The Royal Academy of Engineering

Engineering Change

Towards a sustainable future in the developing world

Edited by Peter Guthrie, Calestous Juma and Hayaatun Sillem

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Edited by:

Professor Peter Guthrie OBE FREng
Professor of Engineering for Sustainable Development
Centre for Sustainable Development
Department of Engineering, University of Cambridge

Professor Calestous Juma HonFREng FRS
Professor of the Practice of International Development
Belfer Center for Science and International Affairs
Kennedy School of Government, Harvard University

Dr Hayaatun Sillem
International Manager
The Royal Academy of Engineering

Consultant editor:
Ian Jones, Director, Isinglass Consultancy Ltd

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Foreword

Historically, the role of the engineer in Northern development has been regarded positively, almost affectionately. Brunel and Telford, Stephenson and Watt, these seminal figures are seen as agents of progress through the early days of industrialisation. By contrast, the role of engineers in development in lower income countries in the last half century arouses a more mixed response. Large scale projects from dams to highways have sometimes become icons of inappropriate solutions to the needs of the poor, or been shown up as ineffective, unaffordable burdens on the country concerned. Despite significant achievements in the provision of essential infrastructure, the reputation of engineering has been tarnished by the failures.

This booklet has been compiled to highlight some of the many ways in which engineers around the world contribute to improving the quality of life of poor people, with a particular focus on Africa. The aim is not to provide a comprehensive treatise on the relationship between engineering and international development. It is certainly not to argue that engineers alone hold the key to poverty eradication. Rather it is to suggest that engineers are key to the development and delivery of a wide range of solutions, as contributors in complex and multidisciplinary teams.

The essays in this collection have been written by engineers and non-engineers with experience or expertise in different aspects of engineering and development. Their perspectives are entirely personal and do not represent the views of The Royal Academy of Engineering. The authors are drawn from both the North and South, on the one hand reflecting the fact that the Academy is a UK-based organisation but one that works with partners around the world, and on the other, the fact that engineering itself is an international endeavour.

The essays are complemented by a series of profiles of engineers from developing countries who have, in different ways, both achieved success on an international stage and contributed to development in their countries of origin and beyond. The stories of these individuals demonstrate that, when put into practice, the themes addressed in the essays can have a powerful impact on the prosperity and well-being of poor communities around the world.

There is a demand for the finest engineers to engage with the urgent need to improve conditions for the world's poorest people. We hope that this collection will help to stimulate a reconsideration of the role that contemporary engineering can play in enabling sustainable growth in developing countries and, ultimately, encourage a process that will enhance the contribution that engineers make to addressing this most pressing of global challenges.

Peter Guthrie OBE FREng
Professor of Engineering for Sustainable Development
University of Cambridge

Millennium Development Goals

The Millennium Development Goals (MDGs) are eight international development goals, established by the United Nations at the UN Millennium Summit in 2000, which member states have pledged to achieve by 2015. The goals have associated targets, most of them quantitative, against which progress can be assessed.

1. Eradicate extreme poverty and hunger
   - Halve the proportion of people living on less than a dollar a day.
   - Achieve full employment for all, including women and young people.
   - Halve the proportion of people suffering from hunger.
2. Achieve universal primary education
   - Ensure that all children (boys and girls) can complete a full course of primary schooling.
3. Promote gender equality and empower women
   - Eliminate gender disparity in primary and secondary education.
4. Reduce child mortality
   - Reduce the under-five mortality rate by two-thirds.
5. Improve maternal health
   - Reduce the maternal mortality ratio by three quarters.
   - Establish universal access to reproductive health.
6. Combat HIV/AIDS, malaria, and other diseases
   - Halt the spread of HIV/AIDS.
   - Establish universal access to treatment for HIV/AIDS.
   - Halt the increase in malaria and other major diseases.
7. Ensure environmental sustainability
   - Integrate principles of sustainable development into national policies and programmes.
   - Reduce loss of biodiversity.
   - Halve the proportion of people without sustainable access to safe drinking water and basic sanitation.
   - Improve the lives of at least 100 million slum-dwellers.
8. Develop a global partnership for development
   - Develop further an open trading and financial system.
   - Address the special needs of the least developed countries.
   - Address the special needs of landlocked and small island developing states.
   - Deal with debt problems, to ensure that debt management is sustainable.
   - With pharmaceutical companies, provide access to affordable essential drugs.
   - With the private sector, take advantage of new technologies, especially in information and communications.

Overview: Engineering a better world

Calestous Juma

For decades engineering has often been seen as marginal in development. The legacy of large, expensive technology projects, ultimately providing few local benefits and despoiling the environment, has coloured many people's views. In addition, poor understanding of the sources of economic growth and prosperity has contributed to a limited appreciation of the role engineering could play in development. The general view of development as applied economics has tended to limit public perceptions of the influence of engineering in social change. But times may be changing. There is a growing awareness that, provided lessons are learned from the past, engineering has a key role to play in the economic development of poor countries.

What is the basis for this belief? The first point is that engineering is primarily about solving practical problems. It is about exploiting humankind's innate ingenuity to design and build innovative systems to meet people's needs.[1] In the developed world, it is taken for granted that a nation's infrastructure can provide clean water delivery and sewerage systems, as much energy as individuals and organisations need, and efficient transportation systems. All owe their origins to practical engineering expertise. But we are only starting to acknowledge the fact that developing countries need to harness the same ingenuity to solve local problems. The traditional view that solutions can be exported through relief efforts or 'poverty reduction' strategies is being gradually but effectively replaced by a deeper understanding of the importance of nurturing local creativity to solve local problems.

A second point is that engineering and innovation are important routes to wealth creation. Pioneering thinkers have long appreciated the economic benefits of investing in science and technology. Adding value and upgrading performance are a way of generating more wealth from limited natural resources (Murenzi, p. 13). And both Masoom Stanekzai (p. 35) and Gordon Conway (p. 25) make the point that investment in infrastructure is a key facilitator of economic development. In the past this might mainly have meant roads and associated infrastructure; today it includes information technology infrastructure and associated software (Hopper, p. 73).[2] There is no doubt that economic growth stems largely from the capacity to produce and move goods, services and ideas. The benefits of engineering and the associated accumulation of skills, especially in connection with infrastructure facilities, are quite evident.[3]

Nevertheless, engineering solutions in the past often failed to deliver either long-lasting benefits or create wealth. Why is there fresh hope that things will be different this time around?

Millennium Development Goals

The scale of the problems facing the developing world hardly needs restating. The Millennium Development Goals provide a clear picture of the challenges, but also, equally importantly, a set of markers by which progress can be measured (see opposite).

