POPULATION: ONE PLANET, TOO MANY PEOPLE?

Institution of MECHANICAL ENGINEERS

Improving the world through engineering

This report has two parts. The first presents projections of change in global population through to the end of the 21st century. The second part outlines what engineers need to do to meet the key challenges of this future world to ensure the provision of food, water, shelter and energy in support of continued human progress.

This report has been produced in the context of the Institution's strategic themes of Energy, Environment, Education and Transport and its vision of 'Improving the world through engineering'.

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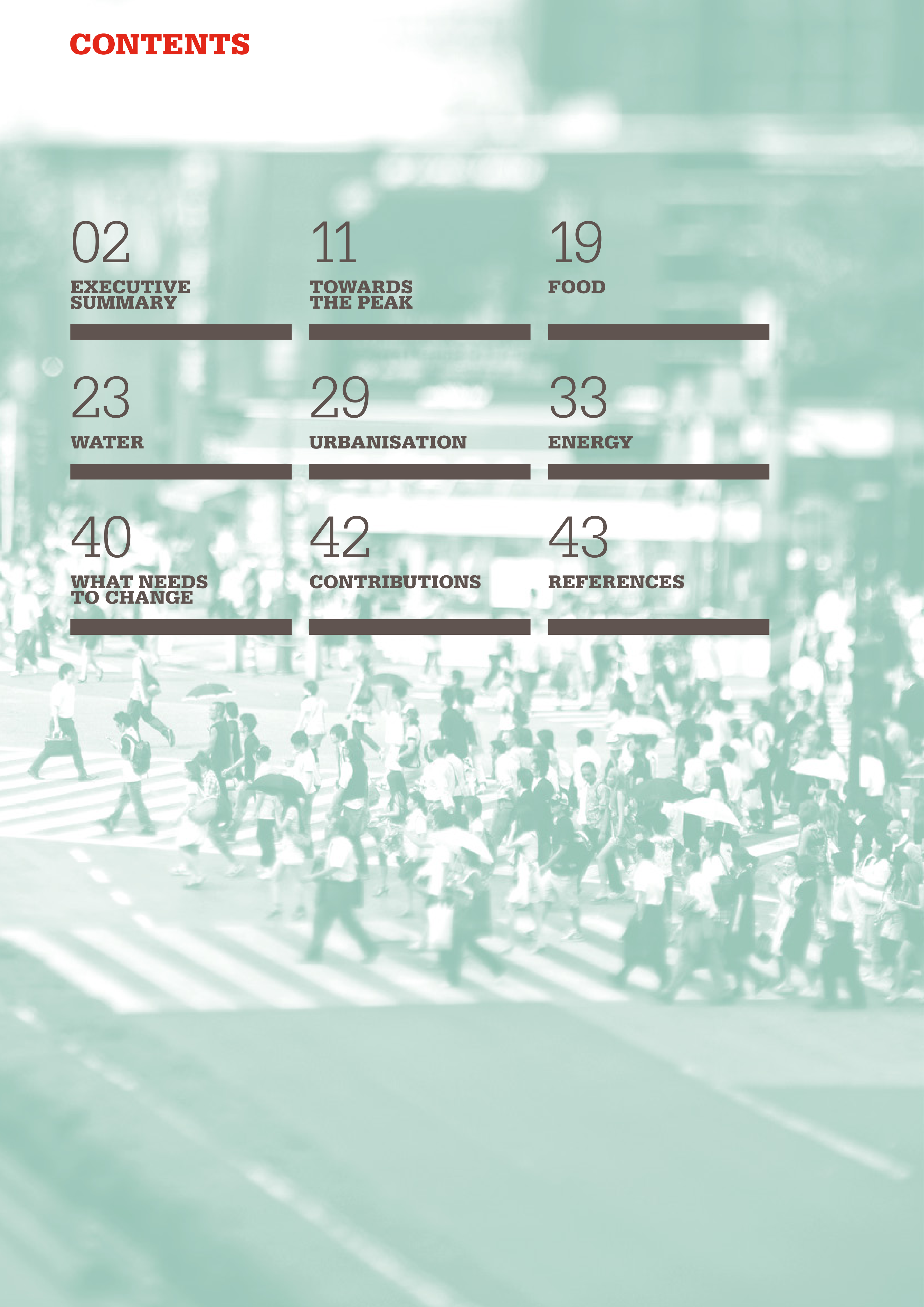


EXECUTIVE SUMMARY

INCREASING PRESSURE

The human population of the world is undergoing unprecedented growth and demographic change. By the end of this century there will be an estimated 9.5 billion people, 75% of them located in urban settlements and striving for increased living standards. Meeting the needs and demands of these people will provide a significant challenge to governments and society at large, and the engineering profession in particular.

In rising to this challenge, the engineers of today, and the future, will need to be innovative in the application of sustainable solutions and increasingly engaged with the human factors that influence their decisions. They will need strong, visionary and stable support from governments around the world.

There are four main areas in which population growth and expanding affluence will significantly challenge society in the provision of basic human needs, and create increased pressure on current resources and the environment:

1. **Food:** An increase in the number of mouths to feed and changes in dietary habits, including the increased consumption of meat, will double demand for agricultural production by 2050. This will place added pressures on already stretched resources coping with the uncertain impacts of climate change on global food production.
2. **Water:** Extra pressure will come not only from increased requirements for food production, which uses 70% of water consumed globally, but also from a growth in demand for drinking water and industrial processing as we strive to satisfy consumer aspirations. Worldwide demand for water is projected to rise 30% by 2030, this in a world of shifting rainfall patterns due to global warming-induced climate changes that are difficult to predict.
3. **Urbanisation:** With cities in the developing world expanding at an unprecedented rate, adding another three billion urban inhabitants by 2050, solutions are needed to relieve the pressures of overcrowding, sanitation, waste handling and transportation if we are to provide comfortable, resilient and efficient places for all to live and work.
4. **Energy:** Increased food production, water processing and urbanisation, combined with economic growth and expanding affluence, will by mid-century more than double the demand on the sourcing and distribution of energy. This at a time when the sector is already under increasing pressure to reduce greenhouse gas emissions (on average across the globe to 50% of 1990 levels), adapt to uncertain future impacts of a changing climate and ensure security of future supply.

The Institution of Mechanical Engineers recognises the scale of these issues and that there is a need to begin implementing the early phases of routes to sustainable solutions. The long timescales involved in many of the engineering-based projects required to meet these challenges, often measured in decades of construction and implementation, mean that if action is not taken before a crisis point is reached there will be significant human hardship. Failure to act will place billions of people around the world at risk of hunger, thirst and conflict as capacity tries to catch up with demand.

EVERYONE'S COMFORT

Global population growth and its impact is an issue that has no respect for national borders. The projections of demographic change presented in this report include a peaking of the world's population in the latter half of the 21st century at about 9.5 billion, up from today's level of 6.9 billion. During the steepest part of this increase, about 75 million people, more than the equivalent of the current UK population, will be added to the planet each year. The effects will be felt to some degree in every aspect of everyone's life wherever they live.

In order to try to capture the various issues around the world, specific attention is drawn to three countries which represent the broad spectrum of projected global trends:

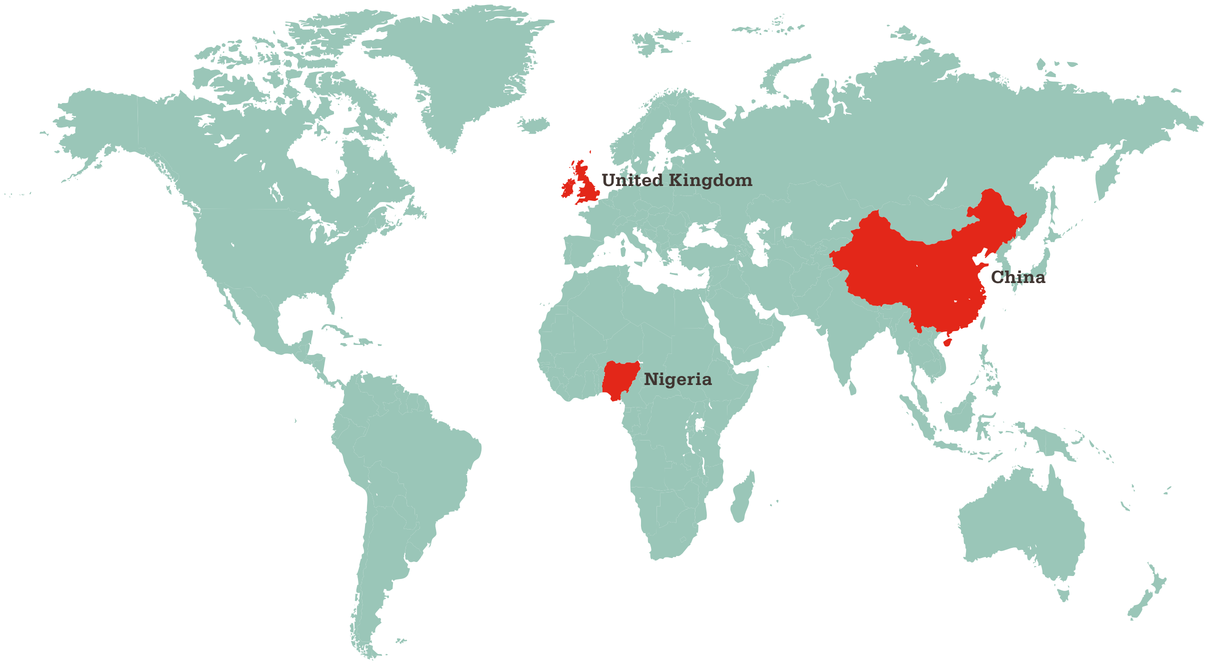
	Population Growth in Recent Decades	Future Projected Population Growth	Demographic Transition Profile
UK	Low	Low	Fully developed
Nigeria	High	High	Developing
China	High	Low	Late-stage developing

UK – Europe

The UK is a post-industrial society with a relatively high standard of living, fully integrated into the globalised marketplace. Projected population growth for this country is low at 14%. This is set within the context of a declining European population, projected to decrease overall by 20% from 0.73 billion to 0.59 billion. Domestic challenges will come from a greater proportion of elderly people in society with those over 65 years making up 23% of the UK population by 2050. Conversely, there will be fewer young people available to support them with 34% under the age of 30. This will create challenges regarding workforce composition, economic development, healthcare, transport strategies and changing consumption patterns for food, energy and consumer goods.

Nigeria – Africa

In contrast to the UK, Nigeria, set in an African context of high levels of population growth and economic development, will have 53% of its population under the age of 30 by 2050. This group will be largely composed of young people migrating to rapidly expanding urban environments in search of improved employment opportunities. Africa's population, as a whole, will double in the 21st century with over 50% based in urban settings. This will result in considerable pressure for increased domestic food production and water abstraction.



China – Asia

Asia, which already accommodates half the world's people, is projected to see a population increase of 25% by 2065. This growth, coupled with high economic development in areas of already stressed and shared hydrological basins, has the potential of increased geopolitical instability due to competition over water resources. For example, major rivers passing through India and China are heavily used and polluted, making it difficult to sustain, let alone increase, current withdrawal rates. In particular, demand from China, which already has 20% of the world's population but only 7% of its freshwater resources, will increase. In the case of groundwater, the current situation is also challenging. Currently, 90% of Northern China's aquifers located under cities are polluted. This is set to be exacerbated as industrial consumption increases.

Geopolitical tensions – Energy, Resources and Urbanisation

Other international geopolitical tensions may arise as the primary source of the world's energy gradually shifts from fossil fuels to new clean-energy solutions. Different nations and emerging areas, such as North Africa – which in the case of solar has an estimated potential for an installed capacity of 400GW – will find themselves rich in resources. In contrast, other regions that dominated the 20th century might struggle to maintain wealth and influence. Countries, such as the UK, that will be heavily dependent on imports of energy, will need to adjust to this New World Order.

The continued industrialisation of Asia, exemplified by the rapid emergence of China, combined with the projected industrial development of Africa, will lead to exacerbation of existing challenges in the sourcing of raw materials and minerals used in manufacturing. In particular, finite sources of Rare Earth Elements, a fundamental constituent of modern communications and clean-energy technologies, will be under threat of exhaustion, possibly leading to international trading tensions and impacting on UK industry and consumers. China currently produces 97% of the world's supply of these technically important minerals and since 2000 has had stringent export restrictions in place.

