ice
Institution of Civil Engineers

Engineering Civilisation from the Shadows

6th Brunel International Lecture

Professor Paul W Jowitt of Heriot-Watt University
ICE Vice President

A
Rotterdam.
Credit: Paul Jowitt

B
Downtown Calgary.
Credit: Paul Jowitt

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Delhi.
Credit: Paul Jowitt

D
Kibera.
Credit: Paul Jowitt


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Credit: Paul Jowitt

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Credit: Carbon Trust

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Credit: © Transport for London 2005

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Credit: Gordon Masterton

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The Brunel International Lecture

The Institution of Civil Engineers (ICE) established the Brunel International Lecture in 1999 in memory of Isambard Kingdom Brunel.

The Brunel International Lectures have covered topics ranging from Infrastructure, Technology for the Third Millennium, Sustainable Development, Poverty Alleviation, and Water for the World.

The 2006 Brunel International Lecture – Engineering Civilisation from the Shadows – draws on elements of all of them. Its focus is on the role of engineering in addressing the twin spectres facing the world in the 21st century: climate change and world poverty:

Poverty

Engineering the poor out of the dark shadows cast by world poverty and the misery it generates.

Climate change

Engineering the world away from the equally long shadows thrown by an energy and environmental crisis and with global climate at a tipping point.

The resolutions for these two issues are not unrelated. It was no coincidence they were the central issues at the G8 summit in Gleneagles in July 2005.

The 2006 Brunel International Lecture is launched in London on 6 June 2006, just over 200 years after Brunel was born on 9 April 1806. Over the succeeding 12 months it will be taken around the world to various venues. In particular:

- Where the Institution has members
- Where the content of the lecture is of local relevance
- Where the Institution seeks to influence change

Continual feedback, comment and input will be sought from people around the world. In that sense, it is a living lecture and will be adapted in the process of delivery. This version is just "work in progress".

A
Ground floor of house in Banda Aceh devastated by Tsunami.
Credit: Amar Bhogal

B
Vast areas of Banda Aceh razed to the ground by Tsunami.
Credit: Amar Bhogal

C
Impact of the Tsunami in Sri Lanka.
Credit:
Gordon Masterton

Engineering Civilisation from the Shadows

Professor Paul W Jowitt of Heriot-Watt University
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Climate change is real

It is now almost universally accepted that global climate change is a reality, and that the activities of the human race – principally through the release of greenhouse gases – are a contributory factor over which we do have some control and which we now need to exercise beneficially.

However unpredictable in terms of their precise spatial and temporal effects, the consequences of climate change – sea level rise, depletion of freshwater water resources, changes in the patterns of rainfall, drought and flooding – will have the greatest impact on the most impoverished people of the world. And those least susceptible to the effects will be those most responsible for the bulk of the causative emissions.

In June 2005, National Science Academies of 11 countries – Brazil, Canada, China, France, Germany, India, Italy, Japan, Russia, USA and the UK issued a Joint Statement[1]: 'Global Response to Climate Change'. Its opening line was: "Climate change is real." It went on to say:

"…human activities are now causing atmospheric concentrations of greenhouse gases to rise well above pre-industrial levels. Carbon dioxide levels have increased from 280 parts per million (ppm) in 1750 to over 375 ppm today – higher than any previous levels in the last 420,000 years."

"…even if greenhouse gas emissions were stabilised instantly at today's levels, the climate would still continue to change as it adapts to the increased emission of recent decades. Further changes in climate are therefore unavoidable. Nations must prepare for them."

"Developing nations that lack the infrastructure or resources to respond to the impacts of climate change will be particularly affected. It is clear that many of the world's poorest people are likely to suffer the most from climate change."

"The task of devising and implementing strategies to adapt to the consequences of climate change will require worldwide collaborative inputs from a wide range of experts, including physical and natural scientists, engineers, social scientists, medical scientists, those in the humanities, business leaders and economists."

The Statement then called on the G8 Leaders – who were about to assemble for their summit at Gleneagles in 2005 – to acknowledge the clear and increasing threat of climate change and to identify cost-effective steps that can be taken now, to contribute to substantial and long-term reductions in net global greenhouse gas emissions. They also called for the mobilisation of the engineering, science and technology community, to develop and deploy clean energy technologies and approaches to energy efficiency, and the sharing of this knowledge with the developing nations, to enable them to develop innovative solutions to mitigate and adapt to the adverse effects of climate change, while explicitly recognising their legitimate development rights.

The Earth's surface has warmed by approximately 0.6°C during the 20th century. The Intergovernmental Panel on Climate Change (IPCC) has projected that over the next century average global surface temperatures will rise further by between 1.4°C and 5.8°C. The IPCC estimates that the combined effects of ice melting and sea water expansion from ocean warming are projected to cause the global mean sea-level to rise by between 0.1 and 0.9 metres by 2100.

In Bangladesh alone, a 0.5 metre sea-level rise would place about six million people at risk from flooding. The IPPC's 2001 report[2] also predicted:

- Increased storminess and drought with major impacts on agricultural production in many parts of the developing world
- A range of impacts on human health, aggravated in many parts of the world by problems of water supply, and hunger and malnutrition
- Massive increases in species extinction rates

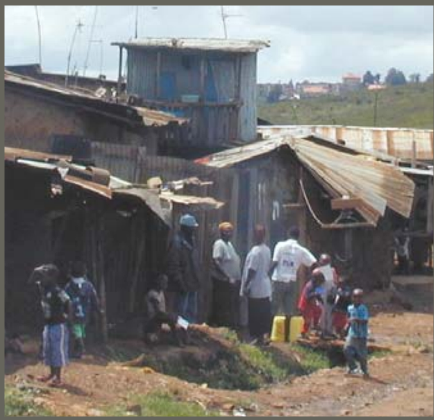
"The task of devising and implementing strategies to adapt to the consequences of climate change will require worldwide collaborative inputs from a wide range of experts, including physical and natural scientists, engineers, social scientists, medical scientists, those in the humanities, business leaders and economists."

A
Kibera.
Credit: Paul Jowitt

B
Mbdoni in Kenya.
Credit: Paul Jowitt

C
Hanna-Nassif in Dar es Salaam, Tanzania.
Credit: Paul Jowitt

D
"To judge the health of a nation, count the taps not the hospital beds."
Credit: WaterAid



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A recent paper by Patz et al[3] reports that the World Health Organization (WHO) has estimated that climate change caused by industrial emissions already accounts for at least five million cases of illness and more than 150,000 deaths per year through illnesses such as diarrhoea, malaria, bacterial contamination of food and malnutrition. This offers further evidence that the issues of global climate change and world poverty are strongly interrelated.

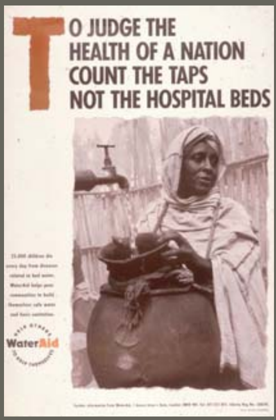
The effects of climate change are not confined to slowly changing and spatially widespread phenomena, but are also manifest in the increased occurrence of short-term episodes of extreme behaviours such as hurricanes and typhoons. There is support for the view that Hurricane Katrina, which devastated New Orleans in late August 2005, was such an event – its power intensified by increased sea temperatures in the Caribbean Ocean. In August 1992 Hurricane Andrew[4] proved to be a near miss for downtown Miami, Miami Beach, Key Biscayne, Fort Lauderdale and New Orleans in particular, but not for some. It resulted in severe damage to the northwestern Bahamas, the southern Florida peninsula and south-central Louisiana. US damage alone amounted to $25 billion, making Andrew the most expensive natural disaster in US history at that time. With Hurricane Katrina in 2005, New Orleans was not so fortunate. The economic damages of Katrina dwarfed those of Andrew – at least $125 billion. The social consequences are even more dramatic – and not countable in dollars…

But perhaps the major lesson to be learned from Katrina and the destruction of New Orleans was how the critical infrastructure of such a major city in the world's richest and technically most advanced nation could so easily be reduced to chaos, and with it the social cohesion of its population.

And with urbanisation increasing apace globally (by 2025, the world's population will have increased by about 1.5 billion to a total of approximately 6.6 billion, and the percentage of those living in urban environments will have increased from 40% to 60%[5]) the greatest risks to humanity will be in the lesser developed countries, and where the criticality of urban infrastructure – where it exists – is even more fragile. And where it doesn't, the consequences are even more awful to contemplate.

> "We are the first generation that can look extreme poverty in the eye, and say this and mean it – we have the cash, we have the drugs, we have the science. Do we have the will to make poverty history?" Bono

C



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Poverty is real

Even without the effects of hurricanes, floods, earthquakes and landslides, the immediate prospects for both the urban and rural poor in many parts of the world is bleak, with little or no access to even the most basic of infrastructure, education, and healthcare, and with little, or at best tenuous, legal tenure to land or property.

Six of the eight UN Millennium Development Goals[6] (MDGs) are directly concerned with the human condition – people's physical health, their economic and social well-being and their capacity to play a full and useful role in the world. Two of them relate to the condition we are in and how we deal with it.

In one way or another, all of the UN MDGs depend critically on the delivery – and the processes of delivery – of the underpinning infrastructure upon which civilisation depends. And not just infrastructure, but infrastructure that delivers real, pro-poor outcomes in the process of its planning, construction and operation.

UN Millennium Development Goals:

1 Eradicate extreme poverty and hunger
2 Achieve universal primary education
3 Promote gender equality and empower women
4 Reduce child mortality
5 Improve maternal health
6 Combat HIV and AIDS, malaria and other diseases
7 Ensure environmental sustainability
8 Develop a global partnership for development

And so, just as addressing climate change will involve engineers, so too will addressing the UN MDGs. This was underlined at a breakfast meeting held in 11 Downing Street on 30 November 2005. The critical role of underpinning infrastructure for development was stated at the outset by Calestous Juma[7] (Chair of the United Nations Science, Technology and Innovation Task Force):

> "At least three key factors contributed to the rapid economic transformation of emerging economies. First, they invested heavily in basic infrastructure, which served as a foundation for technological learning. Second, they nurtured the development of small and medium-sized enterprises, which required the development of local operational, repair and maintenance expertise. Third, their governments supported, funded and nurtured higher education institutions, academies of engineering and technological sciences, professional engineering and technological associations, and industrial and trade associations."

It was reinforced at the same meeting by the UK Government's Chief Scientific Advisor, Sir David King:

> "The key to sustainable development in Africa – that is, development that does not rely indefinitely on foreign aid – is the creation of infrastructure. Part of this is a purely physical matter: a question of civil engineering. The business and finance communities in African nations identify the lack of good roads, railways, air and water transport facilities, energy and water supplies, and telecommunications networks as one of the main obstacles to economic growth."

Of all the UN MDG targets, perhaps those that could have the most impact are those relating to safe water supplies and waste water disposal. Never has there been a truer statement than that which first appeared on a WaterAid poster over 20 years ago: "To judge the health of a nation, count the taps not the hospital beds."