Examination of the goals reveals how engineering could make an enormous contribution to development. There is scarcely one goal that is not, to some extent, either directly or indirectly tied to engineering.[4] Take the case of halving the number of people who suffer from hunger by 2015. Admittedly, hunger is not simply a result of shortage of food. But agricultural productivity will have to improve to keep up with growing demand, which will depend on the engineering community's ability to design agricultural machinery, equipment and related structures. In addition, engineers will be needed to plan, supervise and manage a wide range of systems related to irrigation, drainage, water control and environmental management. Growing concerns over water shortages will require the input of engineers. In addition, expertise in transportation and logistics will be essential in the creation and expansion of efficient agricultural markets. Moreover, modern engineering products such as GPS and mobile telephony are becoming an essential part of the agricultural production system.

Mauritius: Mechanized sugar cane harvester.

Having said that, it would be foolhardy to believe that engineering alone can tackle these challenges. A past mistake was the belief that technological solutions could be delivered ready made, without consideration of the economic, political and social landscape into which they were being dropped. Engineering should be seen as a critical part of a large economic system. But to diminish its role, as has been the case in the last four decades, would be an exercise in folly.

What is needed is a more systems-oriented approach to development, which recognises interconnectedness and complexity. In a globalised world, isolated interventions may have little impact, fail or have unintended negative consequences, if they do not take into account the broader international, regional and national environments in which they are situated, as well as historical, political and social circumstances and sensitivities.

On the other hand, excessive caution could itself be harmful; engineering applications may not be easy to predict, and positive unintended uses may emerge. For example, mobile telephony is now used for banking in many African countries, but this function could not have been predicted based on the use of the technology in countries with well-established banking services. Similarly, cell phones have been widely used in Africa to promote transparency and accountability. Agents of political parties have, for instance, routinely used cell phones to communicate election results from polling stations, thereby reducing the possibility of doctoring the results. This may not itself eliminate corruption, but it can shift the locus of illegal activities to positions where they are easier to identify and curtail.

Another significant aspect of globalisation is the access it provides to the accumulated knowledge of science and technology. Increasingly, both content and tools are available via the internet - often free thanks to 'open access' publishing and open source software development. The principal challenge is to apply what is known in order to deliver local benefits. While this is not the complete picture - local adaptation calls for considerable ingenuity and an understanding of local circumstances - it is undoubtedly true that huge amounts of learning are now available and being added to on a daily basis.

Africa: Children browsing the internet

Many regions of the world, especially Africa and small island states, have not benefited from such knowledge because of the lack of high-speed internet connectivity. This digital isolation could be eased by investments in broadband internet either through undersea cables or communications satellites. Installing and maintaining such facilities will require increased investment in training in engineering and related fields.

One possible way forward is to define universities as critical nodes in the global knowledge ecology, for which they would need high-speed internet access (of at least one gigabyte per second). Governments and other agencies could provide such support in the form of 'broadband grants'. Suitably equipped colleges and universities could access knowledge to design new educational material, identify and incubate technology-based enterprises, and offer information extension services to neighbouring communities. In other words, 'broadband-grant' institutions could help to transform emerging economies in the same way that 'land-grant' institutions modernised US agriculture.

Drivers of change

The key challenge is for developing countries to become self-sustaining economies in which innovation and engineering are both externally networked and internally integrated.[5] Because of the inevitable financial constraints faced by developing countries, the emphasis tends to be on 'simple' solutions - practical, affordable, low-tech. However, 'simple' is a highly misleading description. Considerable creativity and innovation may be needed to develop solutions that work while taking into account environmental conditions, local materials and skills, manufacturing capacity, and constraints on installation and maintenance. As well as the technical challenges, there is the need to engage with people, their community and political representatives, and local academic structures (Cairncross, p. 21). Engineering for the developing world is not an easy option, a simplification of what works in the industrialised countries, but a distinct intellectual and practical challenge. The potential rewards, however, are great both for the population and for the engineer who can see the fruits of his or her labour making a real difference to people's lives.

Tony Karumba/AFP/Getty Images

Another commonly stated need is for capacity-building - of human resources and institutions. Developing countries need to ensure they are training the individuals who can tap into global knowledge reservoirs and apply learning on home soil. This calls for investment in local education and training at higher levels but perhaps also imaginative ways to close skills gaps, drawing upon a country's intellectual diaspora (Murenzi, p. 13) or other sources of knowledge such as retired engineers (Lawless, p. 47). The past few decades have seen great emphasis placed on primary education. Important though that is, there is also a need to invest resources in tertiary technical education, as countries such as Rwanda are now doing (Murenzi, p. 13).

In fact, science and engineering education needs to be strengthened at all levels. Engineering-based enterprises, for example, could be offered incentives that would enable them to serve as learning centres, like the engineering colleges and universities set up in a number of Asian countries.[6] Cell phone and mining companies are among the most successful enterprises in emerging markets and they could provide leadership in creating training facilities for the next generation of engineers. In addition, tools such as radio and TV could be used to enhance understanding of, and engagement with, science and engineering amongst the general public.

Other sectors of society could play a role in bringing the benefits of engineering to the wider public, including the military. However we may feel about it, military engineering is a significant component of global engineering activity, even in the developing world. High levels of military spending raise vexing issues when so many human needs are unmet. Can it be right for so many resources to be devoted to such ends? The question raises complex issues beyond the scope of this book, but while this situation exists can humanitarian benefits be gained from military activities? In industrialised countries, the military has historically played important roles in building and maintaining infrastructure. Similar functions need to be seriously explored in emerging nations, especially given the rise of new threats to human security such as climate change, where the projected increase in natural disasters will demand greater alertness and involvement by the military in emergency operations.

As well as technological expertise, a country needs to ensure that its policy framework is supportive of innovation across many areas of government, from education to business strategy to security (Conway, p. 25). Its political environment must also be aligned with these goals, and be attractive to inward investment (Matthews, p. 63). Stability and sound governance are essential.

Last but undoubtedly not least, financing must be available. Few, if any, developing countries have the resources needed to re-engineer their economies. Industrialised countries need to recognise the importance of working with emerging economies to establish self-sustaining systems. There are signs that companies too are recognising their role in this process - and that it is also in their long-term business interests to contribute to development (Matthews, p. 63). As the rise of Asian economies has shown, many developing countries are potential future centres of economic vibrancy. Partnership in promoting engineering education could provide a viable platform for long-term cooperation and mutual benefits.

Achieving the vision

So much for the principles: how can such things be achieved in practice? A recurring theme is that of the need for partnerships. Impact will be maximised if all those with an interest in development can align their activities and work collaboratively towards common ends. Partnerships can operate at many levels - between governments, on a regional basis, North-South, through academic bodies and learned societies, public and private sectors and non-governmental organisations, and with citizens and their representatives.