Alongside these tensions, there is the potential for increased social and political instability in Nigeria and other African countries from uncontrolled urban development. Today, 18% of all urban housing units are non-permanent structures and one third of the world's urban population live in what are defined by the UN as slum conditions. Some 65% of urban dwellers in Nigeria are classified as living in slums.

Into the future, existing urban infrastructure may become overwhelmed by large-scale migration to cities. These growing city populations may face appalling slum conditions with inadequate sanitation and water access, poor health facilities and lack of transportation. As a result, domestic unrest may emerge which destabilises international trading routes and drives migration away from areas of conflict to more stable regions such as Europe.

In an increasingly linked and co-dependent globalised world, changes occurring in one discrete location can have a significant impact on populations in locations many thousands of miles away. Today, more of us are living longer in mutual dependence on an increasingly crowded planet that has finite natural resources. It will therefore, become ever more important for nations, such as the UK, who have the knowledge of sustainable solutions to help those without it to leapfrog forward technologically and implement them.

ADDED STRESS – CLIMATE CHANGE

This report is focused on the engineering response to population growth. However this is a change that is not happening in isolation. It is important to place this specific issue within the wider context of global change towards the second half of this century.

The most obvious additional factor is that of climate change. While the science is currently undergoing some increased scrutiny, there is still a consensus that significant changes to the planet's climate as a result of human-induced global warming are highly likely. Indeed, many in the world's climate science community have indicated that the global climate is changing faster than originally thought and that there is the possibility of a 3°C to 6°C warming by the end of the 21st century. These projections can only be strengthened when viewed against the backdrop of recent slow progress towards international agreements that would limit the emissions of greenhouse gases, particularly the failure of the UNFCCC's COP15 and COP16 talks to secure a legally binding global treaty.

It is difficult to predict exactly what climate changes will occur in any particular region during the course of the 21st century. There may be some areas where the effects of climate change serve to increase a region's ability to cope with population growth, such as increased agricultural yields or a greater ability to harness energy. However, the effects of increased temperatures and more volatile rainfall in other regions will make coping with higher numbers of people more difficult.

One aspect of climate change that is not yet fully understood is the scale of environmental migration that will occur. Estimates have suggested that up to one billion people could be displaced by climate change over the next 40 years through the intensification of natural disasters, drought, rising sea levels and conflict over increasingly scarce natural resources[1].

MEETING THE NEEDS

Meeting the needs and demands of an unprecedented number of people alongside rapidly changing demographics will provide a significant challenge to the engineering profession. However the evidence shows that sustainable engineering solutions largely exist for many of the anticipated challenges. What is needed is political and social will, innovative financing mechanisms, and the transfer of best practice through localisation to achieve a successful outcome. For example:

- The provision of sufficient **food** through a doubling of global agricultural production in 40 years will be a challenge that engineers can help society meet. The application of biotechnology, improvements in mechanisation and automation, masterplanning for urban production and more efficient irrigation, improvements to food processing and distribution networks, and reductions in post-harvest losses can be addressed.
- Given current techniques and capabilities there is no valid reason why there should be a shortage of water for human use. Fundamentally, there is no shortage of **water** on the planet to meet the anticipated rise in consumption of 30% by 2030. There is however, a spatial and temporal misalignment of supply and demand. Groundwater, available on the planet in a volume over 100 times that contained in all rivers and lakes, will become more important as an engineered source of abstraction. Appropriate resource management techniques for this, as well as shared hydrological basins, will be needed to ensure sustainability of supply. Improved engineering and performance of desalination technologies will be required to help meet needs in coastal areas where consumption outstrips the natural supply of water. This should be accompanied alongside localised improvements in storm-water capture, storage, distribution and recycling, particularly in poorer nations that cannot afford access to other relatively expensive technologies. The profile of water will need to increase in all planning decisions and the localised value of water must be fully understood in the provision of engineered solutions.

- The increase in **urbanisation** to 75% of the world's population by 2050 (an addition of three billion people to the urban environment), will largely occur in developing countries. Increased emphasis on the provision of sufficient services, such as water, sanitation and energy, will present one of the greatest societal challenges of the coming decades. The rapidly growing areas of informal housing and 'slums' will require the provision of sensitively implemented community-focused solutions. Cities are highly individual in terms of size, geography, climate and culture. Engineers will need to develop bespoke solutions in order to make the most of local conditions.
- Evidence suggests that current known technologies for **energy** sourcing and distribution are capable of reducing, managing and satisfying the emerging demand. Large-scale infrastructure, such as concentrated solar power, fourth-generation nuclear fission and high-voltage direct current transmission, will form part of the solution mix. Alongside this will be greater emphasis on the deployment of localised community-based clean technologies in the newly developing nations. As the world shifts from fossil fuel-based systems to more renewable and low-carbon sources, it will need to invest some £29 trillion (US$46 trillion) over the next 40 years. This will challenge governments to fix the market failures that act as barriers to commercial deployment, and instil investor confidence in financial institutions and private sources of capitalisation. Alongside new innovative financing models, the importance of the engineer's ability to work within complex international regulatory frameworks will increase.

Defining North and South

When discussing global demographics, the terms North and South are generally used. North refers to the developed industrialised regions/nations of Europe, North America, Japan, Australia and New Zealand. South generally refers to the developing regions of Africa, Asia and Latin America.

WHAT NEEDS TO BE DONE?

The Five Engineering Development Goals

As we progress towards the UN's Millennium Development Goals[i] completion date of 2015, to achieve a successful outcome in meeting future population growth and demographic change, governments across the globe should strive to adopt the following five engineering-focused development goals:

1. **Energy: Use existing sustainable energy technologies and reduce energy waste.** Access to abundant sources of energy and affordable techniques for its use and distribution, coupled with reducing the environmental impact of fossil fuel consumption, are essential for meeting the challenges of population growth and changing demographics in the 21st century. Rather than waiting for development of new techniques with long and costly paths to commercial maturity, we **must** urgently focus our prime effort on correcting market failures to drive the deployment of the clean technologies known today. Furthermore, we must prioritise research funding to accelerate demonstration of those close to exploitation.

   Energy policy in both developed and developing nations **must** encourage consumption to move downwards and reduce demand, through a combination of engineering and behaviour change. The deployment of energy management technologies, such as intelligent appliances and smart meters, together with reductions in waste through better-insulated buildings and effective use of heat, are examples of engineering initiatives that should be pursued in this regard. Priority must be taken in newly developing countries to engineer many of these approaches from the start, therefore ensuring that the fastest-growing populations in the world leapfrog over the unsustainable failings of the wasteful energy solutions embedded in the infrastructure of mature, industrialised nations such as the UK.

i Eight international development goals aimed at improving life in the world's poorest countries and adopted by all 192 member states for achievement by 2015 (www.un.org/millenniumgoals).

2. **Water: Replenish groundwater sources, improve storage of excess water and increase energy efficiencies of desalination.** If there is one common factor that can be seen in the issues relating to water around the world, it is the unsustainable abstraction of groundwater at a higher rate than natural replenishment allows. This is a major issue due to the importance of groundwater as a source. Governments **must** improve groundwater management and accelerate the adoption of Aquifer Storage and Recovery (ASR) techniques, where water is re-introduced into the aquifer either by the use of wells or by altering conditions to increase natural infiltration. The source of the re-introduced water can be treated wastewater, storm-water or rainfall. Currently most ASR projects are within the developed nations and efforts need to be made to both substantially extend its use and increase its uptake among suitable regions of developing nations.

   Where and when water supply exceeds demand, such as in heavy rain activity, too little effort is placed on capturing and storing that excess supply for use as a source in drier times. Governments **must** provide separate sewerage and storm-water systems to allow the excess to be stored at the domestic and community level and used for domestic and commercial washing functions, lavatory flushing etc. In the developing world this approach should be taken from the outset, with provision for rainfall harvesting, aquifer replenishment and other forms of storage. In the developed world this means moving away from a culture that delivers water at a very high purity regardless of its intended use, and considers all wastewater to be highly contaminated.

   In the past few decades we have significantly reduced the cost of desalination and increased its energy efficiency. However, it still remains one of the most expensive water supply options and is generally restricted to energy-rich nations. We **must** prioritise and accelerate research into reducing the cost of this technology, in terms of both energy and money, so that wider deployment can be realised at coastal and estuarine locations of rapidly growing populations in the South.

3. **Food: Reduce food waste and resolve the politics of hunger.** On average a staggering 25% of all fresh food is thrown away in the North after being purchased. In the South, post-harvest crop losses are as much as half of the entire production. If we are to feed the rapidly growing populations of the South, the huge potential for gains in this area must be made. For the nations of the North, substantial efficiency increases are possible from the consumer, largely through behavioural change that recognises the value of food. By contrast, in the South the challenge is that of implementing existing engineering solutions and techniques, many of which are relatively low-tech, to improve food handling, correct poor storage facilities and rectify inadequate management practice.

   Malnutrition and undernutrition remain widespread in the poorest countries, despite significant levels of food waste and our technical capability to increase production further. Having the scientific and engineering capacity to produce enough food to feed the world's growing population does not necessarily mean there will be no hunger. The politics and social issues of poverty, which results in lack of access for many, **must** be tackled if we are to successfully feed a larger number of people.

4. **Urbanisation: Meet the challenge of slums and defending against sea-level rises.** Of all the issues faced globally by urban-dwellers, both now and in the future, the most prevalent and pressing is that of informal housing areas in the developing world. Non-permanent structures account for 18% of all urban housing units, and one third of the world's urban population live in appalling slum conditions with little or no access to clean water, sanitation or energy infrastructure. In dealing with this issue, society **must** recognise slums are a home and workplace to the people who live there. It is not an engineering solution of decant-demolish-rebuild-return. Interventions need to recognise the established informal economy and neighbourhood values of the inhabitants, and be planned, decided and implemented in association with them.

   Opportunities to build cities from scratch are few and far between, meaning that the expanding urban populations in the 21st century will be largely concentrated around existing sites. For historical reasons, many cities of the world are located in low-lying coastal areas and their people **must** be protected against the threat of extensive flooding from future sea-level rise related to global warming. Three quarters of the world's large cities are on the coast and some of the biggest are based on deltaic plains in developing countries (such as Bangkok and Shanghai) where land subsidence will exacerbate the challenge. Given the long timescales that will be involved in agreeing and implementing strategies, such as engineered flood defence infrastructure or abandonment to the sea of areas currently occupied, assessment of the projected rises and potential solutions needs urgent attention in all coastal settlements around the world.

5. **Finance: Empower communities and enable implementation.** Within the newly developing economies of the South, where the greatest population growth will be experienced, the scale of infrastructure investment required to create energy, water and food sourcing and distribution networks similar to those in the developed world will likely be prohibitive. Local application of mature, understood clean engineering technologies will need to be incentivised. If significant levels of access to energy and water are to be realised and adoption of localised sustainable technologies encouraged, mechanisms such as innovative soft loans and micro-financing, 'zero-cost' transition packages and new models of personal and community ownership, such as trusts, **must** be put in place to reduce the capital investment.

   Similarly, in the urban environment one of the most proven routes to success in the redevelopment of slum areas is the inclusion of the inhabitants in the decision-making and planning process. Instead of direct intervention by local or regional government, innovative programmes **must** channel infrastructure financing and housing loans direct to poor communities, who plan and carry out improvements, thus handing the communities a central role. Programmes in this style also have the benefit of altering the relationships between the community leaders and the administration of the cities, instilling confidence in the urban poor groups that they can influence solutions.