Two billion people worldwide are currently without access to an adequate water supply. The UN's target is to halve that number by 2015. And that in the face of a world population that is becoming more and more urbanised. Providing safe water for one billion people by 2015 means connecting more than a quarter of a million people per day, every day, for the next 10 years. Can it be done? And if so how?

In another pre-G8 call, and from a very different quarter, Bono, the lead singer of U2, laid down the challenge:

> "We are the first generation that can look extreme poverty in the eye, and say this and mean it – we have the cash, we have the drugs, we have the science. Do we have the will to make poverty history?" (Bono)[8]

This section of the paper has set the scene, laid out some of the evidence, and throws down the challenge of Engineering Civilisation out of the Shadows.

The emphasis must be on the delivery of successful outcomes.

A
Isambard Kingdom Brunel.
Credit: ICE

B
Gro Harlem Brundtland.
Credit: UN

C
Joseph Bazalgette.
Credit: ICE

Visions of the future – seeing the big picture

So it is clear that there are two global issues that affect us all and in which we are all players. There will be no spectators as the future unfolds. But there are particular implications for civil engineers and the Institution of Civil Engineers. And not for the first time.

Brunel

To many engineers – and to many non-engineers too – Isambard Kingdom Brunel was one of the 19th century's great heroes. Not just an engineering hero. A man of short physical stature but a giant among his peers. The obvious questions arise: How would Brunel respond to the challenges of the 21st century? Would he have been an engineer at all? If he had, would he be motivated by the fascination of machines or by the needs of people? Would he have seen how to use the former to deal with the latter? Just how would he have dealt with the colossal issues of today?

Brunel's engineering education and training was a combination of the theoretical and practical, of subjects broad and deep, technical and non-technical. When the young Brunel was eight years old, his father, the engineer Marc Isambard Brunel, sent him to a school at Hove on the south coast of England. Here he amused himself by making model boats and surveying and sketching the local buildings[9]. This 'drawing habit' (sketching) was something he picked up from his father, who had always insisted that it was as important to the engineer as knowledge of the alphabet. It undoubtedly helped to develop Brunel's extraordinarily acute powers of observation and visualisation.

His early education ranged from Euclid's geometry to the Latin poetry of Virgil and Horace. As a 14 year old, Isambard was sent to Caen in France, so that he might have an advanced mathematical education, in preparation for taking the entrance examination to the Ecole Polytechnique.

His introduction to engineering practice and project management was rapid. As a young engineer, aged barely 20, he took on heavy responsibilities almost from the start, in the face of great personal and project risks. Few engineers can have paralleled Brunel's induction to civil engineering – as resident engineer for the Thames Tunnel.

Throughout his life, he was a man of tremendous vision, persuasion and innovation. Always driven, often stubborn, sometimes vainglorious, perhaps occasionally almost reckless with his investors' money, and it has to be acknowledged, also with the lives of some of his workforce, but always at the forefront. He got things done, sometimes at whatever the cost.

Brunel's engineering was essentially all about that part of the Tredgold[10] definition of civil engineering to do with trade, commerce and opening up markets, and in particular, getting raw materials to the centres of production and finished goods to market – quickly and cheaply. We see it today still in perhaps his greatest legacy – the Great Western Railway. We see Brunel the man in that most famous photograph, wearing his stovepipe hat and with his trademark cigar, standing in front of the launch chains of the largest boat then set to sail the oceans – the Great Eastern. Ironically, simultaneously his greatest success and failure, and which probably contributed to his early death at the age of 53. But what would he have made of today?

Brundtland

In a dictionary of biography, the name of Brundtland would be found pretty close to Brunel.

Gro Harlem Brundtland[11] chaired the World Commission on Environment and Development, which led to the publication of what has become known as the 'Brundtland Report'[12] in 1987, and which in turn led to the first Earth Summit in 1992 in Rio de Janeiro.

The Brundtland Report also led to the landmark concept of what is now known as sustainable development:

> "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

In many ways, and certainly in the prevailing paradigm of the 19th century, Brunel and his contemporaries were delivering sustainable infrastructure. Brunel was adept at persuading his project sponsors of the infrastructure legacy they were funding, even if he was less clear about the eventual outturn costs.

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."


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Perhaps if he had been, some of his lasting achievements might never have seen the light of day. Major construction projects are frequently under-costed, but once started, are notoriously difficult to stop. And it is no less true today[13,14]. Witness the Scottish Parliament Building, the Channel Tunnel (at the third attempt), the new Wembley Stadium, and the Millennium Dome. Other spectacular examples of cost underestimation were the Sydney Opera House (actual costs approximately 15 times higher than projected), the supersonic Concorde aeroplane (costs 12 times higher than predicted), the Suez Canal (completed in 1869 with actual costs 20 times higher than the earliest estimated costs and three times higher than the cost estimate for the year before construction began).

But what is crucial is the ability and vision to identify those projects of strategic consequence – and to recognise those that aren't. Even Brunel had to deal with the latter – perhaps most notably with his atmospheric railway[15].

Bazalgette

But what about that other 19th century engineering hero, Joseph Bazalgette? Again, not too far away from Brunel and Brundtland in the biographical dictionary of the great and the good. Both men had French backgrounds[16].

But Bazalgette was a character very different to Brunel. Bazalgette's contributions were often much more to do with a less explicit part of the Tredgold definition – public works and the underpinning infrastructure for civilisation itself, rather than directly supporting the means of production and commerce. And, in contrast to Brunel, Bazalgette's works were funded mainly by the public purse rather than by private financiers and entrepreneurs.

Bazalgette's defining issue (sic) was dealing with the problem of urban sewage and its disposal into local water courses and the resultant occurrence of water related diseases such as cholera and their impact on public health. It was a story of overcrowded and congested cities, poverty, slums, disease and a high incidence of child mortality. Social reformers, campaigners and celebrities were calling for action.

No, this wasn't about Africa in 2005. It wasn't Bono and Bob Geldof and Live 8. Their time was yet to come. No, this was London and other UK cities 150 years ago. The social reform campaigners were people like the northern lawyer Sir Edwin Chadwick, Benjamin Disraeli and Charles Dickens' brother Alfred. But there are some parallel and powerful messages here for civil engineers – and others – at the start of the 21st century.

Legislation enacted in the early 1800s had led to a reduction in the number of cesspits and an increase in the use of water closets and the number of sewers taking domestic sewage to outfalls in the Thames where they discharged at low tide. Incoming tides carried the sewage upstream to Teddington Lock and it to'ed and fro'ed up and down the river for days. Combinations of high tides and heavy rain caused the sewers to back up and flood the houses they were supposed to drain. The cause of the cholera epidemics that resulted was at first misunderstood. Some, including Chadwick, believed in the miasmic ('bad air') theory[17,18].

In 1854 the cause of cholera was firmly established by Dr John Snow's demonstration that an outbreak in Soho was due to contamination by sewage of the water supply taken from the Broad Street pump. His advice was simple: "Take away the pump handle."

Meanwhile, Joseph Bazalgette had been appointed assistant surveyor to the 2nd Commission of Sewers in 1849, becoming engineer in 1852, and then Chief Engineer to the Metropolitan Board of Works.

The crunch finally came in 1858 with what was known as the 'Great Stink', when the stench from the Stygian Thames was so bad that the windows of parliament were draped in curtains soaked in chloride of lime, and there was talk of moving the Law Courts to Oxford. Paddle steamers on the Thames – appropriately described as the 'aqua mortis' – had to stop working as their paddles churned up the sewage laden waters.

And then something happened… the Government of the day willed the means and established the institutions to deliver the ends.

Specifically, the Metropolis Local Management Amendment Act (2 August 1858) empowered the Metropolitan Board of Works to borrow £3 million, guaranteed by the UK Treasury, to be repaid by the proceeds of a three penny rate over 40 years[19].

Joseph Bazalgette's response was to construct a system of major intercepting sewers to take wastewater for treatment and safe disposal in the downstream reaches of the Thames, far away from the centres of population. He presented his design calculations to the Institution of Civil Engineers in 1865. Bazalgette's scheme cost £4.5 million and comprised 1,300 miles of brick built sewers, pumping stations and numerous other engineering appurtenances.

With new sources of supply taken from upstream to the west and north of London, and with borehole supplies in the south, the cycle of water-borne disease would be broken. The old London rivers running into the Thames would no longer be the major elements of the supply/disposal system. In consequence, the Thames would cease to be a major cause of disease and nuisance.

When he died in 1891, his obituary in The Times[20] paid a fulsome tribute to a 19th century engineering hero of whom

A
Schumpeter's accelerating waves of technological innovation. Adapted from Joseph Schumpeter

the masses were barely aware, but who had played an unseen hand in extending their life expectancy:

"Joseph Bazalgette: That great, far-sighted engineer, who probably did more good, and saved more lives, than any single Victorian public official… Of the great sewer that runs beneath, Londoners know, as a rule, nothing, though the Registrar-General could tell them that its existence has added twenty years to their chance of life."

Engineering, technology and economics

What were the technical and economic conditions in which Brunel and Bazalgette operated and how do they relate to those of today?

Engineering science – supplanting empiricism with rational explanations of physical behaviour at a range of spatial and temporal scales – was a product of the Age of Enlightenment, whose defining characteristics have been interpreted as follows[21]:

- A self proclaimed movement; inspired by rationalism, underpinned by the new 'philosophy of science'
- Determined to challenge orthodoxy in all its forms (not just the orthodoxy of existing ideas but also of institutions)
- Characterised above all by an optimism and faith in human progress, that sought that we should live in accordance with human reason, with the consequence that the importance of human rights (or at least 'the natural rights of the citizen') came high on the agenda

In their different ways, both Brunel and Bazalgette capitalised on the emergence of this rational phase of technology, and with it the means of mass production and component interchangeability, to build sustainable, enduring infrastructure. Increased efficiency and levels of production were achieved by mechanisation, powered by machines fed by fossil fuels – and whose wider effects were yet to be realised…

It appeared that anything seemed possible. In some ways it was. The civil engineer could repeat Thomas Tredgold's words with confidence: "Civil engineering is the art of directing the great sources of power in nature for the use and convenience of man."

It was against this background and in a prevailing atmosphere of economic opportunity and social responsibility that Brunel, Bazalgette and others operated and thrived, laying the foundations for a civilised society, and which it is now our responsibility to recreate and carry forward into the 21st century.

From the crucible of that 19th century technological and economic powerhouse came much of the world as we see it today, with successive waves of technical innovation and periods of rapid social change. From it sprang the transportation systems of canals, highways, railways and ports; the power systems; the water supply, sewerage and irrigation systems; the production and consumption of consumer goods on a massive scale in an increasingly urbanised society; and the development of large-scale construction and the changing form of cities and towns.

But from it also sprang the problems of congestion, air pollution, damage to the environment, profligate resource use, global warming, over-abstraction of watercourses, water pollution, urban blight and social injustice.