Across many areas it is important to be able to assess progress, through use of suitable metrics. The Millennium Development Goals offer a good jumping off point, but countries need to think about what they need to measure, how to measure them efficiently and how to use the information to shape future developments (Lawless, p. 47). Care must be taken, however, to prevent metrics from becoming a substitute for performance. There is already concern that the pressure for accountability may be displacing risk-taking and therefore undermining investments in areas - such as education - that demand experimentation or whose outcomes are inherently uncertain.

A crucial point is the need to capitalise on knowledge transfer and to close the gap between knowledge and performance. Agricultural productivity, for example, is suboptimal in many developing countries, and relatively simple innovations could undoubtedly make a significant difference. Much of this can be achieved through the use of existing knowledge adapted to local conditions. Enterprise development is a central tool for transforming engineering knowledge into goods and services. Without incentives that foster business incubation and growth, such engineering expertise will be of little utility to society.[7] Crucially, the structures need to be put in place so this becomes a routine aspect of an economy, rather than linked to one-off initiatives. Countries such as

Rwanda are addressing this by making outreach and knowledge transfer a core activity of engineering institutions.

Developing countries still have a long way to go to integrate women into the world of science, engineering and technology (Maduka, p. 41).[8] Governments (both North and South) need to ensure that the obstacles facing women are addressed, and sources of discrimination, direct or indirect, are rooted out. The intellect, resourcefulness and industry of women worldwide are simply too great not to be mobilised in support of development goals. A key starting point is to strengthen participation in engineering education by girls and woman at all levels of the education system. This can be done by building on activities where women continue to play dominant roles or demonstrate strong interest.

Although governments, companies and organisations have the greatest power to influence the future, they can achieve little without the active involvement of people. Too often treated as passive recipients of pre-selected 'solutions', citizens need to be actively engaged at all stages of development initiatives, from identifying the priority issues to contributing to discussions about how to solve them. People may play a critical role even if governments are not actively involved (Younger, p. 83). Many examples exist where projects have been successful because they have been embedded within local institutional structures (Cairncross, p. 21). In other words, the democratisation of engineering knowledge and the related institutions will continue to be a key issue in the governance of technical expertise.

Engineering is a broad discipline, and engineering solutions will come in many different forms. There is a great need for practical simple innovations, such as sanitation systems for poor rural populations (Cairncross, p. 21). On the other hand, there is also a place for 'high-tech, low-cost' solutions, such as diagnostic devices for resource-poor settings. What is essential is that the chosen technology addresses an important human need, is practical, affordable and sustainable.

Future challenges

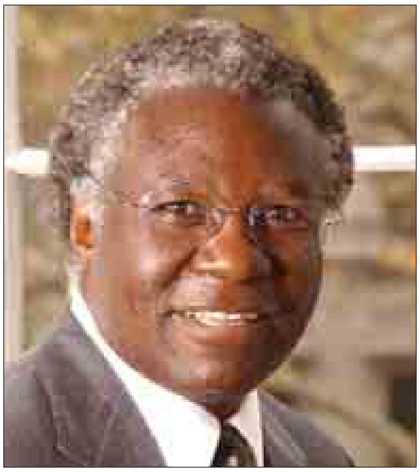
Achieving the Millennium Development Goals remains a huge challenge, exacerbated by profound geopolitical trends - population growth, urbanisation and climate change to name but three. This strengthens the case for innovation still further.

Technology can be an important enabler of sustainable development in an increasingly resource-constrained world, for example in the provision of low carbon forms of energy. Innovations are also need to enhance energy efficiency, from macro-level city planning to micro-level product design (Hopper, p. 73). And engineers have a key role to play in preparing for climate change, developing ways to mitigate its effects and helping communities to cope with climate-related disasters (da Silva, p. 95). While environmental considerations must now be factored into all development projects (Thomas, p. 89), it may be that in the developing world, 'green development' has to be a follow-on to less environmentally friendly but urgently needed works - sometimes called 'brown development' - when circumstances allow (Jowitt, p. 57).

So technology does have a role to play - not as a magic wand but as part of a concerted global effort to improve life for the planet's citizens now and into the future. Four decades ago the prospect of providing low-cost laptops to the world's poor children was a distant dream. Today the debate is over which laptops to adopt and how to introduce them. These products of engineering will radically transform educational systems in the same way that cell phones have transformed communications. From medical delivery systems to solar energy, engineers have the capacity to fundamentally change the way we live.

This vision sees technology working in tandem with global initiatives in finance, trade and environmental monitoring. It is engineering in service to people, not for the glorification of governments, donors or engineers themselves. It is an integrated approach, with engineering a route not a destination, the ultimate aims being wealth creation and healthier, more fulfilling lives for people wherever they happen to have been born.

As scientific and technical knowledge continues to grow at an exponential rate so the time taken to develop and deploy new products contracts. But rapid technology diffusion could result in industrial dislocation, leading to resistance to new products. Economic inequities and social inertia could conspire to stall the use of engineering in development. A new compact of technological inclusion will be needed to enable the global community to benefit from the results of technology and engineering. Only by focusing on the social benefits of engineering while minimising its risks can we hope to design a sustainable future. This task will remain one of the most critical challenges facing future leaders in industrialised and developing countries alike.



Calestous Juma is Professor of the Practice of International Development and Director of the Science, Technology, and Globalization Project at Harvard Kennedy School. He was also Founding Director of the African Centre for Technology Studies in Nairobi, and has served as Chancellor of the University of Guyana. He has been elected to several scientific academies including the Royal Society of London, the US National Academy of Sciences, the Academy of Sciences for the Developing World and The Royal Academy of Engineering.

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Profile: Dr Rajendra Pachauri

Dr Rajendra Pachauri is Chairman of the UN's Intergovernmental Panel on Climate Change (IPCC), the joint winner of the 2007 Nobel Peace Prize. He is also Director General of The Energy and Resources Institute (TERI), a not-for-profit scientific and policy research organisation based in New Delhi, which specialises in energy, environment and sustainability. He has received many honours, both Indian and international, including the Padma Vibhushan, one of India's highest civilian awards, and the French Officier De La Légion D'Honneur. Dr Pachauri began his career with the Diesel Locomotive Works in Varanasi. He obtained PhDs in both industrial engineering and economics at North Carolina State University.

Do you think climate change is a political, economic or technological issue?

All three. It's a political issue because governments have to grasp the nettle and act together, for their own interests as well as the planet's. It's an economic issue, as tackling climate change is going to have an economic impact - though not as much as some people fear, and the sooner we act the smaller the impact will be. And it's a technological issue - technology can help us address the challenge of mitigating the emissions of greenhouse gases, predict what might lie ahead, and provide solutions to the huge problems we face.