RECOMMENDATIONS

Population increase is likely to be the defining challenge of the 21st century, a global issue that will affect us all regardless of whether the countries in which we reside become more crowded or not. Even though there are likely to be no insurmountable technical issues in meeting the basic needs of nine billion people and improving their world through engineering, there is much urgent work to be done in preparing to meet this mid-century peak in a sustainable way. It is evident that many of the potential barriers to developing these solutions and ensuring a successful outcome are not technological, but lie in the areas of politics, social ethics, funding mechanisms, regulation and international relations. The Institution of Mechanical Engineers therefore recommends:

1. **The adoption by governments of The Engineering Development Goals alongside The Millennium Development Goals**. In the key areas of food, water, urbanisation and energy, engineers have the knowledge and skills to help meet the challenges that are projected to arise. There is no need to delay action while waiting for the next great technical discovery or a breakthrough in thinking on population control. In this report we present five Engineering Development Goals for priority action and crisis prevention. Governments around the world **must** adopt these goals and start working with the engineering profession on delivery targets if we are to build on The Millennium Development Goals.
2. **Provide all nations and leaders with engineering expertise**. Many governments around the world lack high-quality engineering advice and guidance to make informed decisions for implementation of the Engineering Development Goals (recommendation 1). Many developed nations already provide assistance in areas of medical knowledge and primary/secondary education with great success – the UK does via Department for International Development (DFID). The Institution recommends that the remit of DFID be expanded to train and second civil, mechanical, water, agricultural and electrical engineers to provide other governments with low-cost, practical and up-to-date engineering expertise.
3. **Help the developing world to 'leapfrog' the resource-hungry dirty phase of industrialisation**. The majority of future economic and population growth is projected to occur in the South. However, knowledge of potential sustainable solutions, and experience of the failings from unsustainable dirty industrial activity, are currently concentrated in the North. If economic market forces are left to be the sole or major driver of intervention and action is delayed, then the same errors are likely to be made. Nations in the developed world, such as the UK, **must** help the developing world to leapfrog the high-emissions resource-hungry phase of early industrialisation to reduce the environmental impact on us all.

> **BY 2100, THE PLANET WILL NEED TO ACCOMMODATE OVER 9.5BN PEOPLE, MANY LIVING IN UNDEVELOPED URBAN ENVIRONMENTS.**

MORE PEOPLE

Around the world, nations are experiencing unprecedented demographic change. The best-known example of this change, of course, is rapid population growth. However, the steep rise in human numbers when combined with equally extraordinary improvements in standards of living, has created a huge expansion in the consumption of natural resources and the creation of man-made engineered systems and infrastructure.

Other important demographic trends include the ageing of populations in developed nations as people live longer lives; larger proportions of younger people in poorer nations as a result of fertility outpacing mortality; and a rising number of migrants who move from villages to cities and from one country to another in search of a better life.

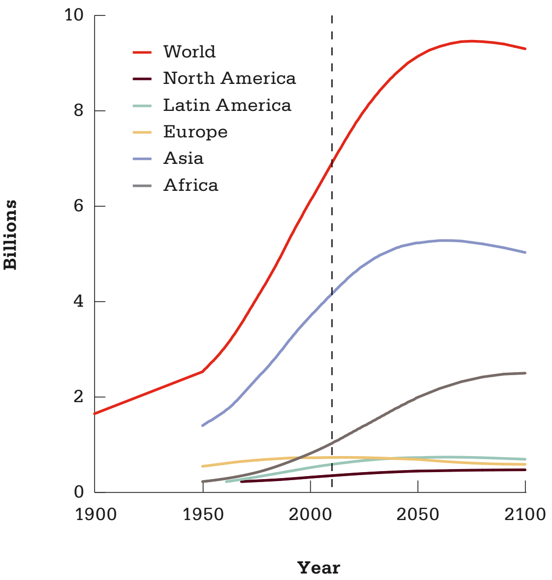
To understand these global trends and their regional variations, the Institution of Mechanical Engineers commissioned international population expert John Bongaarts[i] to outline changes in demographic indicators since the 1950s and provide projections for the remainder of the 21st century. It is within the context of these trends that we have identified the key challenges for society and prepared our engineering response to meet them.

[i] Dr. John Bongaarts is a Vice President and distinguished scholar at the Population Council based in New York USA

The modern expansion of human numbers started around 1800 when population of the world stood at about 1 billion. Over the next 150 years, growth was relatively slow by contemporary standards, reaching 2.5 billion in 1950. During the second half of the 20th century, world growth rates accelerated to historically unprecedented levels. As a result, world population added 4.4 billion to reach 6.9 billion in 2010[1]. This population expansion is expected to continue for several more decades, albeit at a lower rate, before peaking at about 9.5 billion later in the 21st century (adapted from United Nations 2004)[2]. The world's population will then be nearly a multiple of ten larger than in 1800, the time when Thomas Malthus was publishing his proposition that sooner or later population would get checked by famine, disease and widespread mortality[3].

The plot of aggregated world population size over time in **Figure 1** shows the typical S-shaped pattern of estimated and projected population size of societies over the course of the so-called demographic transition. This transition (during which the growth rate starts near zero then accelerates and eventually again drops to zero) usually accompanies the development process that transforms an agricultural society into an industrial one. The years between 1971 and 2016 represent the steepest part of this growth curve, with additions to world population exceeding 75 million per year.

Figure 1: Population projections by region
Source: United Nation World Population to 2300[1,2]



Contemporary societies are however at very different stages of their individual demographic transitions. The global demographic transition began in the 19^{th} century in the North (a term used in this context to refer to the developed industrialised nations of Europe, North America, Japan and Australia/New Zealand). The transitions in these economically advanced regions are now more or less complete and aggregated population size for this part of the world as a whole is forecast to remain close to stable. But, as shown in **Figure 1**, trends for the two principal regions in the North are expected to diverge between 2010 and 2100: a 37% increase from 0.35 to 0.47 billion in North America, and a 20% decline from 0.73 to 0.59 billion in Europe. Continued population growth in North America is attributable to immigration and fertility levels, which are among the highest in the North. Europe's aggregate future decline is caused by very low fertility which is only partly offset by modest levels of net immigration. Population declines are already occurring in some countries in the North (e.g. Russia and Japan) where birth rates have dropped below death rates without sufficient offsetting immigration. However, in the case of the UK the trend is closer to that of North America with an additional 8 million people anticipated, taking the current population from 62 to 70 million by 2100 (a rise of 14%).

Nearly all the future growth in world population will occur in the South (used to identify the developing nations, ie Africa, Asia and Latin America) where the demographic transitions started later and are still under way (**Figure 1**). In 2010, Asia had a population of 4.2 billion, more than half of the world total. Its population is expected to peak at 5.3 billion by 2065. The two largest countries in the South are, however, on different trajectories with China expected to decline from 1.35 to 1.20 billion and India growing from 1.21 to 1.54 billion. Africa, with 1.0 billion inhabitants in 2010, is likely to experience by far the most rapid relative expansion, more than doubling to 2.5 billion by 2100. Latin America, with 0.59 billion in 2010, is the smallest of the regions of the South; its projected growth trend is similar to Asia's, with a peak at 0.74 billion in 2065.

It may seem surprising that population growth continues at a rapid pace in sub-Saharan Africa where the AIDS epidemic is most severe. This epidemic has indeed caused many deaths, but population growth continues because the epidemic is no longer expanding and the birth rate is expected to remain higher than the elevated death rate in the future[4]. As a result, even projections that take account of AIDS mortality expect 1.5 billion more people in this continent by the end of this century. Most populations in sub-Saharan Africa will more than double in size (e.g. Nigeria from 158 to 338 million), with several predicted to triple or quadruple[1].

Demographic transitions in the South have generally produced more rapid population growth rates in mid-transition than historically observed in the North. In some developing countries (e.g. Kenya and Uganda) peak growth rates approached 4% per year (implying a doubling of population size in two decades), levels that were very rarely observed in developed countries except with massive immigration. Two factors account for this very rapid expansion of population in these still largely traditional societies:

1. The spread of medical technology (e.g. immunisation, antibiotics) after World War II, which led to extremely rapid declines in death rates;
2. A lag in declines in birth rates.

To simplify the presentation of results for all population projections discussed in the report, we have adopted the medium variant of the UN projections[1]. The UN has a good record of making relatively accurate projections. However the future is of course uncertain and actual population trends over the next half-century will likely diverge to some extent from current projections. The UN makes an effort to capture this uncertainty by publishing separate high and low projections. For the world, the high and low variants reach 8.0 and 10.5 billion respectively in 2050 and 14.2 and 5.1 billion in 2100, indicating a rather wide range of possible outcomes with uncertainty rising over time.

MORE ELDERLY NORTH AND YOUNGER SOUTH

Over the course of the demographic transition, variations in birth and death rates cause important changes in a population's age composition. Countries in the early stages of the transition have many more young people than countries in the later stages, which tend to have a larger population of elderly people.

Figure 2a presents the percentage of the population aged 65 and higher (elderly). The North has already aged substantially before 2010 and this trend in the proportion elderly is projected to continue, reaching 27% in Europe and 22% in North America by 2050 (23% in the UK). In the South, relatively little ageing occurred before 2010. This trend is expected to turn up sharply over the next few decades with Asia and Latin America approaching 20% by 2050 (13.7% in India and 23.3% in China). The main exception is Africa, where ageing will remain limited over the next few decades as it is still in an earlier phase of the transition (7.1% for the continent and 6.2% in Nigeria).

The opposite future trends are expected for the population under the age of 30 (see **Figure 2b**). Today, this proportion varies from a high of 69% in Africa to a low of 35% in Europe. The current trend is downward due to recent nearly universal declines in birth rates. The most rapid declines in the young populations are expected in Asia and Latin America, which could reach levels below 40% by 2050, like North America. By the mid-century, Africa will have the largest youth population (53%) and Europe the smallest (30%). Projections to 2050 in China, India, Nigeria and the UK are 31.4, 37.8, 53.0 and 34.2% respectively.

Figure 2 indicates a rapid change in the age composition of population over coming decades as is expected during the transition, but in the long run (ie after 2100) age structures might be expected to stabilise, assuming birth and death rates stabilise without large migration flows.

These trends have major implications for mobility strategies, such as transport choices for national, local, rural and urban environments; consumption patterns for food, water, energy and manufactured goods; buildings and welfare of the elderly. Lifestyle choices and expectations, and therefore consumption patterns together with demands on natural resources, will show different characteristics in different regions as a result of these transitional demographics.

Figure 2a: Percent aged 65+
Source: United Nations World Population Prospects[1]

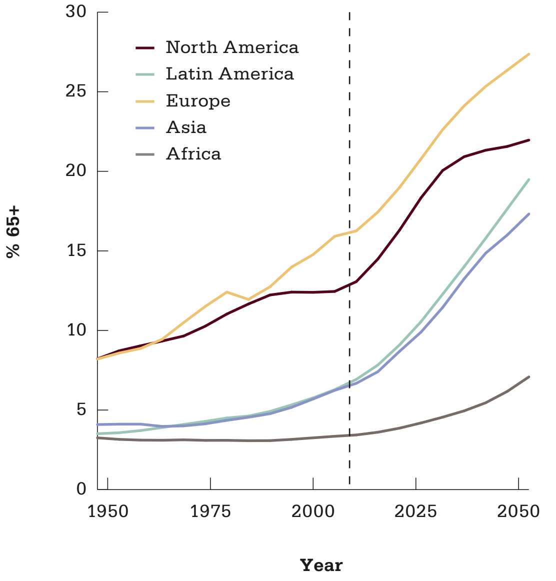
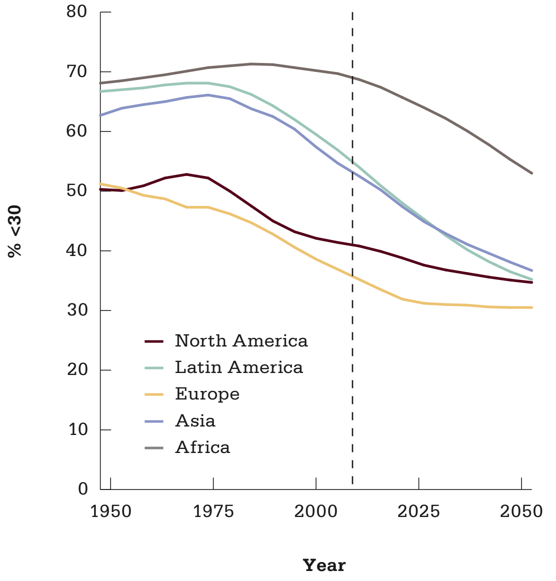


Figure 2b: Percent aged <30
Source: United Nations World Population Prospects[1]



MORE URBAN DWELLERS

The current era of rapid urbanisation began with the onset of the industrial revolution in the North. Employment opportunities in the expanding manufacturing and service sectors were often located in towns. Surplus labour from the rural areas moved to cities in search of jobs and a better life. Urban areas were also attractive because they provided higher incomes, better access to schools, cultural opportunities, healthcare and social services.