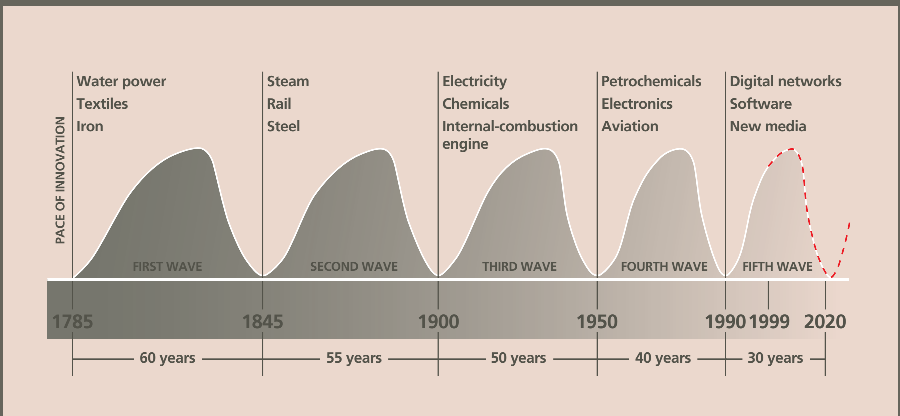
In the era of technical rationality – which has dominated the past two or three centuries – economic and technical progress was generally embedded in narrow technical disciplines which, despite our scientific understanding, did not anticipate the wider physical and non-physical consequences at the systems level[22].

The emergent properties and behaviours of large and complex systems were neither fully appreciated nor fully understood. It was not anticipated that man's activities would lead to impacts on a global scale, which now threaten the environment and man's place in it. No-one foresaw that Henry Ford's production line of Black Model Ts would lead inexorably to changes in urban form, large-scale urban congestion, air pollution (and its linkage to the higher incidence of child asthma), CO_2 emissions or global warming and climate change. The development of large-scale irrigation and hydropower schemes didn't anticipate the loss of biodiversity, ecosystem damage, soil erosion and loss of soil fertility. There was an overriding economic imperative, and the false assumption that the fruits of the planet were a free good.

It is now becoming clear that the earth is no longer a homeostat, no longer able to withstand and rebound from human activity. It has limits. The effects are locked in.

Such realisations mark the end of the era of technical rationality and signal the beginning of a more holistic (systems) view of the world. Increasingly, the response has been the emergence, widespread acceptance and, increasingly, the adoption of the principles of sustainable development in order to direct the economy for social benefit within the confines and capacity of the environment, now and into the future.

There is still some way to go in changing individual, corporate and national behaviours, but there is no doubt that we are now entering the systems/holistic phase, and with it the need to develop systems level solutions.



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In his ICE Presidential Address in November 2005, Gordon Masterton reflected on the challenge of 'Sustaining our Future':

"In its broadest sense we, as engineers, need to view the 'big picture' in all we do. Brunel addressed the big issues of his time – the growth of trade, and transportation's crucial role in this. If Brunel were alive now, his global vision and genius would be applied to the planet-sized problems of today. Solving these problems will require civil engineers working in partnership, crossing disciplines. We need to use our engineering know-how to help influence and educate decision-makers – including the public stakeholders – to take a global view of sustainability issues."

Society has evolved through various phases of social, economic and technological change. Episodes of technological innovation were followed by their economic exploitation in a series of waves[23] that has taken in the emergence of water power/canals/iron/textiles in the late 18th century; steam power/railways/steel in the mid 19th century; and the emergence of electricity/chemicals/the internal combustion engine in the early 20th century. The mid 20th century was characterised by petrochemicals/electronics and aviation. At the start of the 21st century we are in the IT era of digital networks, software and new media, but there is a growing sense that progress isn't the sole province of technology.

It is becoming increasingly clear that tomorrow's underpinning drivers are more about environmental issues and social objectives, rather than simply technological and economic development. And that interface between human/social demands and the application of technology is – as it always has been – the domain of the civil engineer.

"Joseph Bazalgette: That great, far-sighted engineer, who probably did more good, and saved more lives, than any single Victorian public official… Of the great sewer that runs beneath, Londoners know, as a rule, nothing, though the Registrar-General could tell them that its existence has added twenty years to their chance of life."

But the critical infrastructure that benefited the UK, as the foremost engine of the industrial revolution in the 19th and early 20th centuries we now know did not always serve others so well. For example, the initial transport networks in places such as Africa were focused on shifting raw materials to the ports for export rather than to stimulate local industrial development and capacity[24]. And even today, transport costs in countries such as Uganda add the equivalent of an 80% tax to its clothing exports[25].

At the beginning of the 21st century access to the most basic of infrastructure is still seemingly beyond the reach of millions in the developing world and without it the achievement of the UN Millennium Development Goals will remain a dream.

It is time that dream was turned into a reality.

In his introduction to the Brandt Report[26] over 20 years ago, Willy Brandt wrote:

"What limits our response to the challenges of the present crisis? It is not primarily the lack of technical solutions, which are already largely familiar, but the lack of a clear and broadly reflected awareness of the current realities and dangers, and an absence of the political will necessary to meet the real problems. Only a new spirit of solidarity, based on a respect for the individual, the national heritage and the common good, can make possible the achievement of the solutions so desperately needed."

and later in the report with regard to energy…

"Promoting energy research in the third world: …to assist developing countries in negotiating energy contracts and assuring energy supplies; to assist them in the more appropriate use of traditional energy sources, particularly fuel wood, which is now being used at an unsustainable rate with profoundly damaging effects on the environment and agriculture of the world; to examine the feasibility of alternative traditional energy sources, particularly cost effective and low technology means of generating energy; to promote sub-regional and regional co-operation in reducing energy costs and enduring energy supplies for developing countries."

A
Energy efficiency learning curves. Adapted from Benjamin Dessus

B
Contraction and convergence. Adapted from Global Commons Institute

It's about time we delivered.

What limits our response?

The Age of Enlightenment also spawned the other great idea of the time – the growth of economic theory and the nature of capitalism, and the works of people such as Adam Smith (1723-1790), Jeremy Bentham (1747-1832), David Ricardo (1772-1823), John Stuart Mill (1806-73), and Karl Marx (1818-1883).

Economics[27] is essentially rooted in the concept that the human tendency is to maximise economic efficiency – ie 'the optimal allocation of resources'. It says nothing about whether this optimality results in an equitable, a better, a more effective or a more desirable state of affairs. And neither can the 'laws' of economics transcend the laws of thermodynamics and principles of social justice – perpetual growth in world GDP has its price. And the planet and some of its peoples are paying it.

In a pre-echo of Brundtland and Brandt, it was Bentham[28] who coined the imperative "the greatest good for the greatest number" – and with it the dilemma of satisfying two competing objectives simultaneously.

Occam's razor[29] suggests using the simplest models available to understand the world. Engineers and economists alike have tended to do so wherever possible. In engineering, there is always a tendency to see if a linear model between cause and effect will adequately model reality. It often does, as with the use of Hooke's Law to relate stress and strain. Perhaps for economists the equivalent is the Discount Rate, and with it the notion of net present value, to represent the time value of money and reflect the sense of future risks and present-day alternative investment opportunities.

But net present value calculations do not necessarily lead to acceptable decision outcomes for those problems of global proportions. As the economist Heal[30] has observed:

> "If one discounts present world Gross National Product over 200 years at 5%, it is worth only a few hundred thousand dollars, the price of a good apartment. Discounted at 10%, it is equivalent to a used car. On the basis of such valuations, it is irrational to be concerned about global warming, nuclear waste, species extinction and other long run phenomena. Yet societies are worried about these issues, and are actively considering devoting very substantial resources to them."

And if we are looking at issues such as climate change, then we also need realistic physical models of the world that reflect its potential for non-linear behaviour as a result of the accumulation of apparently relatively small changes in external pressures.

In terms of climate change, it is easy to forget the simple heat experiments of school physics and the limitations of linear models. In both a metaphorical and physical sense we are standing on an ice sheet, expecting it to absorb the heat of our activities. But it can only absorb so much for so long. Then it melts. Phase reversal requires an equivalent amount of heat to be taken out of the system. The processes are not instantaneous. The world has inertia, but once mobilised, also momentum – and with it – direction.

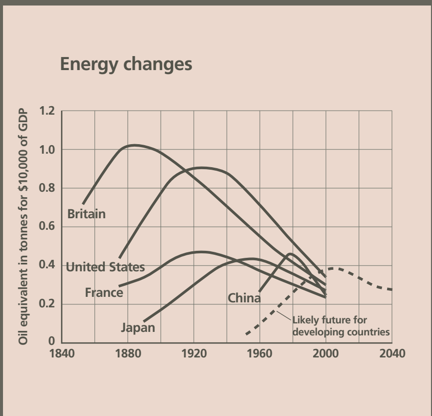
The potential of the Atlantic Heat Conveyor[31] to 'switch' and the Gulf Stream to collapse, is perhaps one of the most threatening examples of large-scale non-linear behaviour. Recent research[32] suggests that melting freshwater from the Arctic ice sheets could dilute the denser Gulf Stream waters, preventing them from sinking and returning to the tropics. Some estimates make the chances of this happening as high as 45% within the next 100 years – if mean global temperatures rise by just 2-3°C (which they are currently set to do). The odds are shortening. The consequences in northern latitudes will be to widen the energy gap to cope with freezing winter conditions and cooler summers, and could lead to tens of thousands of additional, annual cold-related deaths and a dramatic change in ecosystems as the northern hemisphere becomes cooler and drier. In the equatorial regions, the consequences will be drought and famine.

Energy and climate change

It is therefore time to turn our attention back to energy – and implicitly energy resources.

Although we derive energy from a variety of sources, the world is currently powered by a predominantly fossil-fuelled, carbon-based energy system of coal, oil and gas. All of them are non-renewable and out of balance within the timescales of the human race. We now know their wider environmental effects. It is useful to remember that the Stone Age ended long before the world ran out of stones. And one way or the other, the oil age will end before the world runs out of oil.

The patterns of worldwide energy use are disproportionate, and with them the sources of CO_2 emissions. But the patterns are changing with the emergence of economies such as China and India. China is the world's largest user of coal and it is now the second largest consumer of oil and gas[33], though still a relatively small consumer on a per capita basis. But this is changing rapidly with the growth of China as a car-owning, consumer society. Energy use in China has increased by 660% since 1965, compared to 76% in the USA over the same period. By 2020, China's energy use is predicted to double[34]. The emerging economies are still on the technological energy efficiency



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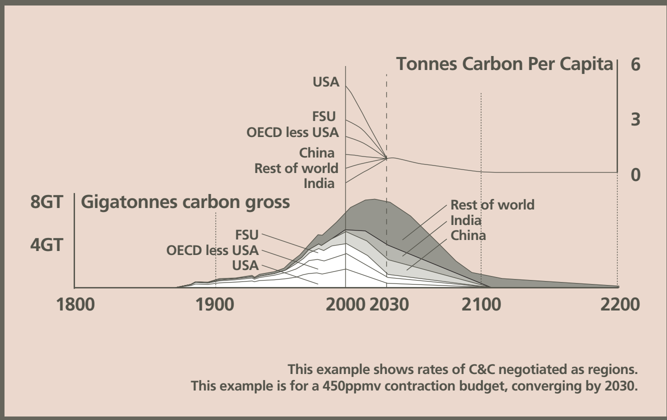


B

learning curve[35], as measured by the variation through time of the ratio of energy use per unit of GDP. Typically, as an economy develops, energy dependency grows very quickly with investment in basic infrastructure, heavy industry, transport networks, and urbanisation. Energy use per unit of GDP then falls off as the economy matures. History also shows that newly industrialised countries are successively less energy-dependent during their primary growth period as they learn technologically from their predecessors. This will temper – but only to a limited extent – the impacts of newly emerging economies.