Can the developing world industrialise in a sustainable way?

It is hard to see how poor countries could industrialise without increasing their carbon emissions, at least in the short term. But sustainability needs to be integrated into development as early as possible - otherwise countries will be storing up problems for later. And, with supportive policy frameworks in place, sustainability can itself foster innovation and provide economic benefits.

The developing world should not aim to follow in the footsteps of the industrialised world - that simply is not sustainable. We have to be brave and acknowledge that the drive towards consumption seen in the past century in industrialised countries cannot continue. I believe we are at a crossroads in human progress that compels a major change in direction. I also believe the current generation is ready for such a shift and is unlikely to be distracted for long by short-term economic adjustments. We have been so drunk with this desire to produce and consume more and more, whatever the cost to the environment, that we're on a totally unsustainable path.

Who should 'share the pain' of dealing with climate change?

Climate change is something that the planet as a whole has to contend with. It is ironic that the countries that have done least to cause it are those most likely to be affected. So there is a moral argument that developed countries should recognise their responsibilities and take an active lead in tackling climate change. But it is also in their long-term best interests to nurture a stable, sustainable Earth, rather than one dominated by conflicts over resources.

You were awarded a share of the Nobel Peace Prize; how do you think your work contributes to peace?

The IPCC is not a campaigning organisation. We draw upon the knowledge and insight of many individuals and groups embodied in the extensive peer reviewed literature available across the globe, to try to give an authoritative view of the climate today, how it is changing and what it may be like in the future. The scenarios we present, depending on the action taken now, paint a very challenging picture for the future of humankind. History tells us that periods of social dislocation and competition for resources are strong indicators of conflict. If we can highlight courses of action that can avert such consequences, we can provide decision makers with opportunities to avoid potentially catastrophic impacts.

What is the role for engineers in tackling climate change?

We really need to understand the climate better and improve our models, so we can say with even more confidence what may happen and what the impact of different interventions might be. Engineers build the world around us, and need to make sure that their work is underpinned by principles of sustainability: 'business as usual' is no longer an option. We are also all global citizens, and need to take personal responsibility for the environmental impact of our actions. However inadvertently, engineers have helped to create the problem - now we need to be part of the solution.

Where should engineers focus their energies?

Human activities have already set in train a series of environmental changes. We simply cannot avoid some degree of global temperature rise - it's a consequence of the basic physics of the system. Social factors also contribute to our future, including the 'lock-in' due, for example, to today's power plants, transportation systems and buildings. So we need to adapt to some inevitable changes - more droughts, extreme weather events, heatwaves and so on. There's plenty for engineers to do there. But adaptation on its own is not enough. We cannot just muddle through, because the scale of the changes, the number of people affected, is simply too great. We need some degree of mitigation, to reduce the impact of climate change. So scientists and engineers also need to come up with ways to reduce greenhouse gas emissions or capture carbon.

I think we need to see a mix of 'carbon-conscious' solutions. Efficient carbon-capture technologies for coal-fired power stations would be a major step forward. So too would innovations that improve domestic fuel efficiency for poor rural populations and reduce deforestation.

Do we need new technology solutions or better use of existing technologies?

Both, probably. There are many things we could do already. In a major training complex at our institute, we use the Earth's thermal inertia to control building temperatures. We have devised four tunnels four metres below the surface through which we blow air. This gives us cooling in the summer and heating in the winter, and all you need is the power of a blower to get air through the tunnels.

In key areas - such as energy supply, transport and buildings - we need engineers to use their imagination and ingenuity to come up with solutions such as these. Practical answers to real problems. But we will also need significant step changes in technologies for energy generation or carbon capture. It's vital that we get a policy framework in place to achieve this, providing incentives for the development, acquisition, deployment and diffusion of technologies.

One critical element that is missing in current policies is an effective carbon price, which would provide a signal and create incentives for producers and consumers to invest in low greenhouse gas products, technologies and processes. It's essential for business to be an integral part of this process.

Why did you choose to study economics as well as engineering?

Engineering solutions by themselves, no matter how elegant they are, will have no impact unless they are widely applied. And for that to happen they must be economically sustainable. That's why I believe that a carbon pricing regime is as important as engineering innovation. A combination of engineering and economics has been enormously beneficial. The problems of the world are multidisciplinary.

Engineering growth: Technology, innovation and policy making in Rwanda

Romain Murenzi and Mike Hughes

More than ten years after the genocide of 1994, Rwanda is gradually rebuilding. With few natural resources, it has identified science, technology and innovation as the route to future prosperity. The Government of Rwanda has introduced a wide-ranging science and technology policy, focused on the application of science and technology to solve the country's many problems. Central to this policy is the training of a new generation of Rwandan engineers and technicians to lead the country's fledgling 'knowledge economy'.

The recent history of Rwanda, which culminated in the genocide of 1994, devastated the Rwandan economy and destroyed much of its infrastructure. Tragically, the loss of up to one million people left the human resource base, in particular of trained personnel, in a desperate situation.

In 2007 the population of Rwanda was estimated at 9.2 million, and with an area of only 26,338 sq. km Rwanda is one of the most densely populated countries in Africa. Landlocked between Uganda, Burundi, Tanzania and the Democratic Republic of Congo, Rwanda is also one of the poorest countries in the world. Its economy is mainly agricultural and more than 80% of the population live on subsistence agriculture in rural areas.

Rwanda has no appreciable natural resource mineral base. The Government of Rwanda has realised therefore that, to achieve prosperity, it needs to develop the human resource base, in particular in the areas of science and technology.

Development of policy and strategy

Rwanda's commitment to science and technology capacity building starts at the very top, with the President of Rwanda. For example, in his January 2007 address to the 8th African Union Summit, President Kagame emphasised that building science and technology capacity is synonymous with economic transformation. It is, he explained, "about applying science and technology holistically - in all levels of education and training, in commercialising ideas, in developing business and quickening the pace of wealth creation and employment generation, in enabling government to provide better services, and indeed in providing basic tools to society at large for self- and collective betterment."

The role of engineering is paramount in this effort. The development of science is not just for science's sake but as a means to solving the many problems facing the country, to acquire, adapt and utilise existing knowledge to solve Rwanda's pressing social and economic development challenges. These include meeting food security and nutrition needs, increasing access to electricity, water and sanitation, improving nutrition and hygiene, fighting disease such as malaria and HIV/AIDS, and widening and diversifying the country's economic base.

The first step was to develop a National Science Technology and Innovation Policy. This was approved by the Rwandan Cabinet in 2005 and recognises that an effective approach must include policies to promote knowledge acquisition, knowledge creation, knowledge transfer and a culture of innovation in order to:

- Promote sustained growth of GDP;
- Advance the quality of life and standards of living for the citizens of Rwanda;
- Improve skills and knowledge among the population;
- Maintain viability of and enhance opportunities for growth in rural areas;
- Integrate technical education with commerce, industry and the private sector.

