

Crossrail

Crossrail is Europe's largest and most ambitious railway construction project aiming to deliver a 73-mile railway line connecting East and West London and their adjoining counties. The key feature of the project is the extraordinary tunnelling programme, with over 26 miles of new tunnels directly under central London and Docklands navigating the hundreds of buildings and tunnels already in place. Everything about the project is on an unimaginably vast scale. To make the Crossrail tunnels, there are eight 7.1m diameter boring machines, with each machine weighing 1000 tonnes. The six earth pressure balanced machines are 150 metres long and are used for tunnelling through London clay. Two slurry machines, which are shorter, are used for the chalk ground conditions found in South East London. It is a civil engineering project on an epic scale.



Noise control

Sound barriers are usually designed to reflect or absorb sound waves, but one company is taking a new approach to noise reduction. Sonobex, a UK company, has pioneered the development of a revolutionary noise control technology, SonoTEC™, that counteracts sound waves by using a metamaterial structure that is able to manipulate and reduce sound energy passing through it. The structure is made from several elements uniquely arranged in order to scatter incoming sound. Complex interference patterns occur between the scattered waves, which lead to the sound energy being cancelled and attenuated. Computer simulations are performed in order to find the optimum design arrangement for a specific sound signature. Designing acoustic panels or barriers appropriate for their application ensures maximum noise attenuation performance is achieved. This technology has been designed into acoustic enclosures SonoENC™, acoustic barriers SonoBAR™ and integrated into designs in power generation and distribution applications for power and distribution transformers, turbo-generators, gas turbines, air compressors and generators. This technology has also been applied in a range of acoustic barriers to address noise pollution from the world's transport infrastructure.

Annex 3: engineering industry in the UK

Each year, EngineeringUK publishes data on the UK's engineering sectors. The latest publication[15] shows that in 2012, the UK had over 565,000 engineering businesses identified as within the *engineering footprint* through the Standard Industrial Classification. These engineering enterprises make up a quarter of the UK's businesses. Engineering employs around 5.4 million people in the UK across all functions.

In the year ending March 2012, UK engineering businesses had made a turnover of £1.1trillion accounting for 24.5% of UK annual turnover. Manufacturing alone accounted for 53% of all UK exports in 2012[16].

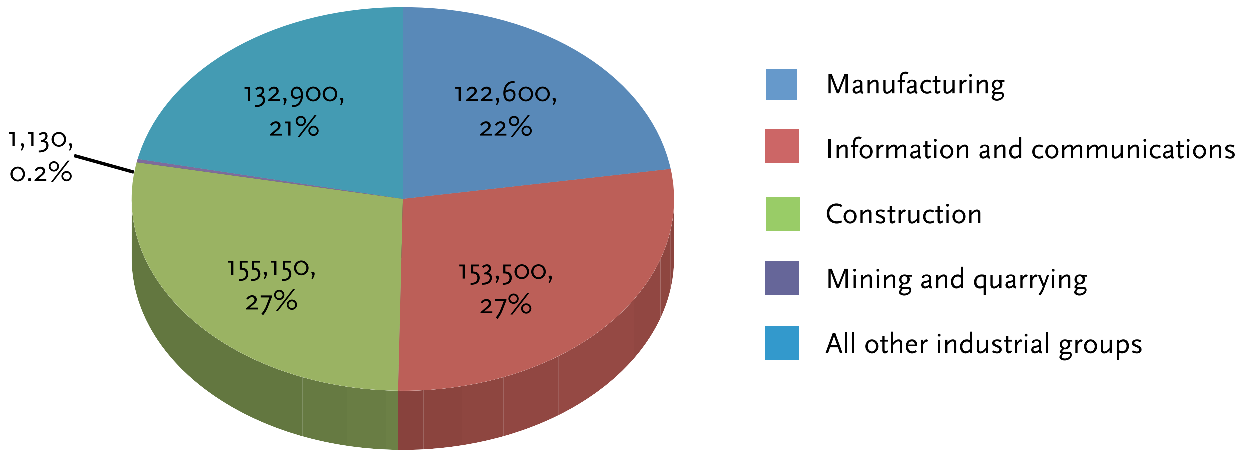
Tables of data and charts on engineering enterprises and employment are provided. The headline data for engineering businesses in the UK are as follows:

- Construction has the highest number of enterprises, with over 155,000 employing almost 957,000 people
- There are over 122,500 companies in manufacturing, which is just over one fifth of all engineering enterprises. However, these contribute to the highest employment within engineering, 2.39 million people
- The information and communications sector has 153,500 enterprises employing 997,500. More workers than the construction sector

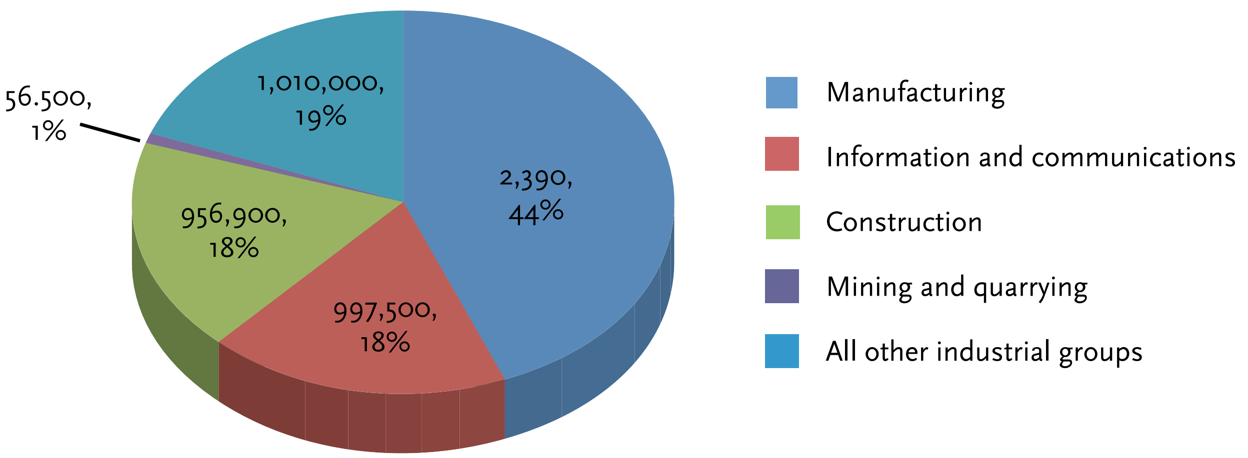
Data from EngineeringUK annual digest 2014. www.engineeringuk.com

Sector	Enterprises	as %	Employment	as %	Turnover	as %
Manufacturing	122,600	21.7	2.39M	44	496Bn	45.3
Information and communications	153,500	27.2	997,500	18.4	165Bn	15.0
Construction	155,150	27.4	956,900	17.6	143Bn	13.1
Mining and quarrying	1,130	0.2	56,500	1.0	68Bn	6.2
All other industrial groups	132,900	23.5	1.01M	19.0	223Bn	20.3