But atmospheric CO_2 levels are reaching critical levels and there must be a strategy to stabilise concentrations to a (relatively) safe level, and with the Kyoto process in limbo, some other process or protocol will be required to arrest the asymmetric pattern of 'Expansion and Divergence' and which leads to a more equitable and less self-destructive use of the earth's resources[36].

The 'Contraction and Convergence (C&C) Strategy' proposed by the Global Commons Institute[37, 38], offers such a process, drawing widespread interest and support, for example from the Indian Government[39], the Africa Group of Nations[40] and the USA[41]. In December 1997 at the United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto – and shortly before they withdrew from the Kyoto negotiations – the USA stated:

> "Contraction and convergence contains elements for the next agreement that we may ultimately all seek to engage in."
> The US Delegation to UN Framework Convention on Climate Change, Kyoto

> "The UK should be prepared to accept the contraction and convergence principle as the basis for international agreement on reducing greenhouse gas emissions, and should adopt a long-term strategy for reducing its own emissions."
> The UK Royal Commission on Environmental Pollution

The integrity of the C&C approach was reinforced by the 2000 report of the UK Royal Commission on Environmental Pollution[42], which concluded:

> "Given current knowledge about humanity's impact on climate and the UN Intergovernmental Panel on Climate Change's findings, we support 550 ppmv[43] as an upper limit on the carbon dioxide concentration in the atmosphere. Major reductions in global emissions are necessary to prevent that limit being exceeded. The UK should be prepared to accept the contraction and convergence principle as the basis for international agreement on reducing greenhouse gas emissions, and should adopt a long-term strategy for reducing its own emissions."

The same report also stated:

> "There is no foreseeable prospect of some magic source of almost unlimited energy with negligible environmental impact. Nuclear fusion has sometimes been advocated as that, but it is still at the research stage and a commercial scale demonstration plant seems unlikely to be constructed before 2050. Its environmental impact, as well as its economic viability, have yet to be clarified."

> "Contraction and convergence contains elements for the next agreement that we may ultimately all seek to engage in."

The US Delegation to UN Framework Convention on Climate Change, Kyoto

> "The UK should be prepared to accept the contraction and convergence principle as the basis for international agreement on reducing greenhouse gas emissions, and should adopt a long-term strategy for reducing its own emissions."

The UK Royal Commission on Environmental Pollution

A
In situ coal gasification and CO_2 sequestration.
Credit: Smart et al

The achievement of a sustainable energy economy requires a strong energy-research base that addresses the basic demands we place on the energy system for heat, power and mobility. Whether at work or leisure, people are at the centre of the energy system and so demand-side solutions need to be innovated as well as supply-side and infrastructure fixes. While market forces may act to resolve some aspects of the energy equation, there are others where the limitation is not technology but a lack of clear leadership and policy development. In the UK we've had the 'dash to gas' and that is now widely recognised as a short term opportunistic response to CO_2 emissions and cost reduction on the back of a practical alternative.

What comes next? Turn back to nuclear? Return to (clean) coal? Go with the wind?

There are many industrial players in the field and we are all energy consumers. There is no dominant profession. Even less a universal sense of direction.

The Asia Pacific Partnership on Clean Development and Climate[44], involving the US, Australia, South Korea, Japan, India and China, is essentially a technocratic response to energy demand and greenhouse gas emissions, placing dependency on technological innovation across a range of energy sources, but particularly on coal. To its members it is seen as a way of keeping the electronic juices flowing without the encumbrances of the Kyoto Protocol (which neither the US nor Australia has ratified). To others, the Asia Pacific Partnership will not deliver anything like the required reduction in the growth of greenhouse gas emissions.

Either way, it would be unwise to rely solely on a technical fix, or imagine that we can somehow engineer (in the narrow technical sense) a solution – and with it the unlikely prospect of a free economic good whilst simultaneously denying that individual/corporate/national behaviours need to change in the face of environmental limits. Technical innovation will be part of the solution, but not alone.

There is no magic bullet.

There are just three approaches:
1. Change our behaviour
2. Change the technology
3. Change the fuel

Changing behaviour

Whose behaviour?

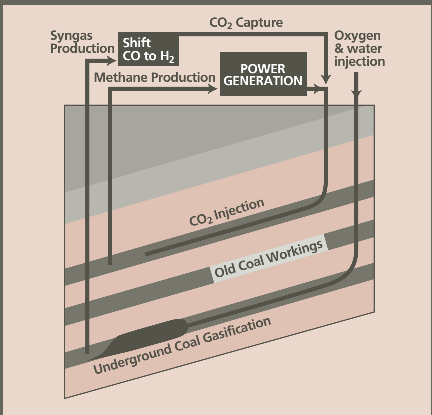
And at what level – personal, corporate or governmental?

Some of the peoples of the world – particularly those in the developed economies – live in a consumer-led, energy intensive and energy wasteful society, whether it be in the buildings we inhabit or occupy, in our travel habits, in the products we consume or through the processes of their manufacture and distribution. The developed world is not a role model for resource efficiency. But for understandable reasons, many peoples in the developing economies and nations of the world strive to do the same, whilst others just struggle to survive. They cannot be denied. And there is no doubt that the developing economies are 'energy poor'.

Behaviour change, which it might reasonably assumed should be the primary responsibility of those making the biggest contribution to the problem, usually comes about – unless by force majeure – through a long process of awareness, acknowledgment, acceptance and only finally by action. For some it halts at step one, and only moves beyond that by a combination of carrot and stick, which generally either means a combination of economic incentives/instruments, taxes, regulation or legislation.

The opportunities afforded by regulation/legislation should not be ignored, not least in the quality of the built environment, where with few exceptions (eg Sweden), the energy efficiency required of new build is derisory. And given the lifetime of buildings, the inefficiencies are locked in unless ways can be found to retrofit energy efficient measures. But surely now it is time that buildings were required to conform to an energy efficiency criterion, or if not, to be required to have some form of energy labelling to acknowledge their energy efficiency at the time of re-sale.

At the international level, the Contraction and Convergence Strategy is based in part on the concept of tradeable permits, incentivising the big CO_2 emitting nations to reduce their emissions by a price mechanism, purchasing quotas from under quota nations in the short term and meanwhile improving their patterns of energy use through a combination of behaviour change and technological efficiency. In the process, there is an element of wealth re-distribution and technological exchange between the richer and poorer nations. A note of caution should be acknowledged – for the energy poor developing nations, the worst outcome for them would be to mortgage their long-term access to energy on a CO_2 futures market trading floor and in which they could end up being the losers.



A

Changing the technology

Clean coal technology; CO_2 sequestration

Coal is still a major world source of energy, and through stack emissions, a major source of CO_2 release to the atmosphere. Flue gases can be scrubbed more efficiently, CO_2 extracted and flue emissions reduced. There are various options[45] for CO_2 sequestration, including: aquifer disposal, injection in depleted (oil/gas) reservoirs, injection in Enhanced Oil Recovery (EOR) processes, sequestering in the form of subsea sediment hydrates, ocean disposal and coal-bed disposal. Enhanced Coal Bed Methane (ECBM) production might also be an attractive option, involving the injection of CO_2 into coal measures where it displaces methane from the coal matrix. The methane can be collected and used as a clean fuel. In a further refinement currently being researched, CO_2 sequestration could be combined with in situ coal gasification. This might be one way of releasing coal reserves in the UK and elsewhere that were stranded in recent years in coal mines deemed to be uneconomic[46]. And if not necessarily a long term solution – it has been said that coal, like oil and gas, is simply too valuable to burn[47] – CO_2 sequestration might provide a vital window pending the long term shift to a much less carbon dependent energy cycle and the long term control of CO_2 and other greenhouse gas emissions to the atmosphere. There are new prospects for coal mines of the 21st century.

Nuclear

The nuclear debate is now once again wide open and it will be controversial – within nations and between nations. It is full of conundrums. 'Carbon free but not risk free'.

When the world's first fully commercial nuclear power plant went into service in 1956 at Calder Hall in the UK, it was claimed it would lead to "electricity too cheap to meter". It didn't turn out that way, and a series of serious accidents (such as at Three Mile Island in the USA in 1979, and at Chernobyl in the former Soviet Union in 1986), coupled with concerns following a succession of incidents connected with nuclear waste disposal and reprocessing, and more recently by the threat of world terrorism, have undermined public confidence and support for the nuclear option.

Nuclear power evokes very deep emotions, not least because of its historical origins as a by-product of a nuclear weapons programme. For some, it represents the absolute antithesis of sustainable development, by leaving a legacy of nuclear waste for future generations to resolve. For others it doesn't even rate as a preferred economic option set against the alternatives, which is itself revealing in the context of the late 20th century privatisation of key utilities:

> "In a market economy, private investors are the ultimate arbiter of what energy technologies can compete and yield reliable profits, so to understand nuclear power's prospects, just follow the money. Private investors have flatly rejected nuclear power but enthusiastically bought its main supply-side competitors – decentralized cogeneration and renewables. Worldwide, by the end of 2004, these supposedly inadequate alternatives had more installed (new) capacity than nuclear, produced 92% as much electricity, and were growing 5.9 times faster and accelerating, while nuclear was fading." (Amory Lovins[48])

Some are prepared to take a more reserved position. The UK's Royal Commission on Environmental Pollution sets out the issues for a new generation of nuclear power plants in the UK, both technical and in terms of securing public support and confidence[49]. Its recommendations are precautionary.

> "New nuclear power stations should not be built until the problem of managing nuclear waste has been solved to the satisfaction both of the scientific community and the general public. Nuclear power could continue to play an important role in reducing UK greenhouse gas emissions. We do not, however, accept the arguments of those who hold that it is indispensable. We do not believe public opinion will permit the construction of new nuclear power stations unless they are part of a strategy which delivers radical improvements in energy efficiency and an equal opportunity for the deployment of other alternatives to fossil fuels which can compete in terms of cost and reduced environmental impacts. Procedures for weighing up these issues will need to allow for debate of a high standard, and at the same time be capable of articulating deeply held values and beliefs."

This appears to be the position of the UK Government (though some would say its mind is already made up). In the UK (and elsewhere too) it is becoming clear that nuclear power is re-emerging as a carbon-free option, but as the UK Select Committee on Environmental Audit[50] has made clear: "The Government should not allow itself to drift into a position in which nuclear appears to be the only alternative."

A
Pelamis wave energy converter.
Credit: Ocean Power Delivery

B
Three Gorges Dam, China.
Credit: DigitalGlobe

What is certain is that the nuclear option needs to be re-engineered – starting with the issues of nuclear waste management and risk. Otherwise, securing the necessary public acceptance will be difficult. There are already concerns that keeping the nuclear option open will effectively foreclose on other carbon free and renewables opportunities, and on initiatives to change energy demand behaviours[51].