Practical steps to realisation

One of the key principles of science and technology capacity building is knowledge acquisition. The last seven years have seen major efforts to promote science and technology. New top-class institutions have been established, principally the Kigali Institute of Science and Technology (KIST), the Kigali Health Institute (KHI), the Kigali Institute of Education (KIE) and the Institute of Agriculture and Animal Husbandry (ISAE). In addition, the faculty of sciences and engineering at the National University of Rwanda has been significantly strengthened.

These institutions are designed to train scientists, engineers, medical practitioners and technologists who can apply science and technology to solve the problems facing Rwanda and drive economic growth.

They have enabled students to study for diplomas and degrees in a wide range of engineering subjects (Tables 1, 2). The eventual target currently being considered is for 50 trained engineers and scientists per 10,000 population. This would equate to approximately 60,000 trained staff and would require additional investment to increase training capacity.

Table 1. KIST faculty of technology: diplomas and degrees

Graduation date	2002 July			2004 March			2005 March			2005 December			2007 March		
	M	F	T	M	F	T	M	F	T	M	F	T	M	F	T
Diplomas	195	51	246	143	31	174	94	10	104	53	4	57	8	4	12
Degrees	22	6	28	75	23	98	168	56	224	242	54	249	210	60	270
Total	217	57	274	218	54	272	262	66	328	295	58	306	218	64	282

M: male; F: female: T: total.

Table 2. Development of professionally qualified Rwandan scientists and engineers

Institute	Estimated average number studying science and technology	Average yearly output degrees and diplomas	Estimated total degrees and diplomas over 15 years	Enrolment growth at 3%
KIST	1,500	375	5,625	6,975
NUR	1,300	325	4,875	6,044
ISAE	1,000	250	3,750	4,650
KIE	1,000	250	3,750	4,650
TOTAL		1,200	18,000	22,320
S_T Trust Fund			5,000	5,000
Revised total			23,000	27,320
Engineers and scientists *(per 10,000 population)*			19	24

The capacity building will take many years to take full effect. To achieve **knowledge transfer**, various programmes and strategies are being developed in parallel to tackle two of Rwanda's critical challenges - poverty reduction, and generating wealth and boosting income through higher value jobs.

Much of the technical knowledge that Rwanda needs to improve the well-being of farmers and diversify the economy is already widely used outside the country. But enterprises will not be able to exploit the competitive opportunities offered by technologies if their workers are not suitably skilled.

To address these issues the Government of Rwanda and the World Bank embarked on a capacity-building and knowledge transfer programme. Teams of international and local experts prepared a series of needs assessments and action plans in high-priority areas - agricultural productivity, malaria control, infrastructure, forest and soil conservation, the environment, and adding value to traded commodities, including foodstuffs.

The emphasis on engineering is evidenced by the engineering background of many of the key people involved in the process. In addition to the engineering background of the Science and Technology Advisor, key members of the World Bank team are also engineers, including most of the technical experts developing the needs assessment and action plans, while engineers have been appointed to key positions in the universities and higher-level training institutes. This reflects the emphasis on developing 'practical solutions to practical problems'.

Action on the ground

Fourteen years after the genocide, Rwanda has left behind the emergency recovery phase and is well into the development phase. Evidence of the impact of science and technology can be seen in many areas.

Information and communication technology

The government of Rwanda recognised the role of information and communication technology (ICT) in accelerating development. An integrated ICT-led socioeconomic development policy has been developed which is designed to support the transformation of Rwanda into a knowledge-based economy by 2020. A series of national information and communication infrastructure plans are being developed to provide infrastructure, equipment and support, and to teach and integrate ICT skills in all sectors. Key projects under way include:

- *Karisimbi project:* An infrastructure project aimed at providing access to information to every home in Rwanda by the end of 2008.
- *One laptop per child:* Rwanda is working with the One Laptop Per Child project with the intention of providing a laptop to every primary school student within five years.
- *One mobile phone per household:* The target is to introduce low-cost phones throughout the country, including rural villages, with a manufacturing plant in Rwanda, and to set up schemes to assist in the purchase of phones.
- *ICT park:* An ICT park is being established which, from its original building in Telecom House in Kigali, will ultimately become the main driver of Rwanda's evolution into an ICT society and mature into a regional hub for ICT innovation.

Energy

Wood, charcoal and biomass are the main fuel sources, even for many middle-class urban Rwandans. As a result, deforestation and soil erosion are serious concerns. Also, shortage of electricity and overdependence on biomass adversely affects productive sectors, schools, health centres and households. Several alternative fuel sources are being developed, including methane in Lake Kivu, geothermal energy, again near Lake Kivu, and microhydro throughout rural parts of Rwanda. The potential of other forms of renewable energy, such as biofuels, solar and wind, is also being evaluated.

Agriculture

Tissue Culture to increase Agricultural Yield (Passion Fruit)

Productivity of such staple crops as rice, beans and cassava is below that of neighbouring countries. Work is ongoing to develop capacity in agricultural research to enhance food security and promote export agriculture. This includes developing outreach strategies for research institutions, primarily the Institute of Agriculture Research, to encourage the take up of techniques and materials related to staples, export and animal products.

Appropriate technology

Even in rainy seasons, which happen twice a year in Rwanda, there are no simple technologies to tap and preserve water. Work is ongoing to develop and diffuse simple, appropriate technologies in Rwanda. This includes agricultural, health, energy, and water- and sanitation-related technologies - such as efficient cooking stoves, farm equipment, school toilets, water purifiers and rainwater harvesters.

Examples of progress can be seen in the Centre of Innovation and Technology Transfer, part of the Kigali Institute for Science and Technology. This Centre has twice won the international Ashendon Award for appropriate technology, once for the development of a high-efficiency cooking stove, and the second time for the development of biogas technologies which are being rolled out to major institutions throughout the country.

Health

Technology is crucial for an efficient healthcare system, from accurate diagnostic tools through to communication of medical data.

Programmes underway include a telemedicine system at district and hospital level, which incorporates a national nutrition and epidemic surveillance information system. Some US$2 million has been invested in new equipment - including a CT (computerised tomography) scanner and ultrasound, echocardiography, mobile X-ray, ophthalmology and respiratory medicine equipment - to help develop a Government-owned hospital, King Faycal, into a regional health facility.

Healthcare also benefits from developments in ICT. The 'TRACNET' system, for example, has been designed to collect, store, and disseminate HIV/AIDS programme information, drug distribution and patient details. The system is being used by all the 134 health facilities offering anti-retroviral therapy.