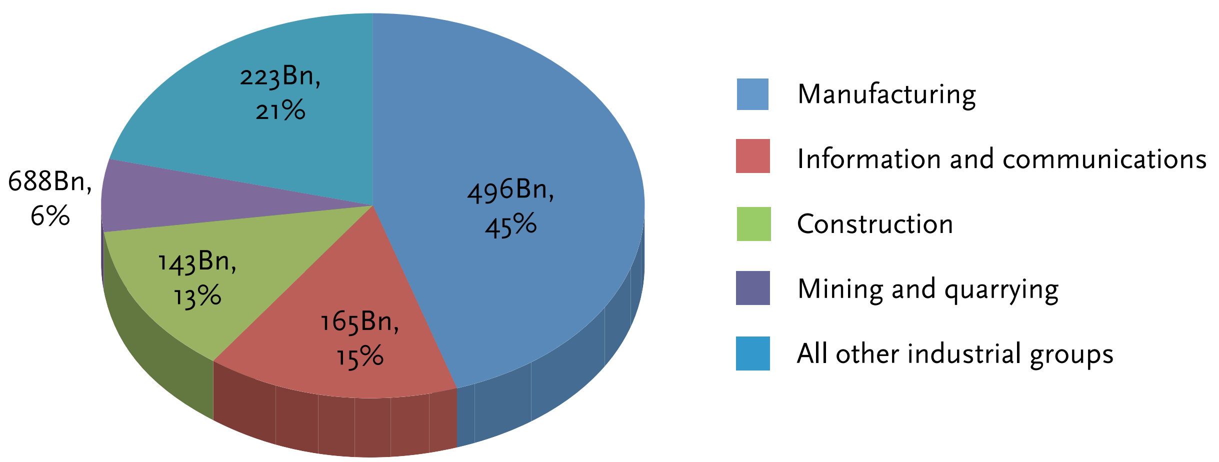
Number of engineering enterprises



Employment in engineering enterprises



Turnover by engineering industry sector



UK engineering activity spans the UK. London and South East England have the most engineering enterprises driven by information and communications industry while North East England and Northern Ireland have the fewest. Sectors industries are often characterised by geographical clusters facilitating specific industries[17]. Aerospace and automotive manufacturing industries tend to be clustered around major employers. Aerospace clusters are found in predominantly in the South West and North West of England, North Wales and in Scotland. The automotive industry is clustered around the major vehicle manufacturing plants in the West Midlands, the North West and North East. Further clusters exist in South Wales, East Midlands and Swindon.

The pharmaceutical manufacturing industry, while widespread, is developing clusters in the North East (Teesside and Tyneside) and Merseyside. Other interesting technologies have developed clusters; for example, many inkjet technology developers are based around Cambridge. Other industries such as the information and communications sector are widely dispersed across the UK, but still clusters are emerging. For example in London around Tech City; Cambridge, Sunderland, Manchester and Bristol.

These clusters develop for a variety of reasons including close proximity to supply chains, access to research and development in HE institutions and availability of sufficiently skilled labour.

Annex 4: engineers in the economy

The size of the engineering footprint and its contribution to the economy shows how important engineering industries are to the UK. However, this is only part of the story. Engineers are pervasive across all sectors of the economy and their contribution in non-traditional engineering sectors is growing.

Analysis of the APS shows that there are 28.5 million workers in the economy[18]. Of those, as shown in Figure 1 below, 2.7 million workers declare themselves as engineers, which is around ten per cent of the workforce. However, the picture is more complex than the APS data suggests. Many individuals with engineering qualifications and using their engineering skills do not declare themselves as engineers in their response to the survey. By making some judgements on the number of people taking engineering qualifications in further and higher education and by examining the APS, the number of engineers working in known occupations with an engineering dimension could be estimated to be 1.6m. This is indicated in Figure 1 as *non-declared engineers*. On this basis, it would also be reasonable to assume that there will be a significant number of people with engineering skills and qualifications working across all other sectors.