But nuclear is certainly back on the agenda, as evidenced perhaps most strikingly by the change of heart by the environmental scientist and creator of the Gaia hypothesis, James Lovelock[52]:

"Nuclear power is the only green solution. When, in the 18th century, only one billion people lived on Earth, their impact was small enough for it not to matter what energy source they used. But with six billion, and growing, few options remain; we cannot continue drawing energy from fossil fuels and there is no chance that the renewables, wind, tide and water power can provide enough energy and in time. Every year that we continue burning carbon makes it worse for our descendants and for civilisation."

And if nuclear is the only solution, is it a solution that will be available to all nations – or only to some?

"To help Africa meet the UN Millennium Development Goals, the continent needs energy. Technology, both large and small, has its role to play."

Grid versus non-grid?

By and large the power supplies in the developed economies have evolved from local generation and local distribution into highly interconnected power grids and with generation focused on high capacity power stations of one type or another.

Power systems evolved in this way for two principal reasons: to protect against local supply failures by interconnecting consumers to a wider network, and to achieve economies of scale and plant reliability by concentrating generating capacity on larger power plants. The economic price of distribution losses was deemed worth paying.

The combination of large-scale interconnected grids and large-scale generation has become the established paradigm, and which it might now be time to question. Smaller scale generation equipment is no longer so inferior in terms of unit costs or reliability to justify the high rates of energy losses in the grid. And it is increasingly the case that grid failures – not generation failures – are the cause of widespread power blackouts, as evidenced by a number of recent large scale power outages in places such as Italy (September 2003), the north-eastern states of the USA and Ontario, Canada (August 2003) and Auckland, New Zealand (January – February 1998). In all three cases the initial incidents were local and relatively minor, but whose effects cascaded into catastrophic grid failures[53].

Such effects had been predicted as long ago as the mid 1980s by Amory and Hunter Lovins, who had warned that the structure of the North American electrical network made the system fundamentally vulnerable. When asked recently if things had improved in the past two decades, Amory Lovins is reported[54] to have said, "I'm surprised the lights are still on."

A

B

The paradigm of the interconnected grid also has implications for many of the renewable technologies and other small-medium scale power generation options (such as combined heat and power schemes), which if connected into the grid are likely to add to grid complexity and proneness to progressive catastrophic failure. There may well be a case for preferring off-grid/local grid/distributed solutions for reasons of improved systems reliability, stability and energy efficiency. And also for enabling low carbon energy generation to become more established in mainstream energy provision, not just in the developed economies but in those of the developing and emerging economies of the world.

Changing the fuel

Wind, wave, tidal?

Wind has become a well-established, carbon free energy source, but not without its detractors, including those who still doubt its economics[55]; those who are against it on environmental/aesthetic/noise grounds; or because it might endanger migrating birds, and not least by its intermittency. By its very nature, the availability of wind energy tends to be in remote and often beautiful parts of the world, and often with the additional problem of being distant from centres of demand and with poor grid and interconnector access. Offshore wind evokes less opposition, and there are some interesting examples being developed to make use of redundant offshore oil infrastructure (platforms and subsea pipelines), for example the Beatrice Project in the Moray Firth[56].

Wave and tidal energy systems are still very much in development and will be required to operate in even more hostile environments than wind turbines. A number of devices are now undergoing extensive marine trials. For example the 'Pelamis' device, developed by Ocean Power Delivery[57] in Edinburgh, is now being tested at the European Marine Energy Centre[58] in Orkney and also in Portugal. The fact remains that more research and development (R&D) investment in renewables such as wave and tidal power is required. For comparison, in the UK over the last 25 years the average R&D spend on nuclear power has been £230 million per year (75% of the total UK energy R&D budget). Over the period 2001-2004, the average spend on renewables R&D was just £7 million per year. There has to be a balance.

Hydrogen?

The proportion of renewables that can be integrated into the existing electricity systems is ultimately limited by two main factors:

1. The intermittent output characteristics of renewable energy supplies
2. The time-dependent nature of end-use electricity demand

Electrolysers could provide a means to balance out these variations and offer a greater capability to capture renewable energy, temporarily store it and then reconvert it to electricity. On the demand-side, electrolysers can serve to 'valley fill' the load profile on a diurnal cycle.

Hydrogen can also be used for several applications besides reconversion to electricity, for example as a direct combustion gas and as a fuel for road vehicles. In the transport sector, a 'market pull' for hydrogen is likely to emerge by 2010 and be significant by 2020[59].

Hydropower?

With some exceptions, often in countries with 'command style' economies, the construction of large-scale hydropower schemes has declined, primarily due to concerns over their social and environmental impacts. The most significant exception being the $24 billion Three Gorges Dam on the Yangtze, containing a storage reservoir of some 600km in length, providing flood control, producing 18 gigawatts of hydropower, but also displacing almost two million people, and resulting in the loss of valuable archaeological and cultural sites, biodiversity loss and environmental damage[60]. Projects such as the Three Gorges Dam inescapably place the civil engineer in a difficult role. Civil engineering is not an apolitical activity – if indeed it ever was – and the civil engineer needs all the skills of discrimination, judgement and conflict resolution. It also affords the young engineer and student a very rich learning experience – see for example the 'Discovery School' Three Gorges Lesson Plan[61].

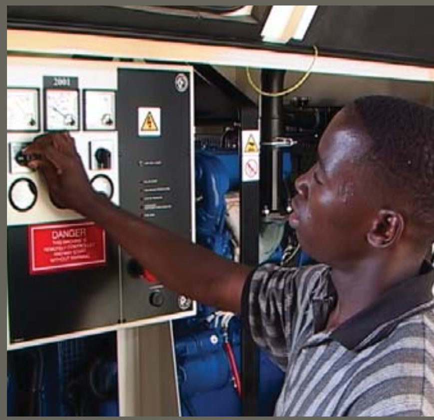
Low head, run-of-the-river schemes offer some possibilities, and whilst they are unlikely to have a major impact on the global energy mix, they could make important contributions locally. A recent proposal[62] to use the Congo to generate enough electricity to power Africa's industrialisation, put to the United Nations Environment Programme (UNEP) Governing Council by the South African power company Eskom, offers a more strategic contribution. The scheme would generate a total of 40 gigawatts (twice the output of the Three Gorges), with about half coming from a conventional hydropower hydroelectric plant at the Inga Rapids, near the river's mouth in the western Democratic Republic of Congo, and the rest coming from run-of-the-river schemes and claimed to be more environmentally friendly.

A
Credit: ABB Access to Electricity, March 2006

B
Credit: ABB Access to Electricity, March 2006

C
Distribution of world spend by region. Adapted from Worldwatch Institute

A



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An energy supply for Africa is a prize worth seeking. As Monique Barbut[63], UNEP said,

"To help Africa meet the UN Millennium Development Goals, the continent needs energy. Technology, both large and small, has its role to play… but we must ensure that this is clean and environmentally-sound technology whether it be coal or oil or wind or solar. Hydro-electricity can also play its part."

The engineer's role in delivering the UN Millennium Development Goals

The energy needs of the developing world, in Africa, Asia or Central/ Southern America, bring us back to the issues of world poverty and the UN MDGs:

"Energy security is a priority for many governments, particularly in recent months as fears of oil supply disruptions dominated the headlines. At the International Energy Agency, we view concerns about energy security as closely linked with economic development and environment – the "three Es". In Africa, energy security concerns are also very real – without access to ample, reliable and affordable energy, economies cannot develop. In many African countries, lack of energy security feeds into a cycle of poverty. At the beginning of the 21st century, it is unacceptable for millions of people to live without access to electricity!" (Claude Mandil[64])

The impacts of energy poverty are not as widely recognised as those caused by access to food, water and shelter, but they are real and have major social, economic and environmental consequences.
In the remote village of Ngarambe, on the edge of the Selous National Park in southern Tanzania, 1,800 villagers have received electricity through a partnership between ABB, WWF and the local community, with the emphasis placed on working with local authorities to establish local needs to ensure affordable and sustainable solutions. The key features of ABB's 'Access to Electricity' programme[65] are:

- Providing electricity to low-income communities
- A bottom-up approach
- A strong focus on affordability
- Prioritising the productive use of electricity in order to generate social and economic development
- Engagement with local partners to build skills and know-how

ABB financed the installation of the mini-grid. The villagers contributed by building the generator house and digging trenches for power cables. The benefits of the Access to Electricity programme for the local population are tangible: the local school can now hold classes at night and provide students with an out-of-hours place to study; the number of pupils has risen from 250 to 350. At the dispensary, the doctor can now also treat his patients at night and will be able to install a refrigerator for medicines. Local women no longer have to make the long climb to the dunes to collect water from a well but can draw water locally using a water pump in the centre of the village. There are plans to install a small sawmill and to automate the maize mill.

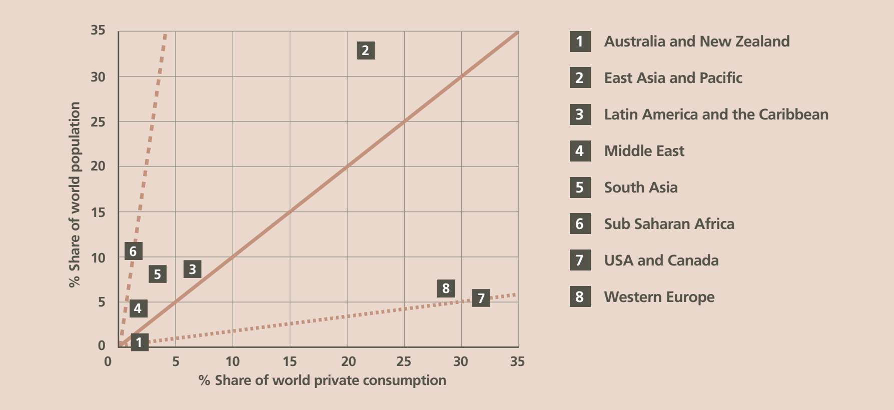
Similar projects are being developed in other parts of Africa and Asia. But the effort needs scaling up if energy poverty is to be addressed at the global level. And not just in terms of energy. Only 64% of Africa's population has access to a reliable clean water supply[66], which is about the same percentage that have no access to electricity[67].

Historically, the civil engineer has played a significant role in development, public health and the alleviation of poverty by providing the underpinning infrastructure of civilisation. A similar task is now waiting to be achieved in the lesser-developed countries.

Lack of access to basic infrastructure is at the root of world poverty and the human tragedies associated with it. Two billion people lack access to safe water; a similar number lack access to a basic power supply; population growth has resulted in burgeoning numbers of people living in urban slums, shanty towns and substandard buildings, often with no legal title to ownership and no connection to basic infrastructure services. Furthermore, the effects of climate change are likely to impact most on the poor and the vulnerable, and will be exacerbated unless underpinning infrastructure services are in place.

The problems of poverty reduction and international development are central to the eight UN MDGs, adopted by the UN in September 2000, and to which world governments have committed to meeting by 2015. On current evidence, the chances of them doing so are slight.

In the past, engineers have driven highways and railroads across continents, dammed mighty rivers, tunnelled under the sea and put men on the moon.
As engineers we are a key profession in the implementation of society's desires and needs. Yet, our profession needs to change in response to new social and environmental challenges – where we claimed to "direct the powers of nature for the use and convenience of mankind" we now need to focus on "working with the powers of nature for the use and benefit of society."