Dam Construction - using readily available equipment and providing local employment

Adding Value to Natural Resources - Coffee Washing Station at Maraba

Drinking water supply

Increasing access to potable water is a crucial challenge in Rwanda. To meet the Millennium Development Goals, drinking water should be available to 6.5 million additional people in rural areas. A sector-wide initiative has been launched to increase access to reliable, affordable and sustainable water services in rural areas. To this end, technicians, plumbers and construction workers, as well as hydrologists and engineers, are being trained at district and central levels to build and maintain the country's water delivery infrastructure.

Food processing and preservation

Because of a lack of storage and processing capacity, surplus food rots. In addition, many of the people who produced these crops do not have the security of a year-round stable food supply. An action plan has been developed for scaling up the local food processing industry and boosting technical and business capacity in food processing and preservation. This especially focuses on food security commodities, such as milk and potatoes.

Value-added exports

Given its geographic and socioeconomic characteristics - such as high transport costs for exported goods and high population density - Rwanda is concentrating on building high-value, low-volume exports. This means adding value to the commodities produced in Rwanda. In the past five years, Rwanda has developed high value-added export industries in such diverse fields as coffee, roses and pyrethrum (processing the flowers into concentrated insecticide for export). Private investors have plans to move into additional value-added sectors, including tea, silk, herbs and essential oils, and speciality vegetables.

Training Rwandan engineers

Rwandan engineers trained in local universities such as KIST and the National University have already begun to play a significant role in engineering development in Rwanda (Box 1).

Centre for Innovation and Technology Transfer

Timothy Kayumba graduated from KIST in 2003, where he studied Civil Engineering and Environmental Technology. His current role is as a 'field engineer' for the Centre for Innovation and Technology Transfer, involved in the implementation of biogas, microhydro, and solar photovoltaic systems for households and institutions.

Ministry of Infrastructure

Celestin Zimulinda graduated from KIST in 2002, where he studied Computer Engineering. He is now a Senior ICT Officer working on projects for the Ministry of Infrastructure such as 'Google Apps', 'Rural Area Telephony', and the Eastern Africa Submarine Cable System (EASSy), which aims to connect countries of eastern Africa to the rest of the world via a high bandwidth fibre optic cable system. In 2005, he obtained a Masters degree in IT and Management from the Illinois Institute of Technology.

MTN-Rwandacell

Etienne Nzitatira graduated from the National University of Rwanda in 1997 with an engineering diploma in Electronic Engineering. After working at Tele10 in Rwanda for two years he joined MTN nine months after its startup. After working as a radio transmission engineer for two years, and then as a switching and prepaid systems supervisor, he was promoted to the position of operations and maintenance manager, where he oversees switching and prepaid systems, radio transmission, and facilities including power systems and air conditioning.

Kigali City Council

Marie-Claire Nyinawumuntu graduated from KIST in 2005 in Civil Engineering and Environmental Technology. She worked with the Kigali City Council as an inspector in charge of Infrastructure. In this role she was responsible for monitoring standards in road and building construction, including liaison with constructors within the city on building and infrastructure regulations. In September 2006 she completed a masters degree course in civil engineering and construction management at Heriot Watt University in Edinburgh, UK. She has since been undertaking practical industrial training in UK, working with West Lothian Council and Amey Construction on transportation and road design projects, gaining experience she hopes to apply on her return to Rwanda.

Box 1: Rwandan-trained engineers
Many engineers trained in Rwanda have begun to take up positions within Rwanda's public institutions and private companies

A vision of the future

An enabling legal and regulatory environment is being created to encourage and motivate science, technology and innovation in Rwanda. The Government will introduce policies and enabling legislation to encourage national capacity to innovate and generate new competitive products and services.

Through the Ministry of Science, Technology and Scientific Research, the Government of Rwanda has developed a programme, in collaboration with the UK's Department for International Development, to define institutional structures and relationships required to implement the national science, technology and innovation policy. A National Commission for Science, Technology and Innovation is to be established as a government agency, and will act as a coordinating body. A National Research Fund is also being set up to provide finance, and will help to establish District Innovation Centres as part of a decentralisation process.

All the engineers interviewed during the preparation of this paper share a common optimism for the future of engineering in Rwanda. They recognise the potential for science and engineering to drive Rwanda's growth and development, and look forward enthusiastically to continuing to develop their own skills and applying them for the future of Rwanda.

Romain Murenzi is a Minister in the Office of the President in Charge of Science and Technology. He holds a PhD in Physics from the Catholic University of Louvain, Belgium. He was appointed Chair and Professor of the Department of Physics at Clark Atlanta University, USA, returning to Rwanda in 2001.

Mike Hughes is Advisor Science and Technology, Rwandan Ministry of Science and Technology, President's Office. He is a Chartered Engineer with over 25 years' experience in the power industry, in both Africa and the UK.

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Water and waste: Engineering solutions that work

Sandy Cairncross

One of the biggest impacts that engineers can have is in increasing access to uncontaminated water and reducing exposure to the waste products our bodies produce. Millions die every year in the developing world because of inadequate sanitation. Ensuring people have access to clean water and satisfactory waste-removal systems may be one of engineering's least glamorous challenges but it is undoubtedly one of its most important.

Engineers are justly credited with achieving important advances in public health. Their work in conceiving and building the urban water supplies and sewerage systems of the industrialised world helped to consign to history the horrors of cholera, typhoid and plague. But the heroic pioneers of sanitary engineering were groping in the dark; in their day, the germ theory of disease was hotly debated, the dynamics of flow in pipes were poorly understood, and no-one knew why sand filtration worked. They were working from first principles and by trial and error, and inventing technologies as they built them. They needed to work across disciplines including public health, chemistry, law and finance, and engage in political manoeuvring, to bring their plans to fruition.

By comparison, the life of modern sanitary engineers seems tame. Many of the key design decisions have already been taken by building regulations, design guidelines and in formulae found in textbooks, or even incorporated in the computer software they use. Specialists are on hand to advise on ancillary disciplines, and health experts are rarely needed because water-borne disease is a thing of the past.

Or is it? The picture in the developing world is very different. More than a billion people still lack access to a water supply, and nearly half the human race lacks sanitation. Nearly two million young children die of diarrhoea each year in the developing world, and billions more are infected with intestinal parasites, stunting their growth and even their mental development. Here, huge challenges await the adventurous engineer.

Engineering systems become ever more complex in rich countries, but in poor communities, cheapness and simplicity are the keys to sustainability. For example, engineers have for years used sophisticated graphs to choose pipe sizes, but these are complex tools beyond the training of most rural water supply technicians in developing countries. It took a more creative engineer to spot that the pipe size was very insensitive to the slope of a gravity pipeline, so that slope parameters could be reduced to two values - flat or steep. Choosing an appropriate pipe size then becomes a matter of reading from a simple table.