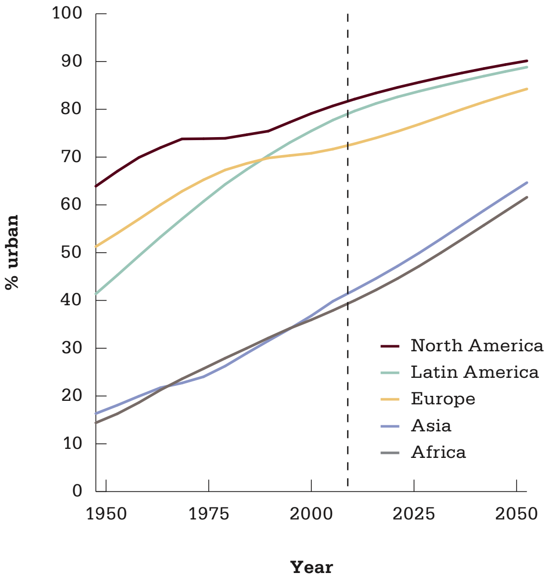
City regions of 1 million or more inhabitants now number 450 worldwide and accommodate a total of 1 billion people. Those with more than 10 million residents, so-called 'megacities', have reached 20 and are anticipated to number 29 by 2025[5].

Rank	Megacity	Country	Population
1	Tokyo	Japan	34,000,000
2	Guangzhou	China	24,200,000
3	Seoul	South Korea	24,200,000
4	Mexico City	Mexico	23,400,000
5	Delhi	India	23,200,000
6	Mumbai	India	22,800,000
7	New York City	USA	22,200,000
8	São Paulo	Brazil	20,900,000
9	Manila	Philippines	19,600,000
10	Shanghai	China	18,400,000
11	Los Angeles	USA	17,900,000
12	Osaka	Japan	16,800,000
13	Kolkata	India	16,300,000
14	Karachi	Pakistan	16,200,000
15	Jakarta	Indonesia	15,400,000
16	Cairo	Egypt	15,200,000
17	Moscow	Russia	13,600,000
18	Beijing	China	13,600,000
19	Dhaka	Bangladesh	13,600,000
20	Buenos Aires	Argentina	13,300,000

Source: The Principle Agglomerations of the World[71]

In the now developed areas of the world, urbanisation occurred at a fairly steady pace during the 19th and 20th centuries. However, little changed in the South until the second half of the 20th century. In 1950 the percentage of the world population living in urban areas reached 29%, ranging from over 51% in Europe and North America, to just 15% in Africa and Asia (see **Figure 3**). Over the past half-century, urbanisation has proceeded at a record pace and the world average reached 50% in 2010, with Africa and Asia more than doubling. China, with 97 city regions of 1 million or more residents, has the highest concentration of any nation. India, the USA and Europe have 40, 39 and 40 respectively. Africa, as a whole has 41. These trends are expected to continue in coming decades with the proportion of urban dwelling reaching between 80% and 90% in North America, Europe and Latin America. Africa and Asia are expected to remain much less urban but nevertheless could reach over 50% in 2050 (China, India, Nigeria and the UK are projected to reach 73.2, 54.2, 75.4 and 87.8% respectively), resulting in a global average of 75% urbanised population. By the end of this century, the global rural-to-urban transition should be nearly complete, with a large majority of people living in urban areas.

Figure 3: Percent urban dwellers
Source: United Nations World Urbanisation Prospect[72]



MORE CONSUMPTION

Within each region and nation, urban areas have somewhat fewer young and old people but more workers than rural areas. This is the result of lower birth rates in urban areas and of worker migration to cities and towns. As a result, the proportion of the urban population under the age of 30 and over 65 is slightly lower than the averages for the total population plotted in **Figures 2a** and **2b**.

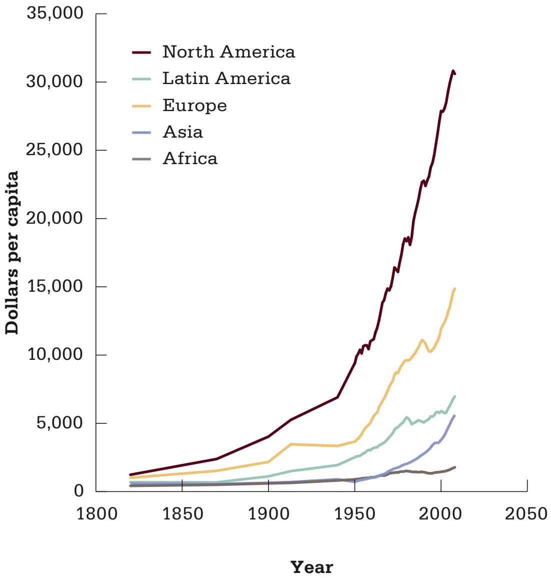
During the transition stage of the 21st century, the age demographics identified in the previous section will lead to different urban requirements in the North and South. In this regard, as the century progresses, the largely urban population of the North will be composed primarily of older people, with one set of urban needs, while the rapidly urbanising population of the South will be younger with different needs. This will mean that for a transitional period, responses to greater urbanisation will be characteristically different in the two regions and not always universally applicable.

The combined effects of rapid overall population growth and rising urbanisation, have produced extremely rapid growth in the size of urban populations of the developing South. This expansion has been difficult to absorb in the poorest countries, where urban infrastructure has been overwhelmed, resulting in overcrowded schools and health facilities, continuous traffic jams, inadequate public transportation and lack of clean water and sanitation. The chronic paucity of housing has led to the explosive growth of slum areas where the poor live in appalling conditions with little access to infrastructure and services. The challenge of slums is likely to remain widespread in future decades.

The industrial revolution created enormous wealth and raised standards of living for billions of people in the North. The most commonly used measure of standard of living today is the **gross domestic product** per person, or GDP per capita. Global GDP per capita today is approximately £5,000 ($8,000) a year (adjusting for differences in the cost of living across the world). Regional disparities in income are large and persistent (**Figure 4**). Real GDP per capita in North America has grown 25-fold since the early 19th century. Average incomes per capita have also risen by an order of magnitude in Europe, Latin America and Asia. Unfortunately, the world's poorest countries, largely located in Africa, have changed at a much slower pace. As a consequence the disparity between the richest and poorest regions has widened. The ratio of the average incomes per capita in North America and Africa has risen from three at the beginning of the 19th century to 17 today.

Standards of living are expected to continue to rise in the future, with the most rapid growth in Asia and the slowest improvements in Europe and Japan[6]. Asia was the poorest region in 1950 but has since seen exceptional growth with GDP per capita, expanding eightfold in half a century. This rise out of poverty of the most populous region, now with rapidly expanding and increasingly affluent populations, implies an unprecedented increase in consumer demand for goods, energy, processed food, water, living space, leisure products and travel.

Figure 4: GDP per capita 1820–2008 (1990$)
Source: Groningen Growth and Development Centre[73]



ENGINEERING THE BASICS

Demographic changes in the 21st century will present civil society, government and, in particular, engineers, with a significant challenge. The provision of food, water and energy, together with comfortable, safe and secure shelter, critically underpin human development. However, their consumption at the scale implied by future population projections has the potential for massive degradation of our social fabric, natural resources and the environment. The challenge is how to apply engineering knowledge, expertise and skills around the world to help adapt for a future sustainable world.[ii]

It is acknowledged that forecasting demographic changes over time includes uncertainty, and the scenarios presented in this report should be considered as possible outcomes rather than a definite prediction of what will happen. The discussions on engineering solutions contained in this second section of the report are in response to the general trends indicated in the modelling, rather than the precise details of the data. By taking this approach, confidence in the applicability of the discussion will be higher.

While this report is primarily focused on engineering solutions that will help accommodate the changing demographics in human population, it is important to note the added stress of climate change. This will place increased strain on the resources used by humans and impact on how people live.

It is difficult to predict with any degree of certainty the exact climate conditions that will become established in any particular region during the course of the 21st century. It is however a recognised possibility that large tracts of currently inhabited land will be unable to sustain significant populations in the future, due to a number of factors such as sea-level rise, increased temperature, severe weather events or the increased incidence of flooding or drought[7].

Conversely, there may be some areas where the effects of climate change serve to increase a region's ability to cope with population growth, such as increased agricultural yields or a greater ability to harness energy or water. This may result in large-scale population migration, placing even more pressure on the regions of the world that emerge from climate change as temperate. Estimates have suggested that between 25 million and 1 billion people could be displaced by climate change over the next 40 years through the intensification of natural disasters and conflict over increasingly scarce natural resources[8].

The Institution of Mechanical Engineers has been very active in providing thought leadership on the engineering response to climate change and recently published a series of ground-breaking publications[9,10,11] on the subject. Where applicable this thinking has been included in the work for this report, which focuses on the four key areas crucial for continued development: food, water, urbanisation and energy.

ii Members of the Institution of Mechanical Engineers from across the globe have worked together with a wide range of engineers from Ove Arup & Partners Ltd to show in this report how we can meet the challenge.

THE UK POPULATION IS ANTICIPATED TO RISE TO AROUND 70M BY 2100.

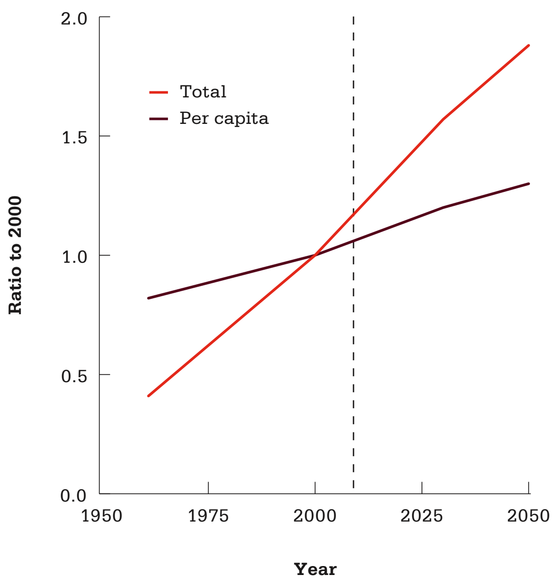
“”

ON AVERAGE, 25% OF ALL FRESH FOOD IN THE DEVELOPED WORLD IS THROWN AWAY AFTER BEING PURCHASED.

Advances in science and engineering over the past century have consistently delivered enormous improvements in the quantity and quality of food available to humans, first in the North and more recently in the South. In the early 1900s, a farmer in the United States fed about 2.5 people. By the end of the century he fed 97 Americans and 32 people living abroad[12]. Today, the supply of food has reached over 3,400 cal/capita/day in the developed world with obesity, due to overconsumption, emerging as a health problem in some nations. In the developing world, caloric supply rose from 2,111 to 2,654 cal/capita/day between 1961 and 2000[13]. Malnutrition and undernutrition have declined substantially but do however remain widespread in the poorest countries. This is despite significant levels of food waste in the developed and developing nations.

Having the scientific and engineering capacity to produce enough food to feed the world's population does not necessarily mean there will be no hunger. The latter is often a political or social problem of poverty which results in a lack of access, rather than a technical limit of productive capacity. It is estimated that about one billion people are undernourished today. This issue was targeted by one of the UN's Millennium Development Goals, but progress towards targets is slow and has been hampered by the global financial crisis[14].

Figure 5: Global demand for agricultural products (rel. 2000)
Source: FAO World Agriculture[13]



With a rapidly growing population in the 21st century, the provision of sufficient food will be an even greater challenge, particularly as dietary habits in many developing societies are changing to embrace increased consumption of processed meats and vegetable oils coupled to a reduction in the demand for rice and wheat. The World Bank predicts a 50% rise in cereals demand compared with an 85% increase for meat between 2000 and 2030[15]. Estimates also indicate that by 2050, livestock will be consuming more food than was consumed by the human population in 1970[16].

These emerging food trends are hugely expanding the demand for agricultural production. Total demand more than doubled between 1961 and 2000 and is expected to nearly double again between 2000 and 2050 (see **Figure 5**). Virtually all the world's prime agricultural land currently available is now used to grow food and fibre for humans and livestock. It is anticipated that 90% of the recent growth in agricultural production worldwide (80% in developing countries) has been due to higher yields and crop intensification, with the remainder due to expansion of land area utilisation. Undesirable consequences include deforestation, the run-off of pesticides and fertilisers and the depletion of fresh water sources.

Step changes in agricultural production are likely to occur through the implementation of new methods derived from a diverse range of scientific, engineering, economic and political disciplines.

The engineering community has always played a significant role in increasing food supply. It will continue to do so through the provision of direct solutions to fundamental needs; such as the application of biotechnology to increase yields and utilise secondary land, increased efficiency of water use both for the growing of food and its subsequent processing, further mechanisation, the reduction of post-harvest losses and better land use management through improved drainage and control of salinity and alkalinity.