C

Prerequisites for development

Humanity now faces its greatest challenges – addressing issues of climate change and sustainability on the one hand and poverty reduction and governance on the other.

There are certain prerequisites for development, without which attempts to improve livelihoods in the developing world will be unlikely to succeed. Such prerequisites include reasonable governance structures; a functioning civil society; and freedom from persecution, conflict, and corruption. In a debate in the Scottish Parliament in November 2005: "Malawi After Gleneagles: A Commission for Africa Case-Study", the Director of the UN Research Institute for Social Development, Thandika Mkandawire cited and then amplified the comments of Nobel Laureate Amartya Sen:

"Development, Amartya Sen[68] has suggested, means the expansion of choice for individuals and societies. It would be the height of irony if aid, which has been used to push for democratic reforms in many countries, were to produce 'choiceless democracies'. To support accountability in the new democracies, there is a pressing need to rethink the institutions that underpin the current management of aid. The message of my remarks is that aid belongs to that category of economic activities in which it is important to proceed by trial and error. This, in turn, requires dialogue and a more deliberative partnership. African politics is changing rapidly."

The impact of global politics, trade and conflicts on development is immense. These include trade rules, tariffs and western subsidies, local and regional conflict, oil diplomacy, governance, and the roles of transnational companies. The importance of a thriving local private sector (large and small) in poverty alleviation is equally critical. A climate in which individual traders and small businesses can thrive is just as important as the growth of larger industry. A functioning local business sector can also help deliver poverty-reduction outcomes through direct involvement in the development of effective and sustainable infrastructure, which in turn is of critical importance for three reasons:

1. It underpins communities by providing the basic needs and services of shelter, access to safe water/sanitation, energy, transport, education and healthcare
2. It provides an internal demand for local skills and employment through its delivery
3. It provides a vital platform for the growth of the local economy and small and medium sized enterprises through improved access to infrastructure services, local skills, and the stimulation of and better access to both internal/local and external/national markets

But infrastructure delivery also requires investment.

Those mired in poverty do not have and cannot afford all the resources necessary to resolve their plight. They will need external investment from business and the international agencies, and assistance from the worldwide engineering community.

Humanity now faces its greatest challenges – addressing issues of climate change and sustainability on the one hand and poverty reduction and governance on the other.

A
Former ICE President Colin Clinton in Kibera.
Credit: Paul Jowitt

B
Kibera/Korogocho urban slums project community group.
Credit: Paul Jowitt


A

Engineering without Frontiers

The Institution of Civil Engineers (ICE), as one of the world's leading professional engineering bodies, has both an opportunity and a duty to play a prominent role in human development and sustainability.

ICE and its members have had a long-standing interest in development work and disaster relief, supporting the establishment of RedR in 1979, establishing the Appropriate Development Panel in 1984, and establishing the Telford Challenge (now Engineers Against Poverty, EAP) with the Institution of Mechanical Engineers in 1998. ICE approved its Sustainability Charter in 2003 and has been actively working to embed sustainability competencies throughout the education and training of the civil engineer.

In November 2003, then ICE President Douglas Oakervee announced in his Presidential Address his intention to establish an ICE Commission – "Engineering without Frontiers" (ICE-EwF) to inquire into society's expectations of the engineer in the 21st century, and in particular to determine the role of the engineer and ICE in achieving the UN MDGs and their contribution to international development.

Momentum was continued during Colin Clinton's year as ICE President, with visits to a number of development and poverty reduction projects in Kenya and Tanzania. These allowed ICE to see what those involved were trying to do, hear of their expectations in terms of international development and poverty reduction and establish ICE's role in this process.

And Gordon Masterton, the current ICE President, in his Presidential Address pointed out the critical role of the civil engineer in terms of building civilisations. A 'Protocol for Engineering a Sustainable Future for the Planet' is ready for signature on 4 July 2006 by the Institution of Civil Engineers, the American Society of Civil Engineers (ASCE) and the Canadian Society of Civil Engineers (CSCE) at their triennial conference in London. This will bring together the work of the ICE-EwF Commission on International Development and Poverty Reduction, with those other key interlinked issues of our times – climate change and energy.

ICE-EwF's relationship to other events can be gauged by the following timelines:

2002
UN Millennium Project established

2003
ICE Presidential Commission – "Engineering without Frontiers" (ICE-EwF)

2004
UK Prime Minister establishes Africa Commission[69]

2005
ICE-EwF develops and secures widespread support for its Principles of Engineering for International Development and Poverty Reduction – formally launched in Nairobi and Dar es Salaam

ICE-EwF Pre-G8 Summit Evidentiary Hearing, 3 June

UK Chancellor leads G8 write-off of LDC debt, 10 June

G8 Summit in Gleneagles 8 July

ICE-EwF media and related activity in response to G8

UN MDG update, September

2006
Brunel International Lecture, 6 June

ICE/ASCE/CSCE Protocol: "Engineering a Sustainable Future for the Planet" Triennial Conference, London, 3-4 July

ICE-EwF's prime tasks were to consider[70]

1. Expectations
What does society expect of an engineer in the 21st century?

2. Critical activities
What are the critical activities required to meet the UN MDGs?

3. Partnerships
How can ICE integrate these ambitions with related organisations already involved?[71]

These have emerged as follows:

Expectations

"The delivery of effective infrastructure services appropriate to international development and poverty reduction."

To provide, maintain, improve and sustain the infrastructure that supports and underpins civilisation: ie equitable access to water supply/wastewater disposal; shelter; transportation systems; waste management and energy.

The same basic requirements apply both in the developed and developing worlds although the starting points are different and so are some of the required solutions and delivery mechanisms. This in turn requires engineering education/ training/ capacity building in 'development engineering', not only in developing countries themselves, but also important to engineers trained in the UK and similar environments engaged in development work.

B

Critical activities

"Advocacy, influence, and the exercise of the engineering skills to make it happen."

The development and deployment of project management and appropriate engineering skills necessary to fulfil society's expectations of the engineer to deliver the infrastructure to achieve the UN MDGs.

The adoption of appropriate forms of procurement and engineering standards for international development.

Partnerships

"The mobilisation of the engineering community in partnership with other sectors to create the high level delivery mechanisms to scale up the response."

An engineering vision for MDG implementation

The MDGs viewed as an engineering project?

If engineering is truly to deliver the best possible outcomes to society, engineers must understand their role in this wider field, and shape their work and their contribution accordingly. So this is our challenge:

As key implementers, how can we produce an action-based plan, to ensure that the MDGs are met while achieving sustainability worldwide?

It raises some key issues.

Engineering activity must be directed towards outcomes – measurable against the MDG targets themselves – not simply the construction of infrastructure artefacts, but infrastructure that delivers.

We need to focus on helping to provide sustainable livelihoods through a 'people centred' approach to poverty reduction. Its starting point should be an analysis of how people survive and thrive, adopting a holistic (systems) view and taking account of the vital role of cross-sectoral partnerships. Capacity building and community involvement is important if development is to be sustainable and not imposed inappropriately by external bodies. Related to this are transaction costs and livelihoods. Problems for the poor are often not to do with supply per se, but to do with the costs and access to supplies and services. This is an important issue in the debate on the benefits of privatisation of utilities and services. It also raises the issue of whether there is a case for a rights-based approach to local governance – especially important in those communities, which are excluded by virtue of illegal/disputed property rights.

Emerging technologies will play a role, perhaps not central but nevertheless important, for example, renewable energy as a means of local access to power, and wireless communications as a means of access to knowledge and services, and indirectly to gender equality. The limiting factors are not a lack of engineering knowledge and technology or knowing what needs to be done, but finding ways of applying that engineering technology, building local capacity to ensure its effective delivery, managing and financing it, and ensuring that its application is maintained.

Whilst engineers must remain experts in their particular fields, they must also understand – and play an active part in – the interactions between infrastructure development, the environment, culture/society/community, the economy and the political/public/private/third sector organisations involved. Just as with the development of energy futures, engineering for international development is not an apolitical activity.

Some key questions need to be answered with regard to:

- Engineering education and professional leadership for development
- Appropriate standards, primary engineering and community involvement
- Procurement, unblocking barriers and finding effective delivery models
- Related high level delivery, political and business issues
- Links with engineering organisations overseas
- Tapping the diaspora, capacity building and institutional learning
- Policy development, advocacy and influence

These issues are addressed over the following pages.

A
"Kids Working Big" in San Mateo Ixtatán, Guatemala. Children developing their own 'engineering' skills, building fog collectors to supplement community water supply under the supervision of EWB volunteers.
Credit:
Christopher Pritchard

Engineering education and professional leadership

What should civil engineers of the 21st century be like? To what extent does the Institution's values and aspirations reflect those of young engineers?

How can society harness the enthusiasm of youth and young engineers to develop their leadership in engineering development? Do we currently have the appropriate structures in industry to enable all this to happen? What changes might be needed to enable industry to support engineers who wish to contribute to development in some way?

There is no doubt that engineering's youth has the energy and motivation to help deliver the world from the shadows of poverty, as amply demonstrated by the activities of Engineers Without Borders (EWB) – a worldwide movement of predominantly young engineers, with national branches in over 50 countries covering all the world's continents. This international engineering partnership of youth represents hope for the future. In the UK alone, EWB-UK has 14 branches and over 2,000 members, and whose activities range from running training courses, undertaking research and supporting international development projects[72].

ICE's routes to professional membership explicitly recognise development engineering as a valid route to membership[73] and ICE is seeking to extend its QUEST Award scheme to other developing countries along the lines of the very successful scheme that has been operated in Pakistan over the past few years through the Ghulam Haider Scholarship[74] to support engineering students through their studies.

Appropriate standards, primary engineering and community involvement

Are engineering standards, currently required to attract project funding, creating a barrier to development and what are the alternatives? The outcomes important to society and to the poor people may not be the same as those measured by professionals (ie access may be more important than road standards). What are the merits of promoting and practising the concept of primary or local resource based engineering?

ICE's Appropriate Development Panel, members of the ICE-EwF's Presidential Commission and others are working to determine appropriate technical standards to accelerate development. With support from UNESCO, the Royal Society of Edinburgh and the UK's Department for International Development (DfID), ICE's Appropriate Development Panel, EAP, EWB and others are working with ICE's international membership to build international capacity and skills in development engineering.

Procurement, unblocking barriers and finding effective delivery models

How could development infrastructure be realised more quickly? What are the project financing and procurement issues? Could a joint venture 'pain and gain' model, or multi-sector partnership (involving communities, NGOs, the private sector, local/national governments, international financial institutions, the professional institutions and engineering youth) be used to help unblock development projects?

What is the role of Corporate Social Responsibility (CSR) in improving pro-poor outcomes from development engineering? Could the benefit of development funding be improved by tightening conditionality aspects relating to pro-poor outcomes and poverty reduction? And should there be a more appropriate form of contract/contract protocols, involving not just the project funder, local client and the contractor/consultant, but also community groups, NGOs and volunteer engineers, and local engineering professions/institutions?