Some water and sanitation schemes in the developing world have failed to produce the expected health benefits, and engineers have had to turn their hand to epidemiology to find out why, to see how the benefits could be increased, or to make the case to funding agencies to support more projects. Eminent examples of such engineers turned epidemiologists include John Briscoe, Chief Water Advisor of the World Bank, and Mike Muller, lately Head of the South African Department of Water Affairs.

A common problem with rural water projects is that the social infrastructure is not there to maintain them. The engineers who build them try to solve the problem by setting up village water committees, barefoot pump mechanic systems and other such arrangements, often unaware that they are establishing the embryo of local government - something that took 100 years in Europe, and requires anthropological understanding and political skills that do not usually appear on the engineering curriculum. Even so, back in the 1980s Armon Hartmann, working for Swiss development aid, showed in Lesotho that even an expatriate engineer could deploy these skills to good effect to build reliable village institutions and so reduce the water supply breakdown rate. Many other engineers had similar experiences, such as Eli Ouano, a Filippino engineer who built institutions to maintain drainage systems in the backstreet communities of Manila.

In rich countries, water supply and sewerage are seen as linked because both involve pipes laid beneath the street. Sanitation for poor people, however, has few similarities with water supply. On-site stand-alone technologies are usually used, such as pit latrines and pour-flush toilets. Thus, while a toilet (for those who have one) is a part of one's house, usually installed at the expense of the householder, the water supply is usually in the public domain - a tap or a hand pump at the end of the street, or on the village green. In such circumstances, sanitation cannot be installed by a civil engineering contractor in the way sewers would be laid; sanitation has to be sold, like other home improvements. Thus, sanitation engineers in developing countries have to learn about marketing.

The principles of marketing are often summed up as the four Ps: product, price, promotion and placement. With regard to the first two Ps, engineers need to develop toilet designs that poor people want and can afford. This requires a dramatic change in their mindset. Most sanitary engineers are civil engineers, and the cost of their designs only becomes clear when contractors submit tenders. With a marketing approach they must think like mechanical engineers designing products such as cars or refrigerators; they must design for a market niche and to a target price. If the price of the product is too high, the engineer cuts something down or removes it. Bjorn Brandberg, a Swedish engineer working in Maputo, Mozambique realised this when he conceived a minimal (but affordable) latrine product consisting of no more than a concrete slab, designed to be laid on an unlined pit and surrounded with a fence for privacy. Hundreds of thousands of his slabs have since been sold.

To understand how best to address the other two Ps - promotion and placement - market research is needed. Mimi Jenkins, another engineer, studied how and why people in rural Benin came to the decision to install a toilet in their homes. The answer turned out to have little to do with health and much more to do with social status, convenience and security - as it does in many other settings in the developing world. She also used a Geographic Information System (GIS) to show how latrine ownership spread outwards from larger towns to smaller ones, and along main roads into the countryside before reaching the remoter villages.

In many cities in developing countries, most households already have a toilet of sorts, but face immense problems of maintenance. What do you do, for example, with your pit latrine in the middle of an overcrowded shantytown when the pit is full? Local artisans, like the notorious 'frogmen' of Dar es Salaam, Tanzania, have come up with an original but far from ideal solution to the problem - climbing into the pit. The challenge for the engineer is to develop a more hygienic, affordable and sustainable approach to pit-emptying services, where local tradesmen can offer a service that gives them a livelihood but is affordable to poor households.

Various engineers have applied their ingenuity to the problem. Manus Coffey, a consulting mechanical engineer, developed the Vacu-tug, a vehicle with a large tank and a suction pump, but it was expensive, and not able to enter all the narrow alleyways in a typical shantytown. A Swiss NGO sought to develop a cheaper, hand-operated alternative using recycled oil drums, but it lacked the robustness needed to resist heavy usage. Stephen Sugden, of the London School of Hygiene and Tropical Medicine, recently developed 'the gulper' (Figure 1), a portable, low-cost device cheap enough to be affordable to local tradesmen, which is currently undergoing field trials.

Figure 1.
The 'Gulper' being used to empty a pit latrine hygienically in a shantytown in Dar es Salaam, Tanzania. Being small, light and portable, it can be used in confined spaces and on premises only reachable down narrow, winding alleys which do not allow access by vehicles. It is also affordable to local artisans.

Sanitation remains a problem in many poor rural populations, but the world is also experiencing a significant shift towards urbanisation. Half the world's 6.6 billion citizens now live in cities, and numbers are projected to rise to 5 billion by 2030. Providing adequate water and sewerage systems for these city dwellers will be a huge challenge. Yet a recent evaluation of a new sewerage system in a Brazilian city illustrates how much can be gained from good sanitation. Increasing sewerage coverage from 26% of households to 80% in Salvador, Brazil, reduced the prevalence of diarrhoea by 21% (42% in the areas that were initially most badly affected). Since diarrhoea currently kills more people than HIV/AIDS, TB and malaria combined, this represents a significant public health gain. Interestingly, even households not connected to the system seemed to gain, presumably because they were exposed to less environmental sewage from their neighbours' houses.

The Salvador project was not cheap. It relied on an investment of US$220m in 1996. But this first citywide evaluation does indicate that the investment has generated a good public health return. It also revealed that it was the sanitation infrastructure - not the presence of toilets in households - that provided the benefits, arguing for public investment. In other locations, citywide interventions may be too expensive or impractical to consider, so neighbourhood-based schemes, as being introduced in Bangkok, Thailand, may be a better option.

Sanitary engineers have learnt over the years that water supply and sanitation hardware need to be supplemented by hygiene promotion if their full health benefits are to be realised. Engineers have been in the forefront of the study of hygiene and of hygiene promotion in developing countries. Some of the first studies of hand-washing practice in the community, for instance, were carried out by Bilqis Hoque, a Bangladeshi engineer. She drew attention to the way most people in rural Bangladesh washed their two hands separately, without the rubbing together necessary to remove dirt and bacteria. She also showed that people in wealthy households, and those owning a latrine, were more likely than others to wash their hands properly, although people who knew the importance of hand washing for health were not.

Val Curtis, an engineer at the London School of Hygiene and Tropical Medicine, has built on this finding - that knowledge alone does not produce more hygienic behaviour - to develop a science of behaviour change that has been put into practice on a vast scale. Her approach, involving the marketing expertise of multinational soap companies, has informed the design of national programmes to promote hand washing with soap in Ghana, Peru, Senegal, Vietnam and elsewhere. Her findings, insights and advice have been so valuable to Unilever that it has supported her research continuously for a decade.