Figure 1: Engineers throughout the UK economy

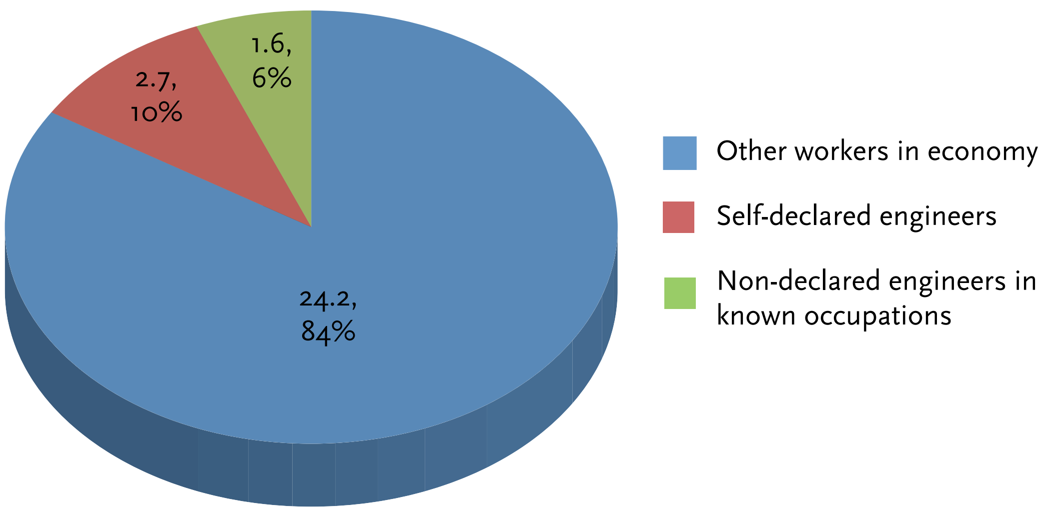
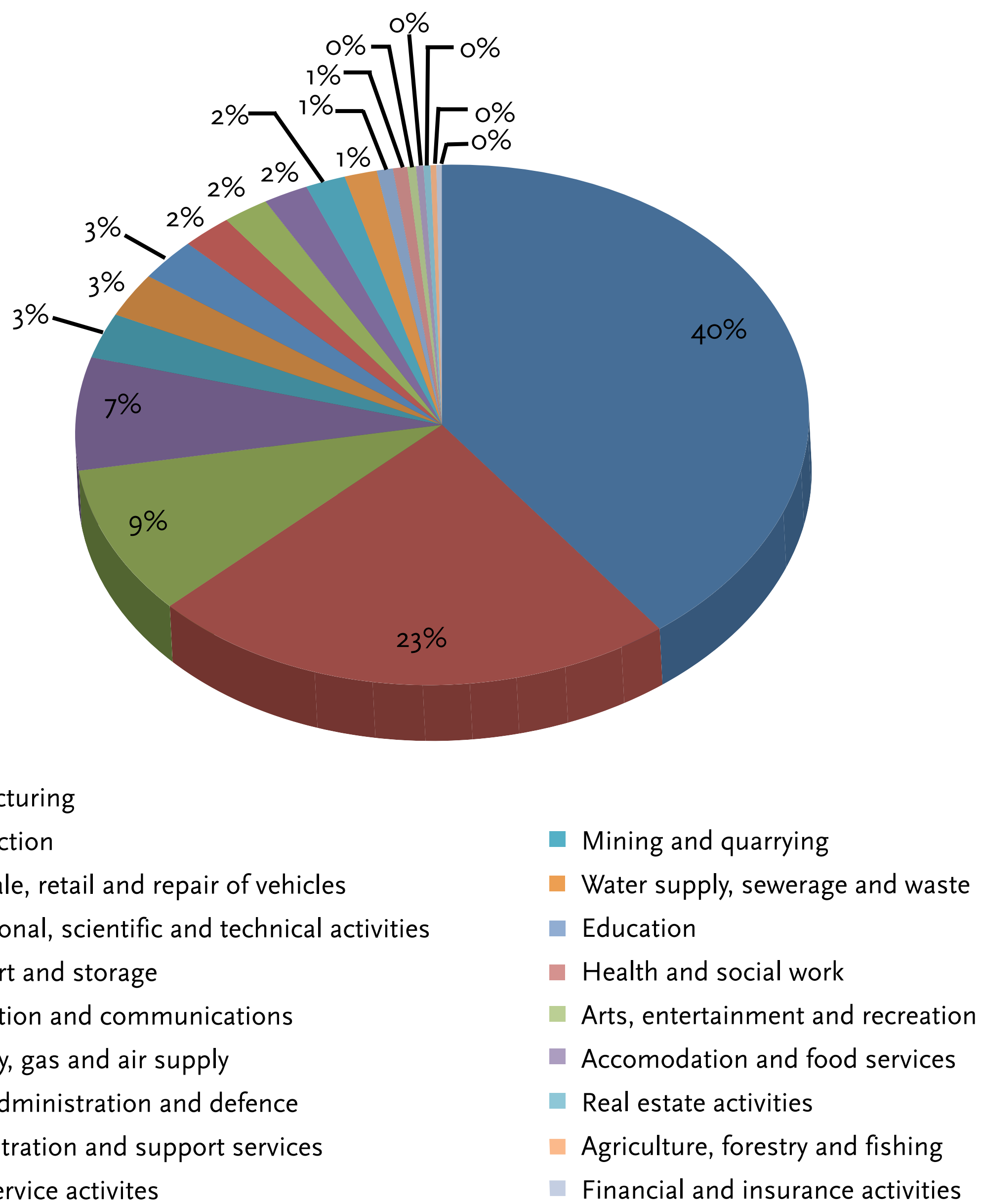