A piece of action-based research on Appropriate Procurement, undertaken by EAP on ICE-EwF's behalf, has been particularly encouraging, resulting in a series of Round Table meetings in Kenya, Indonesia, India, London and Nigeria[75] together with a presentation to UK DfID.

The work is now at a stage where it can be tested, and a number of companies have offered to apply the Appropriate Procurement Guidelines on real projects. This activity has also benefited from close links with Ron Watermeyer (former President of the South African Institution of Civil Engineers – SAICE) and his significant experience[76, 77], of similar issues in South Africa and internationally. Watermeyer's experience and work with respect to procurement processes in South Africa confirms that "it is simple to develop the concepts and much more difficult to implement them" – but that it can be done[78, 79].

Watermeyer was seconded to the South Africa government in 1995 to lead a three-man procurement reform task team established to reform the procurement system from two points of view – good governance and the use of procurement to achieve social objectives. He had previously been project manager of Soweto's contractor development programme and was closely involved in community-based job creation programmes.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In his SAICE Presidential Address, Watermeyer[80] stated:

"In South Africa, the question of who benefits from the construction process, in terms of employment and business opportunities, has been introduced into the construction process since the early 1990s. In the future, the approach to construction will increasingly shift to embrace global issues relating to social equity and cultural issues, economic constraints and environmental quality. Projects will in the future be increasingly assessed in terms of a 'triple bottom line' which embraces economic, environmental and social considerations."

ICE and SAICE/Ron Watermeyer are now collaborating on the development of an internationally recognised protocol for infrastructure procurement.

Related high level delivery, political and business issues

What stance might engineering bodies legitimately take in relation to politics and business issues? In particular, what might their position be on the issue of services privatisation in developing countries? In the 2004 Brunel Lecture, John Banyard described the financial limitations on the private sector in providing water for the world[81]. The problems are not always financial, as recent reports and events have shown. According to Action Aid[82], donors are still using their influence to:

"…push poor countries into privatising basic services such as water, with little concern for the views of the public or poor people's needs. Donors, in particular the World Bank, have been crucial in pushing the Tanzanian government to privatise the water system in Dar es Salaam…

Since City Water took over, water tariffs have increased substantially, but water quality has not improved. Whole areas are being cut off because a few households fail to pay their bills. Customers continue to receive bills without receiving water, sometimes resulting in bill collectors being 'chased away with dogs and knives'.

Poor people are being marginalised: neither the World Bank, nor the government, nor City Water, have paid much attention to the needs of poor men and women."

The Tanzanian government has since terminated its 10-year contract with City Water consortium, claiming the company had made less than half the required investment and had failed to improve services. Similar concerns over privatisation have also been reported by the UK's leading water charity WaterAid[83].

But there are high level models for delivery that offer a way forward and which reflect the ethos of partnership between engineering organisations, NGOs and local communities, such as that referred to previously in terms of access to energy. In the water sector, the efforts of many NGOs such as WaterAid and Oxfam make an invaluable contribution, but again, the effort needs to be scaled up and involve the international engineering community. There is growing evidence that this is beginning to happen. Among the emerging initiatives are Water and Sanitation for the Urban Poor (WSUP)[84], a Royal Society of Arts (RSA) Project[85], and other business partnerships formed from leading engineering consultancies.

The WSUP partnership[86] – between NGOs, business and academia with the United Nations Development Programme (UNDP) as an observer – has a stated mission to:

"advance the UN MDGs for water, sanitation, and associated health benefits through multi-sector, stakeholder partnerships delivering sustainable, equitable, and affordable water and sanitation services to the urban poor in developing countries."

For these and other partnerships to succeed, the process of procurement from the aid agencies and governments needs to be adapted to provide a more direct route from outline planning and design to project delivery – such that overheads can be reduced, the principles of equitable procurement upheld whilst still offering a prospect of a reasonable return to the delivery partnerships.

The RSA project has also been seeking to develop a model for corporate investment in water and sanitation in the developing world through partnerships with local communities and governments, based on the belief that economic development stimulated by improved water and sanitation offers direct benefits to communities and corporates alike.

The RSA project begins from two propositions:

1. Aid is inadequate, both in scale and efficiency, to make serious progress on development and that the resources needed for effective development are better met by communities, markets and the private sector
2. The cheapest and the fastest route of changing the total poverty cycle is the provision of water and sanitation

The RSA project is based on the "infrastructure networking" techniques developed by Project Champion Himanshu Parikh (Director, Buro Happold, India), providing integrated water and sanitation infrastructure at a fraction of the cost of

A
Post-earthquake Pakistan, construction of pit latrines.
Credit Tim Hayward, RedR-IHE

B
Post-tsunami Sri Lanka, example of temporary housing.
Credit: RedR-IHE

C
RedR-IHE Logistics Course 2004.
Credit: RedR-IHE

conventional methods. The project is still seeking to attract corporate engagement on the scales required, but meanwhile is working with the Byrraju Foundation in Hyderabad to bring clean water and improved sanitation to villages in rural Andhra Pradesh.

Links with engineering organisations overseas

Could ICE improve its working links with sister engineering organisations in developing countries to better understand and support their aspirations and priorities with respect to pro-poor development and disaster risk reduction? How can we work together to build capacity in engineering for development?

One of the most successful – and most effective – organisations for tapping into engineering and related expertise in times of humanitarian crisis has been RedR – Engineers for Disaster Relief – established by Peter Guthrie in 1980, as a result of his experience working with Oxfam as the only engineer for the Vietnamese boat people in Malaysia. He "saw the pressing need for engineers to help in this sort of work and compiled a register of engineers, who volunteered from across the engineering profession, who would be available at short notice to work with front-line relief agencies". Guthrie's vision has evolved into an international federation of RedRs providing training and recruitment services for humanitarian professionals across the world, with offices and branches in Australia, Canada, East Africa, India, London and New Zealand. In 2003, RedR-London merged with the International Health Exchange to become RedR-IHE. The International Health Exchange brought the added value of 22 years of health expertise from the relief and development sector.

RedR has widespread cross-sectoral support. In the wake of a variety of both natural and man-made disasters the business community has been prepared to assist RedR through direct sponsorship and by the release of personnel to undertake particular RedR missions to relieve humanitarian suffering across the world. Perhaps it is now time to consider how the skills of RedR and its experience in disaster relief can be moved up the "supply chain" to build a wider partnership to assist in disaster prevention, risk reduction and the relief of world poverty.

Tapping the diaspora, capacity building and institutional learning

Concerns are often expressed about the migration of skilled manpower (engineers, nurses, doctors, teachers etc) from developing countries, in some cases as a result of active recruitment from the developed world. As noted by Calestous Juma[87], this diaspora need not be a wholly negative phenomenon:

> "The real policy challenge for African countries is figuring out how to tap the expertise of those who migrate and upgrade their skills while in the diaspora, not engage in futile efforts to stall international migration. The most notable case is the Taiwanese diaspora, which played a crucial role in developing the country's electronics industry. This was a genuine partnership involving the mobility of skills and capital. Countries such as India are now understudying this model."
> Calestous Juma

But as Juma also notes, along with others such as former ICE President Tony Ridley and Gordon Conway (former President of the Rockefeller Foundation, now Chief Scientific Advisor at the UK Department for International Development), infrastructure development offers a vital opportunity for capacity building, technological learning, and the development of local businesses. An example of the integration of education, capacity building and practice based learning is described by Conway[88]:

> "An interesting experiment to try and rectify (the lack of suitably qualified personnel working at the local level) is being conducted at Makerere University in Uganda as part of the government's program of decentralisation. The University is embarking on a large program of training young Ugandans for service in local government – in agriculture, health, planning etc – building into the curricula extended periods where the students spend time as interns in local government offices. Equally important, however, is the participation of the intended beneficiaries – the rural poor – themselves. We have long embraced the notion of such participation, but far too often this has been rhetorical."

The benefits of this general approach are also noted by Ridley and Lee[89] with specific reference to infrastructure:

> "Infrastructure development provides a foundation for technological learning, because infrastructure uses a wide range of technologies and complex institutional arrangements. Governments traditionally view infrastructure projects from a static perspective…they seldom consider that building railways, airports, roads and telecommunications networks could be structured to promote technological, organisational and institutional learning."
> Tony Ridley and Dato' Ir Yee-Cheong Lee

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Policy development, advocacy and influence

To what extent and how should the Institution make its members more aware of the issues surrounding development and sustainability? Involvement in high-level policy issues will always have the potential to be controversial.

But, ICE must be bold. It must:

- Advocate to government, business and the international community the vital importance of effective infrastructure in the fight against poverty[90]
- Argue and demonstrate the need for appropriate procurement processes engaging the international engineering community together with developing the local economy and the local skills base
- Play a major role in the Anti Corruption Forum[91] to fight corruption in international development projects
- Build and support the international engineering community in creating the partnerships to deliver
- Advocate its view that the UN MDGs will only be met if they are treated as a series of projects, with a project management plan, and which civil engineering is well placed to help to deliver

We need to communicate and advocate these positions vigorously – to governments, businesses, our members and other stakeholders. We are doing this already: in a UK Parliamentary debate on international development Tony McWalter[92] stated:

> "In the body of evidence is a memorandum from ICE, and if Members are interested in reading only one memorandum, they should read that one, because it contains so much that is relevant to our essential problem."
> Tony McWalter MP

We will continue to do this by establishing an International Development Stakeholder Forum to influence the key players and decision-makers.

And we need to prepare ourselves – our people, our profession and our industry – for the challenges that need to be faced and resolved.

In the build up to the G8 Summit in Gleneagles in July 2005, ICE-EwF held a Pre-G8 Summit: "Scaling it Up" in June. UN Millennium Project Advisor Calestous Juma sent the following message for the event:

> "There is one practical area of focus which is how to build engineering competence in Africa and it is critical for your meeting to send clear messages about the transition from delivering 'aid' to helping to build competence. This is the only game in town that people will play."
> Calestous Juma

The event attracted over 70 participants from industry, the UK Government's Department for International Development, UNESCO, NGOs and ICE Technical Boards and members to explore ways of "Scaling Up" the response to meeting the UN MDGs, and to mobilise the response from the industry.

The Summit was followed by a media campaign and political influencing, issuing the key messages on the following page.

"In the body of evidence is a memorandum from ICE, and if Members are interested in reading only one memorandum, they should read that one, because it contains so much that is relevant to our essential problem."
Tony McWalter MP

Key messages to G8 leaders and the media

"The ICE-EwF Commission welcomes the outcomes from the G8 summit and the move to write off LDC debt. The door is now open for engineers to work in partnership with other key stakeholders – communities, governments, NGOs, international agencies and financial institutions to start work on the critical infrastructure – in particular water supply and sanitation – needed to achieve the UN MDGs: – 'to measure the health of a nation, count the number of taps, not the number of hospital beds'."

"ICE will be communicating these views to G8 leaders and the UN, advocating the ICE-EwF 'Principles for Development and Poverty Reduction' as a platform for partnership, collaboration and delivery by all parties."

"The world is at a tipping point in terms of international development and the UN MDGs. There is a window of opportunity, opened further by the mood of public opinion, the work of the Africa Commission and the pressure on the G8 leaders at Gleneagles in July, to address poverty reduction and climate change."