For example, the projected increase in urbanisation will mean that, in many cases, food will have to be transported greater distances before the final destination is reached. This might also be an outcome of climate change in the mid 21st century, as projections show a possible widespread increase in productive land[17] in areas such as East and South East Asia, Northern Europe, North America and the polar regions which are remote from major concentrations of future population growth. Increases in the efficiency of the distribution infrastructure and logistics techniques, alongside reductions in transport-derived greenhouse gas emissions, will be needed to ensure maximum benefit can be realised for all.

In addition the role of food production within urban areas may become more important, although it is unclear whether the scale of such efforts will ever be able to make a meaningful contribution to the nutritional requirements of most cities. There are however examples for precedence, as is shown by Havana, where half of all the fruit and vegetables consumed in the city is grown within the city limits[18]. To realise this potential, masterplanning of land use at a building, development and city scale will need to consider the extra requirements of such initiatives.

Table 1: Indicative % of crop losses after harvesting in a developing nation.
Source: Postharvest Technology of Fruit and Vegetables. A.K Thompson[19]

Crop Estimated	% loss of total crop
Apples	14
Avocados	43
Bananas	20–80
Cabbage	37
Carrots	44
Cassava	10–25
Cauliflower	49
Citrus	20–95
Grapes	27
Lettuce	62
Onions	16–35
Papayas	40–100
Plantain	35–100
Potatoes	5–40
Raisins	20–95
Stone fruit	28
Sweet potatoes	35–95
Tomatoes	5–50
Yams	10–60

FOOD WASTAGE

There are huge gains to be made in the reduction of post-harvest food wastage in developed and developing countries alike. For the nations of the North, there are few losses from farm to supermarket. There are however significant savings and efficiency increases possible from the consumer. On average a staggering 25% of all fresh food is thrown away after being purchased at the shop or market.

By contrast, in the South the challenge is that of providing the appropriate infrastructure, distribution knowledge and storage capability, both domestic and commercial. Table 1 provides indicative figures for the scale of crop losses after harvesting in a developing nation, with variation between a few per cent to nearly all the production. In India for example, between 35% and 40% of fruit and vegetable production is lost each year between the farm and the consumer. This is an amount greater than the entire consumption of the UK, being wasted largely due to poor storage facilities, and inadequate handling between cold chains during transportation and poor management practice. The Institution of Mechanical Engineers believes that though the implementation of existing engineering solutions and techniques, many of which are relatively low-tech, the prevention of these losses could contribute to securing basic foods for the expanding population.

Mechanisation

The use of mechanical engineering through mechanisation to improve agricultural production and food processing in the developed world is one of the central food success stories of the last 200 years. Since the beginning of the Industrial Revolution the continued development of machines, resulting in tools such as a 30-ton combine that can harvest enough wheat in one day to provide a week's worth of bread to Manchester, has helped increase yields sixfold in countries of the North. Automation and robotics offer further potential improvements in the coming decades as we move towards lightweight 21st-century machines capable of 24-hour operation in all weathers, communicating with each other, autonomous and never losing track of what they have done. Such devices will be powered with low-carbon emitting clean-energy sources and could assist newly developing nations leapfrog the 'dirty' fossil fuel-based technologies of the 20th century.

Solutions will also be required in the field of water efficiency in agriculture, particularly where population growth pressure is exacerbated by climate change-induced water stress. Reductions in the water embodied in crops could be realised by many techniques. These could range from placing sensors on the sprinkler arms that deliver water to the crops, to detecting areas with a higher level of water stress, to the use of GPS technology to inform or control water delivery patterns.

The issue of embedded water applies not only to direct food products such as cereals, rice and beef, but also to processed foods. The consumption of processed food is on the increase and as a result the use of water in processing operations is also on the rise. For example, the production and processing of meat uses about 12 times the amount of water that is used in the case of wheat; producing one calorie of beef protein uses 54 calories of fossil fuel[20] and there are 15,500 litres of water embodied in each kilogram of beef[21].

“”

WATER CONSUMPTION IS ANTICIPATED TO RISE BY 30% BY 2030.

In general, agriculture is the largest user of water, consuming 70% of all water consumed globally[22], and up to 90% in developing countries such as India. Therefore, reductions in agriculture water consumption will have a significant impact. Indeed as a result of the anticipated changes in diet and projected doubling of food production by 2050, water extraction for agriculture is projected to increase by more than 20% by 2025, with some scenarios projecting between 35% and 60%[23].

Fresh water is essential to human well-being: in addition to its use in agriculture and food processing, it fulfils the physiological need for fluid intake and it is required to maintain hygiene and sanitation. However, domestic use accounts for only 10% of withdrawals worldwide, whereas industrial and energy related processes consume the remaining 20%[24]. Geographical patterns of abstraction for this sector have followed the redistribution of manufacturing and other industrial activities from the North to the South, and are likely to lead to increased stress in the developing world in the coming decades. The industrial growth profile of an individual country has a significant impact on the abstraction of water for industry, ranging from a low of 10% in undeveloped nations to as much as 60% for those that are fully industrialised. For example, water abstraction for industrial and energy uses has fallen in the USA and UK, but increased in China, India and other developing Asian nations, and continues to increase in these areas. Globally, extraction for industrial use is anticipated to increase by 50% by 2025, driven largely by economic development in Asia.

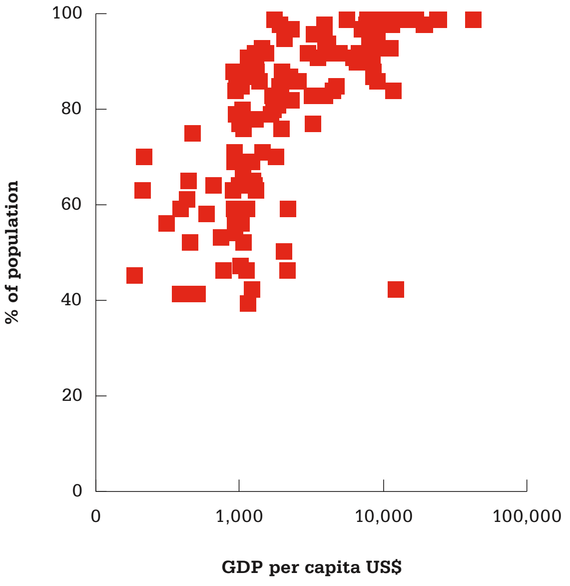
Overall, worldwide water consumption is anticipated to rise by 30% on current figures by 2030. In Northern Europe and North America, issues are likely to be largely related to water quality (and flooding in relation to climate change) and disruption to industrial/agricultural supply chains linked to water-stressed regions overseas. In particular, difficulties in meeting the supply needs of industry in Asia and newly developing African nations, as result of the combined effects of population growth and changing climate, may lead to difficulties in the sourcing of manufactured consumer goods. It is however possible, that disruptions to food supply chains originating in these regions will be offset by increased opportunities for agriculture in areas where climate change has enhanced productive capacity and growing options.

Globally, the issue is not one of a fundamental shortage of water. Rather it is a case of supply not matching demand at a certain time and place where people are living. Many of the techniques, technologies and practices necessary to address water security already exist[25] but need to be refined, improved and localised. Where and when supply exceeds demand, too little effort is placed on capturing and storing that excess supply. Many regions of the world are experiencing water stress, but the causes and solutions can be very different.

The availability of fresh water varies widely from negligible in arid regions (much of the Sahel and parts of the Middle East) to massive in rainforest areas (e.g. Central Africa and the Amazon). In 2006, 54% of the world's population had access to piped drinking water, 33% had other improved sources, leaving the remaining 884 million people without improved access[24].

While high-income countries can overcome a lack of natural water sources, for example, using desalination technology in oil-rich countries in the Middle East, poor countries cannot. The most severe water shortages are therefore found in poor countries with a lack of natural sources. **Figure 6** plots the percentage of the population with access to improved drinking water by GDP per capita in 2006. Access is near 100% in almost all countries with incomes over £6,000 (US$10,000) per capita per year. In several poor countries it is below 50% (e.g. Ethiopia, Chad, Niger, Nigeria, Somalia).

Figure 6: % of population using improved drinking-water, 2006
Source: United Nations Population Division, PRED 2009[74]



In Northern Asia, particularly China, low population growth is anticipated alongside massive economic growth, which might be inhibited by water stress. Furthermore, changing diet choices and increased demand for consumer goods among an expanding and increasingly affluent population will likely drive more water-intensive agriculture/food processing and increased industrial water usage. Despite China currently being home to about 20% of the world's population, it has only 7% of the freshwater resources. This, coupled with a lack of enforced regulation during recent development, has led to many significant issues.

Two thirds of China's cities experience water shortages, with 110 being classed as 'severe'[26]. In Northern China, 90% of the aquifers located under cities are polluted. These issues have been exacerbated by the rapid urbanisation of the region. The population of Shenzhen has increased tenfold since its selection in 1980 as China's first special economic zone. Intensive groundwater abstraction has led to the intrusion of seawater into the groundwater, reducing its viability as a source of fresh water for the city[27]. This problem is not however confined to urban environments. In the rural Fuyang Basin in China, farmers switched to groundwater irrigation over a number of decades, leading to the water table falling by up to 50m[28].

One of the fundamental geographical issues in China is the fact that the rainfall largely occurs in the south of the country, whereas many of the urban centres are in the north. This has led to the development of the South to North Water Transport Project, with the aim of transporting 50 billion cubic metres of water each year to the drier north at a cost of about $50 billion[29]. However, the transportation is mainly using canals and rivers, meaning that losses through evaporation are significant and likely to rise with the future higher temperatures projected by global warming models.

Southern Asia, for example India, is projected to experience high population and economic growth in already stressed shared hydrological basins, and this might be expected to lead to geopolitical instability. Major rivers in India and China are very heavily used and polluted, making it difficult to sustain let alone increase current withdrawal rates. Climate change is expected to exacerbate potential water shortages here.

In sub-Saharan Africa, where there is projected to be high population growth and high economic growth, starting from relatively low current levels of population and economic development, there is likely to be localised stress based on variable hydrology which will impact on economic development. In addition, the increasing urbanisation of these populations into cities which are poorly served by water and sanitation service infrastructure (e.g. slums) is likely to lead to societal tension and civil conflict.

Nigeria, as with most of the newly developing world, currently has a water usage characteristic dominated by agriculture. Inefficiencies in the use of water and the difficulty of regulating such a freely available commodity have led to significant depletion of groundwater reserves. Attempts have been made in the past to introduce water regulation but it is largely unenforceable and there is little pro-active action on environmental and water issues[30].

In 2000, only 14% of Nigerians were served by pipe-borne water and the vast majority of the population are dependent on groundwater from either hand-dug wells or boreholes[31]. In addition, about 8 million of the population, mainly those in urban areas such as Lagos are dependent on vendors for their water supply, who ultimately source the water from commercial boreholes. Actions such as these have depleted local aquifers to the point where saline intrusion has led to the abandonment of many sources in and around the Lekki peninsula in Lagos[32].

Indeed if there is one common factor that the Institution of Mechanical Engineers has identified in the issues relating to water around the world, it is the unsustainable abstraction of groundwater at a higher rate than natural replenishment allows. This is a major issue due to the importance of groundwater as a source. The volume of groundwater on the planet is over 100 times that contained in all rivers and lakes[33]. However groundwater reserves in many areas are suffering from problems of depletion, salinisation and pollution.

Challenges such as these could be eased by the increasing adoption of Aquifer Storage and Recovery (ASR). In ASR, water is re-introduced into the aquifer either by the use of wells or by altering conditions to increase natural infiltration, usually dependant on whether the aquifer is confined. The source of the re-introduced water can be treated wastewater, storm-water or rainfall. However, ASR is not feasible in all areas and alternative technologies will also be needed.

Aquifer Storage and Recovery (ASR)

ASR can combat environmental problems caused by aquifer depletion, such as the salination of the water resource and ground subsidence, and can be used to replenish water supplies for potable or agricultural use, or even for ecosystem support such as in the Florida Everglades[34]. While the technique is based on a relatively simple principle, the practical execution of a project is highly complex. Care must be taken on understanding the effects of the project on the wider area and ecosystem, and to combat any geo-chemical reactions between the highly oxygenated injection water and the aquifer substrate[35].

