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.

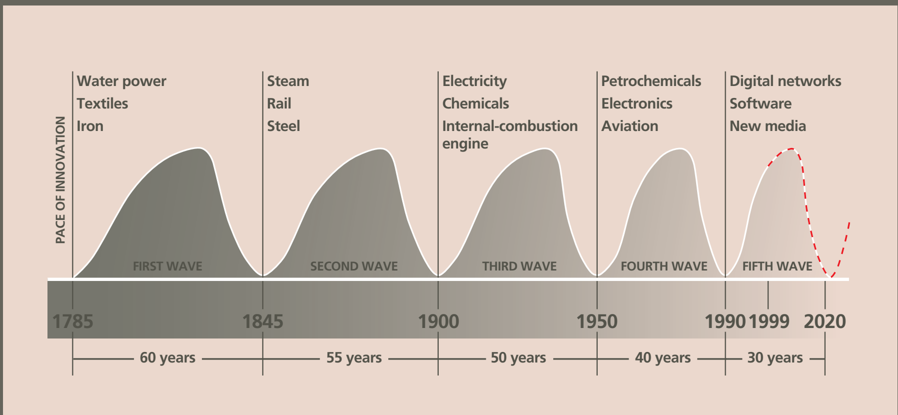
In the era of technical rationality – which has dominated the past two or three centuries – economic and technical progress was generally embedded in narrow technical disciplines which, despite our scientific understanding, did not anticipate the wider physical and non-physical consequences at the systems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

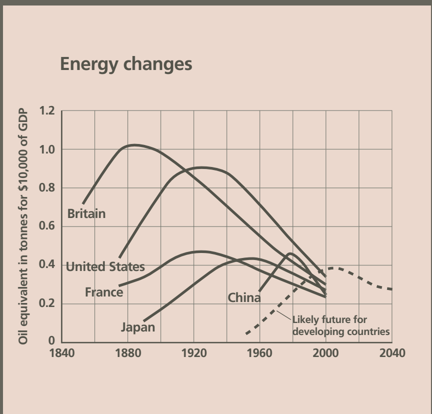
The potential of the Atlantic Heat Conveyor[31] to 'switch' and the Gulf Stream to collapse, is perhaps one of the most threatening examples of large-scale non-linear behaviour. Recent research[32] suggests that melting freshwater from the Arctic ice sheets could dilute the denser Gulf Stream waters, 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 2-3ºC (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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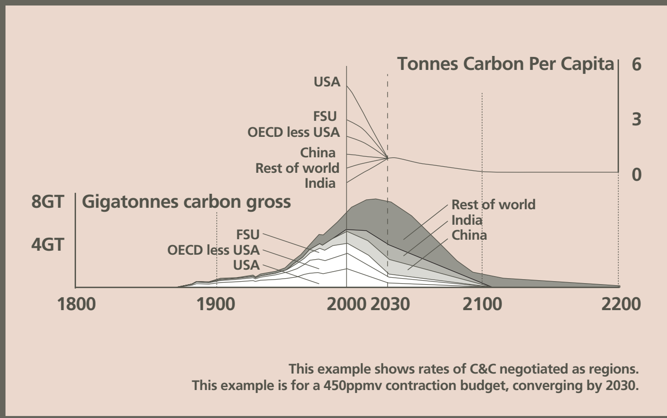

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learning curve[35], as measured by the variation through time of the ratio of energy use per unit of GDP. Typically, as an economy develops, energy dependency grows very quickly with investment in basic infrastructure, heavy industry, transport networks, 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?

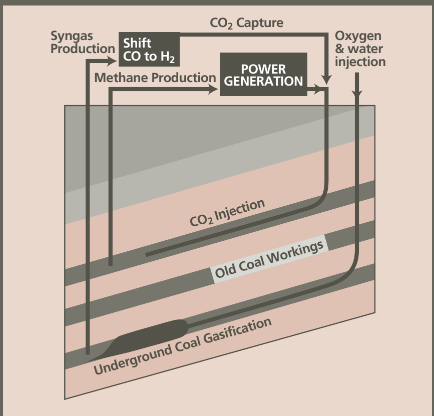
And at what level – personal, corporate or governmental?

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.



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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

B

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."