"Engineering and engineers have a vital role to play over the next 10 years, making their contribution to development and poverty reduction and the achievement of the UN MDGs."

"The engineering community is ready to unlock the human endeavour, to create the international partnerships, and build the infrastructure that will reduce world poverty and deliver the UN MDGs – on time, on budget."

"Will us the means and the engineering community will deliver the ends."

A – B
The long march to making poverty history.
Credit: Paul Jowitt

The next steps

International development and poverty reduction is now firmly high up on both the international political agenda and the Institution's.

In both cases, this represents a sea change in recent times. Despite scepticism from some quarters, never has the issue of international development been so prominent in the minds of the public (both in the UK and internationally), the international community (governmental, inter-governmental), NGOs, business, and not least, across the generations of ICE's own membership. It is also coupled, through the UN MDGs and the 2005 G8 summit, with the other major global issues of our times – climate change, carbon emissions and energy policy.

As one ICE-EwF Commissioner and former ICE VP has indicated:

"The Institution has a role to represent its individual members on a collective basis, and by doing so, to influence for the public good the direction of government and society.

This has the uncomfortable consequence that ICE must have a position on issues that it has historically choked on."

The challenge for ICE – and others – is how to embed and build on what has been achieved so far, transferring momentum to other bodies outside ICE establishing effective interactions and relationships to move the agenda forward and to create multi-dimensional partnerships for delivery within and beyond the engineering community.

We need to start the process of engineering civilisation out of poverty and away from the threat of climate change – now.

- Engineering the world away from the equally long shadows thrown by an energy and environmental crisis and with global climate at a tipping point
- Engineering the poor out of the dark shadows cast by world poverty and the misery it generates

Postscript: paying the price?

Brunel, Bazalgette, Bentham, Brundtland…

At the beginning of the 21st century people such as Bob Geldof and Bono have mobilised international opinion. To reiterate:

"We are the first generation that can look extreme poverty in the eye, and say this and mean it – we have the cash, we have the drugs, we have the science. Do we have the will to make poverty history?"

Be in no doubt: There will be 21st century engineering heroes to parallel Brunel and Bazalgette.

The engineering community is ready to unlock the human endeavour,to create the international partnerships and build the infrastructure that will reduce world poverty, ready to deliver the UN MDGs – on time, on budget.

Will us the means and the engineering community will deliver the ends.

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The engineering community is ready to unlock the human endeavour, to create the international partnerships and build the infrastructure that will reduce world poverty, ready to deliver the UN MDGs – on time, on budget.

Will us the means and the engineering community will deliver the ends.

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Ron Watermeyer (former President SAICE)

All ICE-EwF Presidential Commission Members and Advisors
Members of ‘the Edge’

About the Author

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Paul Jowitt is Professor of Civil Engineering Systems and Executive Director of the Scottish Institute of Sustainable Technology at Heriot-Watt University. He is also a Board Member of Scottish Water.

He is a graduate of Imperial College, London and was a Lecturer in the Civil Engineering Department there from 1974, until he took up the Chair of Civil Engineering Systems at Heriot-Watt University in 1987. In 1989 he was appointed Head of the Civil Engineering Department and then Head of the combined Department of Civil and Offshore Engineering from 1991 to 1999.

Since 1999 he has been Executive Director of the Scottish Institute of Sustainable Technology (www.sistech.co.uk), a joint venture between the University and Scottish Enterprise, established to put sustainability into practice. Its operational activities are based at Heriot-Watt University (predominantly at its main campus in Edinburgh but with links to the International Centre for Island Technology in Orkney).

Paul Jowitt's major research interests concern the issues of sustainable development, risk, and the development of systems-level solutions within civil engineering, the built environment and environmental management. A recent paper for the Institution of Civil Engineers (ICE) on the educational formation of the civil engineers and their role in terms of sustainable development was awarded the 2005 ICE Trevithick Prize.

Major areas of activity have included water resources systems modelling, asset and resource management and the environmental and engineering applications of systems modelling, optimisation, reliability and risk assessment. This research has been funded mainly by a combination of research grants and water industry research contracts in such areas as water distribution systems, wastewater treatment plant modelling & control, drought management and sustainable water resource management.

Paul Jowitt is Vice-President of the Institution of Civil Engineers, and Chair of the ICE Presidential Commission ("Engineering without Frontiers") to examine society's expectations of the civil engineer in the 21st century and the engineer's contribution to meeting the UN Millennium Development Goals. He also serves on ICE's Environment and Sustainability Board and was Chair of an ICE Council Task Group to embed sustainable development into civil engineering curricula and professional development. He is a former Chairman of the East of Scotland Region of ICE and the Scottish Hydrological Group.

He is Editor of the international journal 'Civil Engineering and Environmental Systems', a former Editor of ICE's Water, Maritime and Energy Journal (1998-2001). In 1996 he presented a lecture on water resources at the Edinburgh International Science Festival entitled "From the Metamorphosis of Ajax to the Sweet Water of Leith". He is a member of 'The Edge' – an ICE/RIBA/CIBSE Ginger Group created to increase public and political awareness of the role of engineers and architects.

In his private life he enjoys old cars and old houses. He is the co-owner and restorer of one of Edinburgh's last surviving (and B-listed) mews stables properties adjacent to the Water of Leith in Edinburgh's Dean Village. Since 1966 he has been the owner, driver and restorer of a 1937 Morgan Motor Tricycle (a Matchless MX4 990cc V-Twin powered Barrel Back Super Sports). He also enjoys painting and sculpture, and, when given the chance, sailing.

He is a trustee of the charity Engineers Against Poverty, the Forth Bridges Visitor Centre Trust, and The Steamship Sir Walter Scott Trust.

Endnotes

1 Joint Science Academies' Statement: "Global Response to Climate Change", June 2005, http://www.royalsoc.ac.uk/displaypagedoc.asp?id=13618

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3 Jonathan A. Patz, Diarmid Campbell-Lendrum, Tracey Holloway and Jonathan A. Foley; "Impact of regional climate change on human health", Nature 438, 310-317, 17 November 2005.

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7 Calestous Juma (Professor of the Practice of International Development, Kennedy School of Government, Harvard University), Editor, "Going for Growth: Science, Technology and Innovation in Africa); Published by the Smith Institute; 2005; ISBN 1 902488 97 0.

8 Bono: http://www.worldvision.org.nz/rampant/MakePovertyHistory

"We are the first generation that can look extreme poverty in the eye, and say this and mean it – we have the cash, we have the drugs, we have the science. Do we have the will to make poverty history? In 2005, the leaders of rich countries have the opportunity to lift millions of people out of poverty. At the G8 Summit, at the UN Special Session on the Millennium Development Goals, and at a ministerial conference of the World Trade Organization, trade rules, aid, and the unsustainable debt of developing countries – issues critical to the future of the world's poorest people – will be up for discussion. But will world leaders deliver on their rhetoric? In 2000, rich countries made a commitment to play their part in ensuring that the MDGs are met – but their promises remain unfulfilled. Five years later, they should ensure that a new round of international summitry becomes a platform for action."

9 Adrian Vaughan, "Isambard Kingdom Brunel: Engineering Knight Errant"; John Murray; ISBN: 0-7195-5282-6; 1991.

10 The full version of Tredgold's definition is as follows, which shows the strong interconnection between civil engineering and the economic cycle:

"Civil Engineering is the art of directing the great sources of Power in Nature for the use and convenience of man; being that practical application of the most important principles of natural Philosophy which has in a considerable degree realised the anticipations of Bacon, and changed the aspect and state of affairs in the whole world. The most important object of Civil Engineering is to improve the means of production and of traffic in states, both for external and internal Trade. This applied in the construction and management of Roads – Bridges – Rail Roads – Aqueducts – Canals – River Navigation – Docks, and Storehouses for the convenience of internal intercourse and exchange; – and in the construction of Ports – Harbours – Moles – Breakwaters – and Lighthouses, and in the navigation by artificial Power for the purposes of commerce."

11 Gro Harlem Brandtland was a Norwegian Labour politician and Prime Minister three times between 1981and 1996 and Director-General of the World Health Organization (WHO) from 1998–2003.

12 "The Brundtland Report: Our Common Future", World Commission on Environment and Development, OUP, ISBN-10: 0-19-282080-X; ISBN-13: 978-0-19-282080-8, 1987.

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14 Bent Flyvbjerg, Nils Bruzelius and Werner Rothengatter, "Megaprojects and Risk – An Anatomy of Ambition", Cambridge University Press, 2003, 218pp, ISBN-13: 9780521009461.

15 The Atmospheric Railway, http://www.bbc.co.uk/history/society_culture/industrialisation/brunel_isambard_02.shtml

16 Bazalgette's French grandfather arrived in London in around 1775 via the Americas and Jamaica, a rich man, a property owner, a creditor of Royalty, and sometimes described as a tailor. Bazalgette's father served in the Royal Navy. He was wounded in 1809 and retired with the rank of Commander in 1814. Isambard Kingdom Brunel's father Marc was also a navy man – in the French Navy, but for political reasons he fled to New York where he became the city engineer, before arriving in England in 1799 and then working for the Admiralty.

17 "Sir Edwin concluded his somewhat prolix communication by advocating the bringing down of fresh air from a height, by means of such as structures as the Eiffel Tower, and distributing it, warmed and fresh, in our buildings". A discussion at the Royal Society of Arts on the disposal, of sewage, reported by *The Builder*, 1 February 1890, pp350-1. Chadwick's suggestion, if somewhat inadvertent, relates much more to the natural ventilation of buildings in the 21st century… Right solution, wrong problem!

18 It was also Chadwick who had earlier written to Councillor John Shuttleworth of Manchester in 1844: "For all purposes it would be of the greatest importance that you should get the advice of trustworthy engineers, of whom I am sorry to say there are marvellous few – a more ignorant and jobbing set of men I have rarely met with." He would be confounded…

19 Stephen Halliday, "The Great Stink of London: Sir Joseph Bazalgette and the Cleansing of the Victorian Metropolis", Sutton Publishing, 1999, ISBN:0750919752.

20 The Times, 16 March 1891, p4, "Joseph Bazalgette: That great, far-sighted engineer, who probably did more good, and saved more lives, than any single Victorian public official. When the New Zealander comes to London, a thousand years hence, to sketch the ruins of St Paul's, the magnificent solidity and the faultless symmetry of the great granite blocks which form the wall of the Thames Embankment will still remain to testify that, in the reign of Victoria, 'jerry-building' was not quite universal. Of the great sewer that runs beneath, Londoners know, as a rule, nothing, though the Registrar-General could tell them that its existence has added twenty years to their chance of life".

21 Professor Jon Side, "A new enlightenment: engineering a sustainable future", International Centre for Island Technology, Stromness, Orkney, Inaugural Lecture, Heriot-Watt University, February 2001.

22 David Elms "Why are we here?" in Elms D G and Wilkinson D (1995), "The Environmentally, Educated Engineer: Focus on Fundamentals"; CAE Publications, New Zealand Canterbury, NZ. ISBN 0-908993-08-0, pp 15-23.

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