Currently most ASR projects are within the developed nations such as the USA and Australia and efforts need to be made to increase its uptake among suitable regions of developing nations. It is however unclear whether the technique can effectively combat the depletion of fossil groundwater that is occurring in some countries, most notably in North Africa. Fossil groundwater is water that infiltrated into the ground about a millennia ago, often under climatic conditions different from the present, that has been stored underground since that time[36]. The Institution of Mechanical Engineers urges nations with ASR experience to invest in further research and development in this area.

Extended use of ASR may make groundwater in many regions a viable sustainable source of water. In rural areas in particular, this would be a benefit, as groundwater abstraction requires significantly less infrastructure to install than surface transport. Effectively, the ground is the pipe.

Desalination is a technology that is likely to be increasingly used in the future. Advances in the underlying membrane technologies over the last few decades have significantly reduced the cost of desalination, in terms of both the financial and energy requirements. However, it still remains one of the most expensive water supply options and is generally restricted to energy-rich nations.

While desalination is commonplace in traditionally arid regions of the developed world, such as the Middle East and Australia, it is increasingly being used in more-temperate climates where population growth has outstripped the natural supply of water. In London for example a desalination plant has recently been opened at Beckton, in the lower estuarine reaches of the River Thames, to supply water to the South-East of England in times of drought[37].

The energy consumption of this plant is reduced by the use of brackish river water as a source as opposed to sea water. Desalination cannot be considered in isolation and should be part of a suite of technologies that is adopted to combat future issues with water supply.

What is clear is that decision-makers need to become more aware of the issues of water scarcity and work more closely with the engineering profession in finding localised solutions. In the planning of development projects, water needs to be placed higher on the agenda. This may range from increased domestic water recycling to the implementation of city-wide strategies. As cities grow, water infrastructure will need to be expanded and enhanced. This is an opportunity to implement solutions to one of the most fundamental issues with water use – the fact that water is usually delivered at a very high purity regardless of its intended use and that wastewater is considered to be contaminated to the highest degree regardless of what it has been used for.

At the simplest level, the first step may be to provide separate sewerage and storm-water systems to allow the less-contaminated storm-water to be stored during heavy rain activity and used as a water source in drier times. This may become increasingly important in areas that experience rainfall pattern changes as a result of climate change, particularly in the case of countries such as the UK, where the characteristics are projected to include more-extreme rain events and droughts[38]. Hong Kong is an example of a city in a climate that includes severe monsoon seasons that has a separate storm-water system to cope with large inundations. In larger developments, rainwater collection for use for clothes washing and lavatory flushing should be strongly encouraged with separate non-potable distribution networks. In coastal areas, salt water could be used for lavatory flushing.

Where solutions seem to be appropriate, wider issues of living conditions and the central role of water in the spreading or prevention of disease need to be taken into account. In Nigeria for example, it has been suggested that water distribution in sachets may be a low-cost solution to the almost endemic inadequacy of pipe-borne water. However, many issues are seen within this industry related to unregulated practices such as poor hygiene in both production and distribution[39]. What may seem like an elegant low-packaging way of distributing water can create issues in an unlikely way, such as the fact that many end-users open the sachets with their teeth. This simple action exposes them to the outside of the sachet, which may have been handled in an unsanitary fashion by vendors with almost no access to lavatory facilities.

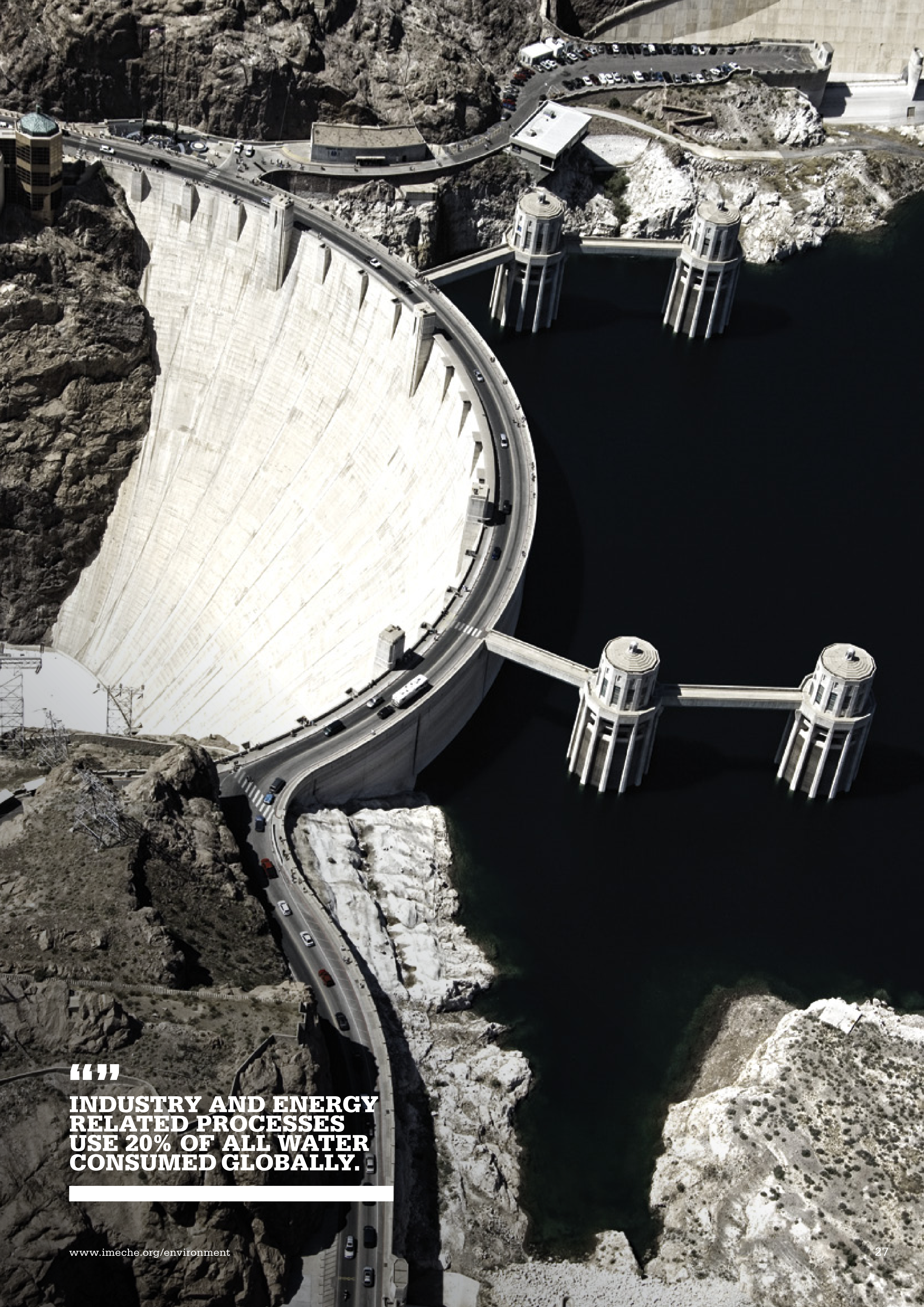
Engineers need to increase awareness of these national, regional and local attitudes and conditions. These factors, coupled with the governmental policies of the area, will affect the solutions that are most appropriate for given situations.

The Value of Water

Recently, the United Nations explicitly recognised water as a fundamental human right[40] which lends even more importance to the management of the resource. In addition, engineers need to be aware of the different cultural, political and social attitudes to water that vary across the globe.

Social attitudes are varied; in some cases, such as regions of India, even the poorest communities are willing to pay for sanitation provision, whereas they see water as a commodity that should be free. Conversely, in Malaysia for example, people consider water worth paying for but see sanitation as a basic right.

Where there is a degree of water infrastructure, the political and organisational contexts which lead to construction will be highly individual. In most cases the overseeing body will be state-controlled and will be prey to the pressures that are exerted from many areas on the administration of a country that is striving to develop economically.



INDUSTRY AND ENERGY RELATED PROCESSES USE 20% OF ALL WATER CONSUMED GLOBALLY.

75% OF THE WORLD POPULATION WILL LIVE IN URBAN ENVIRONMENTS BY 2050.

URBANISATION

Alongside food and water, shelter is a basic human need[41] and in the 21st century 'shelter' for the overwhelming majority of humans is going to be located within an urban setting. Of the population increase that is expected to occur by 2050, almost all is in urban areas in less-developed countries. The urban population is expected to increase from 3.3 billion in 2007 to 6.4 billion 2050[42]. This presents one of the greatest societal challenges of the coming decades but also a significant opportunity, as cities have the potential to be very efficient places to live in terms of a person's environmental impact.

Opportunities to build cities are few and far between, meaning that the expanding cities need to be created around existing legacy infrastructure that is often not adequate to meet the needs of the current population, let alone the expected influx of people from rural areas. Coupled with this, for historical reasons, many cities of the world are located in areas that have natural extents to expansion and increased susceptibility to natural disasters such as flooding or earthquakes.

Of particular concern are the effects of climate change-induced sea-level rises on coastal cities. Three quarters of the world's large cities are on the coast[43] and some of the largest are based on deltaic plains (such as Bangkok and Shanghai) where land subsidence will exacerbate water-level rises. Often the homes and people located in the most vulnerable areas are those that are least able to withstand disaster.

While these issues will affect all coastal cities, those in the developing world are often necessarily focused on shorter-term issues. In Lagos, for example, much of the recent effort has been put into the developing of a robust administration. In a city fraught with issues around transportation, sanitation, unemployment, the direction provided by stable leadership is a source of hope. Proposals have been put in place by the Transit Authority for an urban rail system[44] and considered masterplanning is in place for the development of the city which allows for the provision of infrastructure to meet future needs as opposed to efforts being reactive.

When considering the issues faced by cities, thoughts often turn to mega-cities such as Lagos, Tokyo, and Mumbai, homes to tens of millions of people. However, more than half of the world's urban population live in cities of fewer than 500,000 people.

In addition, all established cities have a very deeply ingrained culture that takes on aspects from the region it is located in, but can also have a well-developed character individual to that urban area. Engineering solutions need to work with these differences. Trying to make a solution fit without proper consideration of these aspects that have traditionally been considered by engineers as secondary to the engineering issues will lead to failure.

Urban Transport

A successful city that is to provide homes, work and services to its inhabitants, needs not only buildings but a wide range of supporting infrastructure, not least of which is transport[45]. How people inter-relate with one another is a very important factor. In almost all cities, technology will play a part in this aspect, but there will always be a need for an effective, efficient transportation system.

In China, cities often have a multi-polar layout where the majority of inhabitants travel only locally. Increasingly high-speed rail is used to unify the nodes into a single urban area, often blurring traditional municipal boundaries but leading to an increase in supply and logistics efficiencies. The opening of the Wuhan to Guangzhou line in 2009 reduced the rail travel time between these two cities, both of about 10 million inhabitants, from ten to three hours, thereby significantly increasing the connectivity between two previously disconnected places. By 2012, China is projected to have completed 42 high-speed rail links covering more than 8,000 miles.

In other areas and in smaller developments, cities are very centre-biased, with the most important issues being efficient local mass-transit solutions to move away from car use. Underground metro systems are often proposed as the panacea, but the levels of investment needed are significant and a more appropriate solution is often to enhance above-ground transport options[45].

In developing countries, maximising the benefit seen for a given investment is crucial. By integrating systems[45], efficiencies can be brought to more than one area, but this requires careful planning. This can be in terms of improvements in efficiency either during construction or during operation.

Transport is a good example of how each situation needs to be considered within the context of an integrated holistic approach. The same is true in every aspect of a city's functionality, from food deliveries to sewage systems to energy provision. There is no one solution for a city of the future.

As cities expand, they will be under pressure to be more independent in terms of resources and waste. The Institution of Mechanical Engineers has shown that the energy from waste by combustion, anaerobic digestion or other means can be a low-carbon energy source[46], but it must be considered within the context of other aspects of the country's waste and energy systems.

The energy generated from the waste needs to be compared with the carbon intensity of the energy it is replacing. The emissions of the energy recovered can be significantly affected by whether heat, electricity or both are generated[46]. The alternative way to recover the energy from waste, that is collection of land-fill gas, may be entirely appropriate in regions with well-developed waste management processes, but inefficient in other areas.