Figure 2, which shows the breakdown of self-declared engineers by industrial sector, demonstrates the pervasive nature of these engineering skills throughout the economy. Manufacturing and construction dominate with a combined 63% of the employment of self-declared engineers. Next follow retail, wholesale and motor trade activities and business services activities including consultancy, professional and technical research.

The remaining sectors make up approximately 20% of the self-declared engineering workforce employments. However, in these areas there is an increased likelihood of individuals with engineering qualifications, using their engineering skills who are not declaring themselves as engineers.

Figure 2: Distribution of self-declared engineers working in the SIC economic sectors

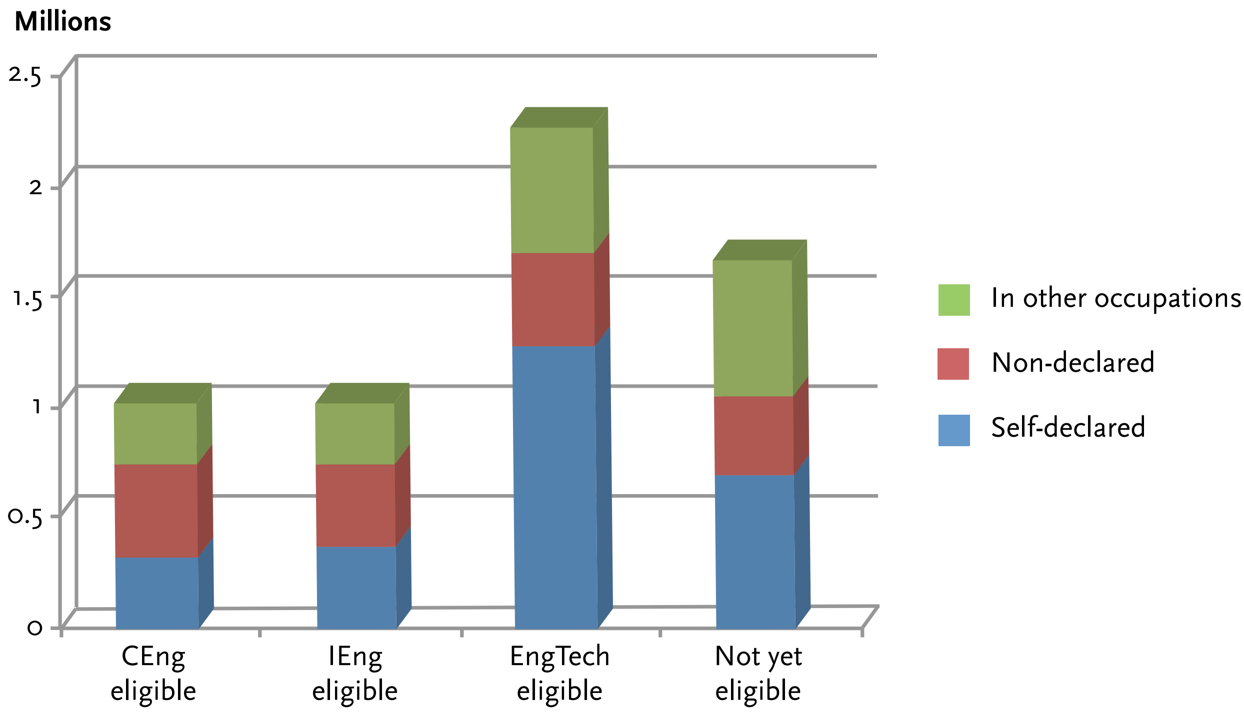


The APS also provides information on the occupations of individuals through the Standard Occupation Classification (SOC) and the sectors in which they work, through the Standard Industrial Classification (SIC). By analysing SOC and SIC codes, not only can we identify where engineers are working in the economy, but also in what level of occupation and with what level of qualification they are holding. This analysis reveals further important information, notably that many individuals declare themselves as working at a professional occupational level (SOC codes 1 and 2) and yet they do not declare themselves as possessing the appropriate level of qualifications for the specific occupation.

By examining the qualification levels and the occupation levels and then mapping against the Engineering Council registration requirements, we are able to show the profile of engineers by professional registration level as shown in Figure 3 below. It is possible to approximate the distribution of occupational levels, using these proportions, across the engineering sectors to provide a view of the make-up of the engineering workforce.

Finally, there is a concern that the APS dataset does not provide as accurate as a picture as could be achieved were individual professional affiliations recorded. The following example illustrates the problem.

Figure 3: Deployment of engineering skills by registration level



- In the survey, the number of respondents declaring themselves as chemical engineers under the appropriate Standard Occupational Code is 9880