Of all the issues faced globally by urban-dwellers, both now and in the future, one of the most prevalent and pressing is that of informal housing areas. 18% of all urban housing units are non-permanent structures and one third of the world's urban population live in what are defined by the UN as slum conditions[47]. The situation is much worse in some areas with Nigeria, for example, having about 65% of its urban population living in slums[48].

In dealing with the issues of slums, planners must recognise that it is not simply an engineering solution they are seeking – they are aiming to improve the lives of the inhabitants. The 'simplest' solution of decant-demolish-rebuild-return fails to acknowledge the slums as a home and workplace to the people who live there. Where programmes such as these have been implemented in the past they have often failed.

A narrow, technical solutions-focused approach was adopted, for example in Mumbai, in the middle of the 20th century, where substandard housing was demolished and the tenants provided with upgraded housing. Even though much of the housing was on the same site as the original, many of the poor were unable to continue with their jobs, and communities and social networks were destroyed through being dispersed[49].

In addition, a lack of understanding of the operation of the slum areas saw these programmes severely affecting the informal economy that so many rely upon. The informal economy is characterised by local small-scale family operations and provides an income for many slum-dwellers. However, the opportunities afforded by these activities can be destroyed when upheaval causes the breaking of social ties.

So, as is the case with many issues of urbanisation, starting from scratch is not feasible. There needs to be an understanding of the local value of water, sanitation and energy, and interventions targeted at each issue. These include the provision of innovative community infrastructure financing and ownership models[50], provided by maximising local options without resorting to large-scale publicly funded interventions.

As is the case with many other issues posed by population growth, there are often very few technological barriers for why solutions to increasing urbanisation cannot be found. The issue is one of planning, developing the right solution to fit in with local geography and culture and, most importantly, effective implementation through availability of innovative finance, ownership models and community participation. The importance of the maintenance of existing infrastructure should also not be underestimated as a method of increasing the efficiency of a system as a whole.

Unfortunately, early planning decisions are often taken without the availability or input of engineers. Of all the aspects that cities may need to address in the future, the engineering of the solution provides not only the constraints but also the opportunities for an innovative solution.

To maximise the benefit realised from any infrastructure improvement, engineers need to be consulted and involved at the very early stages. Furthermore, engineers should be in contact with local and regional decision-makers to ensure they are on hand to provide support when needed. In addition, the profession needs to increase its understanding of local innovative funding and ownership models, political situations and social context, in order to develop solutions that align with these drivers.

Successfully Transforming Slums

The internationally renowned Favela-Bairro neighbourhood improvement programme in Rio de Janeiro has brought basic infrastructure and municipal and social services to the slums of that city. The first phase in 1995 concentrated on infrastructure improvement that included water, sewage and transportation improvements along with maintenance issues such as refuse collection. The second phase concentrated on more social aspects such as the construction of child-care centres, the training of community members in hygiene along with action on property rights, highlighting the importance of security and tenure in community development[51].

One of the most proven routes to success in the redevelopment of slum areas is the inclusion of the inhabitants in the decision-making and planning process. This approach has been taken in Thailand with the national Baan Mankong (secure housing) programme aimed at targeting the Millennium Development Goals. Instead of direct intervention by local or regional government, the programme channels infrastructure financing and housing loans direct to poor communities, who plan and carry out improvements, thus handing the communities a central role. Programmes in this style also have the benefit of altering the relationships between the community leaders and the administration of the cities, instilling confidence in the urban poor groups that they can influence solutions.

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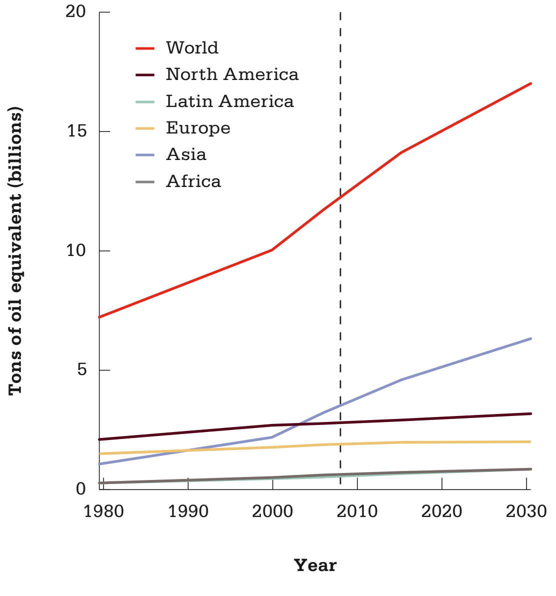
OVER 1.5 BILLION PEOPLE IN THE WORLD DO NOT HAVE ACCESS TO ENERGY.

Food, water and shelter are basic human needs, but energy is the foundation of industrialised economies worldwide and underpins our current way of life. Global energy consumption is estimated to currently be circa 12 billion tons of oil equivalent and has risen steadily over time as economies expanded. Per capita energy use varies widely among countries and is highly correlated with GDP per capita. Most energy today comes from fossil fuels (oil, coal and natural gas) with small contributions from hydro-electric, nuclear, biomass and other renewables. Global demand for energy is expected to continue to rise at a steady pace for the next two decades, reaching 17 billion tons of oil equivalent in 2030, an increase of about 46%[6]. Most of this increase is projected in Asia, see **Figure 7**, notably China and India, where economic growth is rapid and energy-intense sectors dominate. The projected annual rate of growth in energy consumption is lower than in total economic growth due to anticipated modest future declines in the energy intensity of GDP.

Figure 7: Primary energy demand 1980–2030
Source: IEA World Energy Outlook 2008[6]



Although it is difficult to project likely demand beyond 2030, the curves in **Figure 7** suggest further growth of demand throughout the 21st century. Some have predicted a doubling of supply by 2050[52], and quadrupling by 2100[53], in response to a combined effect of increasing population and progress towards higher standards of living around the globe. However, it is possible that implementation of different approaches to meeting demand in emerging economies of Africa, combined with a future slowing down of demand in Asia as economies there reach a post-industrial phase similar to Europe and North America, may lead to a levelling off of supply globally in the latter half of this century.

Energy strategies in both developed and developing nations that encourage consumption to move downwards and reduce demand, through a combination of engineering and behaviour change, are likely to emerge in response to a range of economic, environmental, political and social drivers. The deployment of energy management technologies, such as intelligent appliances and smart meters, together with reductions in waste through better insulated buildings and effective use of heat, are examples of engineering initiatives that can be pursued in this regard. Care can be taken in newly developing countries to engineer in many of these approaches from the start, therefore ensuring that the world's growing populations leapfrog over the unsustainable failings of many of the wasteful energy solutions embedded in the infrastructure of mature industrialised nations such as the UK.

Currently, the environmental impact of energy consumption is mainly attributable to the by-products of the combustion of fossil fuels. The anthropogenic production of carbon dioxide, the principal greenhouse gas emitted by the energy sector worldwide, is growing annually and is closely coupled to global energy consumption. Other pollutants include soot, heavy metals, oxides of sulphur, nitrogen and carbon. The environmental impacts of fossil fuel consumption, in particular climate change, will become very damaging unless much stronger government interventions are implemented to reduce current dependence on this fuel[9].

There are many conflicting reports on the size and accessibility of the world's reserves of fossil-fuel energy sources. Few argue that 'Peak Oil' will not happen, but there are many opinions on when productivity reductions from existing sources will outstrip the discovery of new fields. In the case of conventional sources, the UK Energy Research Council reports that there is a significant risk of a peak before 2020[54] whereas a UK Government report commented that proven reserves are equal to over 40 years of current production[55].

What is certain is the amount of energy that needs to be used to extract fossil fuel will rise inexorably in the coming decades, effectively reducing the net energy available from them and having a significant impact on the price of energy. This scarcity combined with the need to reduce greenhouse gas emissions may lead to fuels being restricted to use for the purposes that most suit their characteristics. For example, the high-energy density required by aviation is most suited to liquid fuels, be they biofuels or fossil fuel derived, whereas electricity is more viable for some ground transport.

Concerns over anticipated climate change, combined with future security of supply worries are, even in the absence of an international legally binding agreement on greenhouse gas emissions reduction, causing the world's economies to strive for commercially viable low-carbon (ie non-fossil fuel-based) alternatives. It is therefore reasonable to assume that in the long term, the energy generation solution that is developed to meet the needs of a larger global population will contain a significant proportion of low-carbon technologies[56]. It is likely, however, that despite the projections for increases in future demand, engineering technology which is currently relatively well understood, mature or in advanced stages of development, will be able to contribute the required energy throughout the 21st century without the need for major new scientific breakthroughs.

One of the fundamental concerns over new high-tech solutions that are at the very start of their development curves is the lengthy timescales and large budgets needed to develop them to a point where they can deliver energy at a scale that can make impact in meeting demand. The area of nuclear fusion is a good example of how long highly complex electricity generation technologies can take to reach commercial maturity. It has been in scientific development for many decades and, despite ongoing progress towards the building of the prototype International Thermonuclear Experimental Reactor (ITER) to demonstrate the technique, the technology is unlikely to be ready for deployment before 2050[57].

This lengthy gestation period is also predicted for space-based solar power, where orbiting solar collectors are used to harness the sun's rays before beaming the energy down to earth in laser or microwave form for distribution as electricity. Some estimates indicate that prototypes won't be developed for 20 years, requiring an investment of tens of billions of dollars[58].

In contrast to developing new techniques with long and costly paths to commercial maturity, there are many technologies in existence today with proven track records that could increase their contribution to meeting the world's increasing energy demand. Research into the modification and re-engineering of existing methods is also more likely to realise results at a realistic timescale.

The use of algae to provide biofuels is an example of a technique that is developing particularly quickly, with projections of commercial maturity within ten to 15 years[59]. Another such technology is Concentrated Solar Power, which has the potential to contribute up to a quarter of the world's energy needs by 2050[60]. Compared with these projections, it is currently being under-utilised. There are various applications of the technology utilising point collectors, parabolic troughs or solar towers. The first commercial generator, located in Spain, was operational in 2007 with 75,000m^2 of mirrors concentrating the power of the sun towards the top of a tower with the capability of generating 11MW of power[61].

Alternatively, the development of the fourth generation of nuclear reactor technology has an understood route to delivery in the 2030s[62]. China has already constructed, and begun testing, its first fourth-generation nuclear reactor[63]. While nuclear power has its issues, it is highly likely to play a part in future energy scenarios. When combined with fast-breeder reactors, the new installations will make much more efficient use of the world's finite resources of uranium. Developments in the use of thorium as a source of neutrons for reactors could also result in a potentially long-term supply of energy, with the advantage of going some way to decoupling the link between nuclear power generation and weapons[64].

INFRASTRUCTURE AND ACCESS

It must be remembered that an effective power infrastructure requires not only generation but also transmission, distribution and some degree of storage. Once again, there is no technological reason that long-range High Voltage Direct Current transmission techniques cannot effectively link areas of population with regions of the world that are rich in solar resource, for instance, without the need to wait for future breakthrough developments in the materials used in power transmission. For example, increases in conductivity through the use of superconductors are possible now, but the materials require cooling to a very low temperature to operate, with the attendant energy costs. Room-temperature superconductors and other technologies such as carbon nanotubes are being developed in the laboratory, but are a long way from being a commercial product that can withstand the rigours of manufacture, installation and operation.

Within the newly developing economies of the South, the scale of infrastructure investment required to create an electricity transmission and distribution network similar to the developed world may be prohibitive and many of the emerging generating technologies simply too costly and inappropriate to meet their needs. As a result of the often large distances involved in connecting rural communities of a few hundred houses to an electricity grid, local-generation technologies such as solar photovoltaics have reached parity with the cost of centrally generated energy[65]. In recent years, for example, more rural Kenyan communities have bought unsubsidised photovoltaic cells than have connected to the subsidised national grid (although this still accounts for only a tiny fraction of the rural population). Other mature, relatively low-tech engineering technologies such as wind, micro-hydro, energy-from-waste with Combined Heat and Power (CHP) and biomass gasification feeding a CHP generator are also viable if the right geographical conditions exist.

The role of biomass should not be underestimated either, with a third of all energy consumption currently coming from this source. Low-efficiency biomass stoves have the secondary effect of resulting in very poor internal air quality in homes with ineffective ventilation. The efficiency of cooking can be significantly increased, along with health prospects, with the use of simple stoves that are the basis of numerous programmes worldwide[66].

Over 1.5 billion people in the world do not have access to energy, the largest concentrations of whom are located in Africa and Asia. When considering the provision of energy for these poorer communities, it is often the capital investment associated with installation which provides the biggest barrier to implementation. Evidence shows, however, that people are willing to spend a significant amount of their income on the improved way of life that better energy can provide, if they have access to suitable low-cost finance. Mechanisms such as innovative soft loans and micro-financing, 'zero-cost' transition packages and new models of individual and community ownership must be put in place to reduce the capital investment cost if significant levels of access to energy are to be realised in developing countries and adoption of localised sustainable technologies encouraged.

This increased prevalence for local electricity generation, and the greater proportion of the energy mix coming from naturally intermittent renewable sources, increases the importance of energy storage technology. The scale of the solutions needed would vary widely dependent on the scale of network connected, and the question of who pays for the cost of storage is potentially an issue for resolution. In the developed world, large-scale installations such as pumped hydro or compressed air that support a national grid are required.

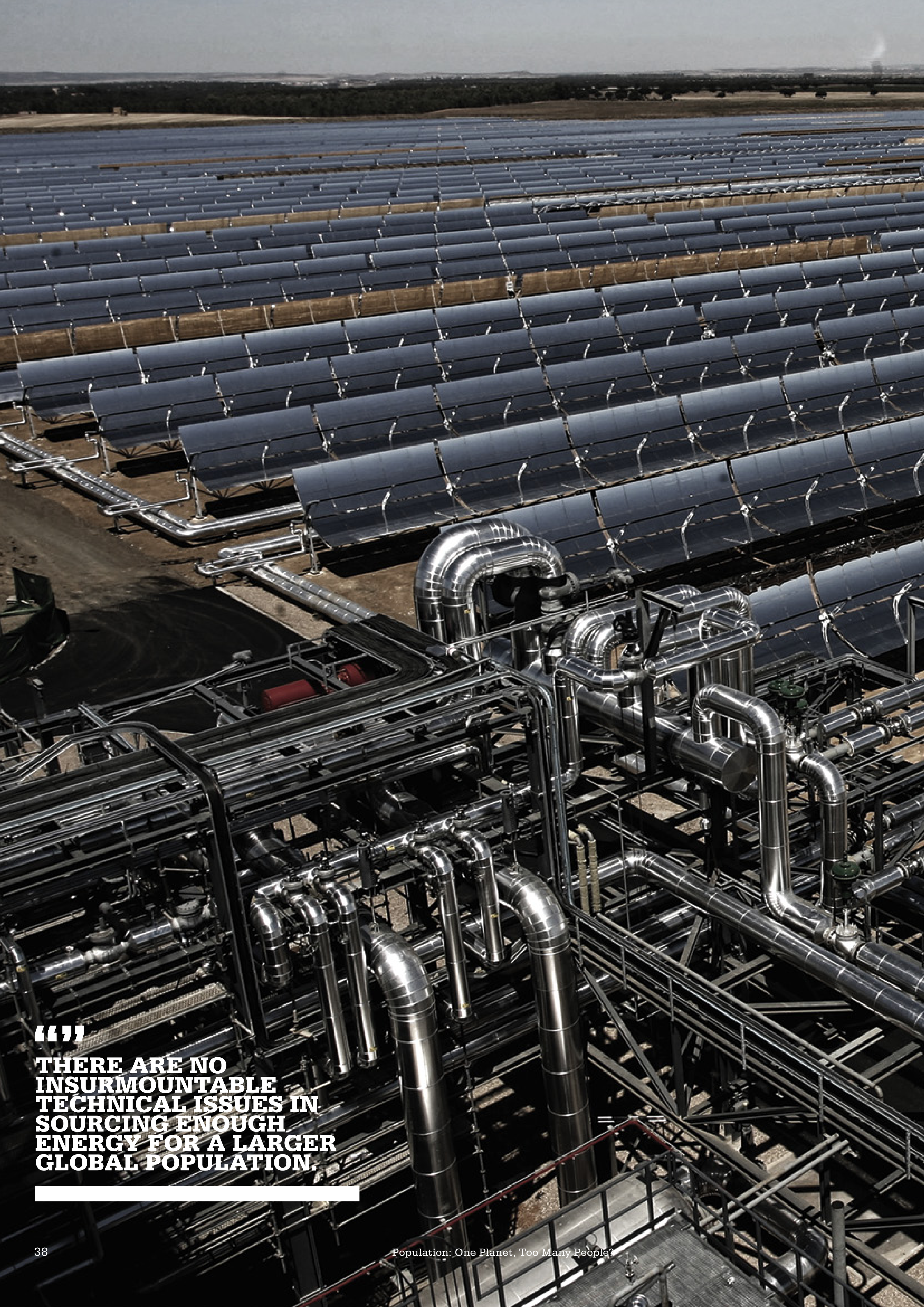
However, in the developing world, smaller-scale local solutions such as batteries will be used. This raises an associated issue in that emerging battery technologies are often based on the use of finite and increasingly rare resources of minerals such as lithium, zinc and tantalum. Other energy storage options are available and the application of the variety of technologies depends on the size of the installation. Fuel cells are an area currently undergoing development, but the inefficiencies of the current technology mean that about two thirds of the energy is lost in conversion (although this figure does include transportation, which would not be an issue in the application under discussion)[67]. It is evident that continued development is needed in this field.

Minerals depletion, particularly of Rare Earth Elements, requires urgent action. In addition to being central to a number of emerging clean-energy technologies[68], such as batteries, fuel cells, hybrid cars, wind turbines, nanotechnology and low-energy lights, these minerals are used extensively in consumer electronics including computers and mobile phones. Shortages of these materials could hamper future efforts to implement sustainable low-carbon emitting energy solutions. The development of these technologies is also under pressure from artificial shortages of minerals caused by international trade restrictions. In the case of Rare Earth Elements, China currently produces 97% of the world's supply and has had export restrictions in place since 2000[69].

The example of Rare Earth Elements is extreme, but similar shortages are being faced with associated trade restrictions relating to a number of materials, from tantalum to scrap metal. Fundamentally, there is a need for all societies to embrace the principles of sustainable consumption and reduce their impact on the planet through efficiency, substitution or curtailment. The Institution of Mechanical Engineers can help in these goals by encouraging the widespread adoption of a number of concepts throughout the design process, such as design for remanufacture and re-use, and society should see resource restrictions as an opportunity to develop more efficient and sustainable solutions as a response to these drivers.

Even though the Institution of Mechanical Engineers believes there are no insurmountable technical issues in sourcing enough energy for an increasingly affluent larger global population, and providing it to where it is needed, the solutions that will deliver a successful outcome are by no means simple. The difficulties lie in the areas of regulation, financing, politics, social ethics and international relations. These issues will influence the engineering solution in any given circumstance and engineers need to ensure that all participants are understanding of them to allow local conditions to be taken into account. There is little point in developing an excellently engineered solution to a problem if it is ignored because of the reality of local constraints and opportunities.

History has taught us repeatedly that without access to abundant sources of energy, economies ultimately collapse in the face of diminishing returns on investments in higher levels of complexity[70]. As we move forward in an increasingly globalised economy, to meet the energy needs arising from enormous changes in world population demographics, it is important for engineers, communities and governments to work more closely than ever before towards sustainable solutions that result in benefit for all.



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THERE ARE NO INSURMOUNTABLE TECHNICAL ISSUES IN SOURCING ENOUGH ENERGY FOR A LARGER GLOBAL POPULATION.

WHAT NEEDS TO CHANGE

Population increase and demographic change is a global issue that will affect us all, regardless of whether the countries in which we reside become more crowded or not. As the world moves towards the projected peak of nine billion in 2050, engineers represented by professional bodies such as the Institution of Mechanical Engineers have the knowledge and skills to meet many of challenges that are expected to arise. In addition, these can often be solved using technologies that are either available today or are relatively close to being proven. There is no need to delay action while waiting for the next greatest technical discovery or breakthrough idea on population control. The development, demonstration and deployment of currently viable technologies should instead be prioritised and accelerated by govenments around the world. The Engineering Development Goals presented here provide a way forward based on the findings presented in this report and offer society a logical next step beyond the current Millennium Development Goals which expire in 2015.

It is evident that the barriers to deploying solutions are not technological. The issue is often one of implementation and in this area action should be taken by society and political leaders at national, regional and local levels. Communication between these groups and the engineers would increase awareness, understanding and clarification of the possible engineering options, their potential benefits, limits, constraints and trade-offs. Government in the UK, and other developed countries, should work with the engineering profession to develop the Engineering Development Goals further and establish targets for their adoption alongside the Millennium Development Goals.

While communication between engineers, the public and decision-makers is important, it is also true that communication between different strands of the engineering industry needs to improve. As projects deal with more-complex issues around population growth, the engineering profession must work together to provide integrated, viable and truly sustainable solutions.

In addition, the engineering profession should make efforts to further its understanding and knowledge in areas of work that have until recent decades been considered secondary to its core technical activity. To develop viable solutions to what is an inherently human issue, engineers must be increasingly mindful of the social impacts of interventions, to allow these issues to be integrated into designs and to allow more-effective communication with specialists in these fields.

However, the opposite also applies. Planning and governance of national, regional and local administrations around the world would be enhanced if decision-makers had access to the best engineering knowledge and expertise available.

The UK, as an example, has a strong science and engineering base and Government can call on the expertise of over 30 professional engineering institutions if required. However, many other nations lack this pool of knowledge and mechanism for the transfer of emerging 'best practice', with the result that off-the-shelf technologies may be purchased which are not suited to their local needs.

As many nations already provide or share medical advice and assistance to others who may lack the facilities or professionals, the Institution of Mechanical Engineers believes this practice should be more widely adopted for engineering.

By providing nations with professional engineers that have knowledge of sustainable approaches, which are seconded overseas for a given period to examine the local/regional requirements, establish the needs and viability of available technologies, and advise on the best ways forward, we can help developing nations avoid making many of the mistakes we have over the decades. It is our belief that the Department for International Development, respected for its overseas development efforts, should further expand its engineering and technology remit to include this additional service.

On a larger scale, some of the issues discussed will be solved only through international co-operation, which will inevitably lead to the establishment of agreements and legislation. These will require careful alignment with the technical capability of the solutions proposed and there is a role for engineers to ensure that legislative tools are robust and appropriate.

Efforts should also be made to address the inherent global imbalance of the challenge. The majority of the population growth is projected to occur in the developing world whereas in many cases knowledge of potential solutions, and experience of the failings from unsustainable activity, are currently more concentrated in the developed world. If economic market forces are left to be the sole or major driver of intervention and action is delayed, then the route to an acceptable solution may be more difficult.

This aspect is even more important when the added complicating factor of climate change is considered. Helping the South to leapfrog the high-emissions, dirty, unsustainable phases of agricultural and industrial development, while raising growing populations out of poverty and improving standards of living globally, has benefit for all. As a first step in this direction, the Institution of Mechanical Engineers encourages the UK Government to take a lead on proposing and championing the Engineering Development Goals in the international community as the next step beyond the Millennium Development Goals.

CONTRIBUTORS

The Institution of Mechanical Engineers would like to thank the following people for their assistance in developing this report:

- Roger Alley CEng CEnv, Hong Kong
- Obinna Akabogu, Nigeria
- Malcolm Ball CEng, UK
- Silvia Boschetto CEng, UK
- Andrew Bowden, South Africa
- Dr Colin Brown CEng, UK
- Vera Bukachi, UK
- Susan Claris, UK
- Paul Cosgrove, South Africa
- Simon Dodd IEng, UK
- Keith Evans, UK
- Dr Tim Fox CEng CEnv, UK
- Sarah Gillhespy CEnv, UK
- Richard Knights CEng, UK
- Andy Lawton CEng CEnv, UK
- Andrew McDowell CEng, UK
- Alice Owen CEnv, UK
- Umair Patel, UK
- Dr Clare Perkins, UK
- Dr Edoardo Piano CEng CEnv, UK
- Slavis Poczebutas, Hong Kong
- Dr Simon Roberts CPhys, UK
- Ed Sayce, UK
- Andy Sheppard CEng, UK
- Jonathan Ward CEng, UK
- Albert Wei, USA
- Rory Williams, South Africa
- Peter Wilkie CEng CEnv, UK
- Rainer Zimmann CEng, UK

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Institution of Mechanical Engineers

1 Birdcage Walk
Westminster
London SW1H 9JJ

T +44 (0)20 7304 6862
F +44 (0)20 7222 8553

environment@imeche.org
www.imeche.org