- The number of Chartered Engineers registered with the Institution of Chemical Engineers is 10,960
- The UK membership of the Institution of Chemical Engineers is approximately 20,200 excluding student members

The number of professionally registered engineers and members of the IChemE suggests that the figure drawn from the LFS is incorrect and that respondents to the survey are declaring themselves under another occupation, possibly design and development engineers. This is important, as the true contribution of specific engineering skills and disciplines cannot be accurately determined if such inaccuracies exist.

Annex 5: key education statistics

Over recent years, the key annual statistics of the education system with respect to engineering are approximately:

In schools

- In 2014, over 735,000 students sat mathematics GCSE across schools in England at Key Stage 4
- 40% (275,000) of those students did not manage a C grade or above
- The proportion of young people taking individual science GCSEs (physics, chemistry, biology) is increasing. In 2014 the number was around 135,000
- Over 200,000 students are entered for design and technology across the UK each year. It remains one of the most popular GCSEs with students despite a declining over recent years

In post-16 education

- 35,000 student choose to sit A-level physics
- 28,000 students choose A levels in both physics and mathematics
- Around 145,000 engineering vocational qualifications are achieved at Level 2.
- Some 70,000 engineering vocational qualifications achieved at Level 3
- For engineering, ICT and construction Apprenticeships in 2013, there were:
  - 331,400 applications
  - 73,900 starts
  - In engineering, 51,000 starts with 80% at level 2
  - In ICT, 9,200 starts with 10% at level 2
  - In construction and building services, 13,300 starts with 80% at level 2

In higher education

- 21,000 engineering first degrees achieved in higher education institutions
- 13,700 engineering first degrees achieved by UK-domiciled students
- Of which, were EU and 5,500 non EU domiciled students.
- 15,600 students achieving postgraduate degrees in engineering (excl. PhD and PGCE)
- 3,900 UK-domiciled students achieving postgraduate degrees in engineering (excl. PhD and PGCE)
- 2,400 doctorates achieved in engineering
- 850 doctorates achieved by UK students in engineering

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