The fact that Unilever, the UK's largest private sector purchaser of advertising, is paying for an engineer's advice on how to change people's behaviour counters the stereotypical view of engineers as technically gifted but weak on psychology. At least, the accusation cannot be made against engineers who take up the real and substantial challenges of engineering for public health.

Picture: Save the Children

Sanitation is, perhaps, still a Cinderella area, attracting far less attention and investment than it deserves. Politicians may be keen to have an airport named in their honour, less so a sewage works. But while infrastructure is important, so too is understanding people's behaviour. This most private of activities is a crucial aspect of public health, and the development of sanitation systems that reflect people's needs and way of life could make an enormous contribution to meeting the Millennium Development Goals.

Sandy Cairncross is Professor of Environmental Health at London School of Hygiene and Tropical Medicine. A public health engineer by profession, and an epidemiologist by vocation, Dr Cairncross is interested in environmental interventions for disease control and their technical and policy aspects. Most of his career has been spent in research and teaching, and about a third in developing countries implementing water, sanitation and public health programmes. He is Chair of the Advisory Committee of the Global Sanitation Fund, and an editor of Tropical Medicine & International Health.

Globalising innovation: Engineers and innovation in a networked world

Gordon Conway

Technological innovation will be an important route by which the Millennium Development Goals will be met. Technological progress is a shared human resource, and a significant challenge for developing nations is to ensure that they are in a position to benefit from accumulated knowledge and skills, by tapping into global networks of research and application.

Engineers are almost always innovators. It is in the blood. Sometimes, of course, an engineer pulls a well-tried and tested technology or process off the shelf to solve a problem. But often the problem is slightly different or a new process or technology comes along that offers a more efficient or a cheaper solution. The engineer has to adapt what he or she has done before. This is the basis of innovation. With the rapid pace of technological change it is increasingly common for problems to change and for new technologies to become available. Innovative adaptation becomes the norm. And for many engineers it is the innovation inherent in technological change itself that preoccupies them.

These comments equally apply to engineers in the developing countries, although most are primarily occupied with innovative adaptation. The challenges they face are embodied in the Millennium Development Goals. Most of the goals are concerned with hunger, health and education, and at first glance provide few challenges to engineers. But agricultural development depends crucially on water supplies; health improvement needs new simple diagnostic devices and efficient vaccination tools. Moreover, both increasingly rely on the modern biotechnologies to produce new crops and medicines.

A cheap incinerator for sanitary napkins that helps girls attending schools, Uganda (a) In use. (b) The engineer who developed it

Even attaining gender equality in education has an engineering component. In Uganda a simple incinerator designed by a Makerere University engineer can be installed in girl's toilets as a means of disposing of sanitary napkins. Many girls drop out of school when they reach puberty because of a lack of privacy and facilities. In schools with the new incinerators, girls actually outnumber boys in the upper classes.

The obvious engineering challenge lies in goal 7 - improving access to drinking water and adequate sanitation. But the key challenge here lies in 'access'. We often know how to provide good safe water and hygienic sanitation but the costs tend to be high and so the technologies are affordable only by the better off in developing countries. The need is to design such systems so that they are cheap, simple and easy to maintain by individual families or communities.

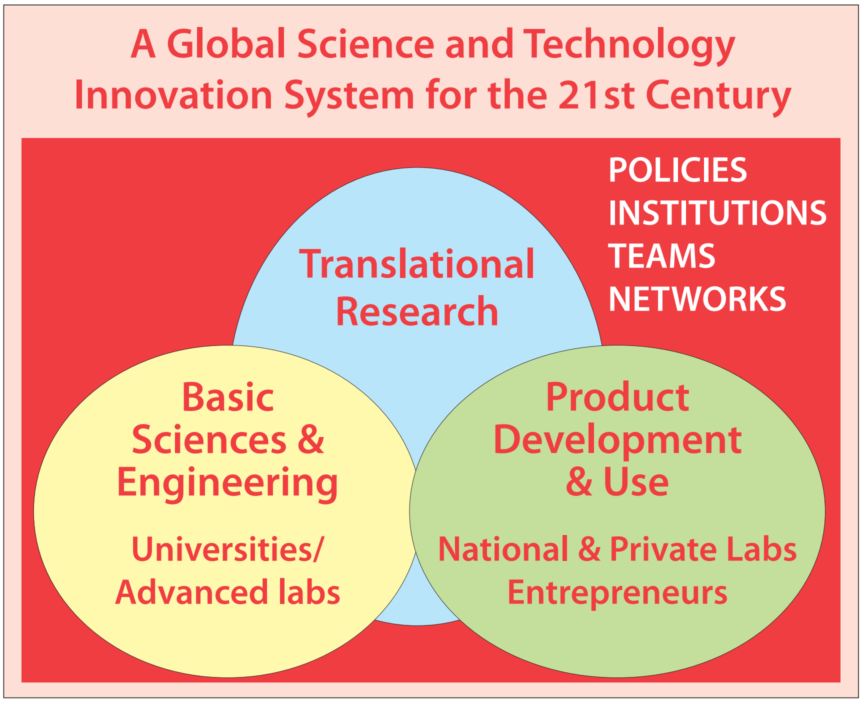

Figure 1. Elements of a 21st century global innovation system.

There are also many cross-cutting themes that have strong engineering components. First is infrastructure, the importance of which was emphasised by the 2005 'Commission for Africa'. It includes public utilities and works, transport engineering, research and other facilities, and related infrastructure services that ensure the structures are maintained and sustainable.[1]

Probably most important, at least for emerging economic powers such as China and India, is the provision of energy. Most developing countries are severely short of energy. At one extreme is a country such as Rwanda with a mere 95 MW of power capacity, mostly produced by hydro but with some oil-fired stations using diesel transported by road from the Kenyan coast. Rwanda could exploit some of the 700MW potential of the methane gases in Lake Kivu, but there are considerable technological hurdles to be overcome.

At the other extreme is China's achievement of 95% of the population supplied with electricity. However, this rapid growth has resulted in significant emissions of polluting gases such as sulphur dioxide and most significant, as a contributor to global warming, carbon dioxide. It is estimated that China will add 900GW of coal-fired power by 2030, creating an installed coal-fired capacity four times that of the European Union. The challenge is to find engineering solutions to the capture and storage of carbon, and to find cheap and efficient renewable low-carbon-emitting energy systems.

Where are these technological and engineering solutions going to come from? In the past, individual engineers and inventors might have come up with solutions. To some extent this still characterises some of the early innovations in electronic communications - such as Jobs and Wozniak's development of the Apple computer, Berners-Lee's invention of the World Wide Web, and its exploitation by Page and Brin in the form of Google and by Omidyar's eBay.

Nevertheless, modern inventions are primarily the result of the combined work of 'the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies'.[2] Such 'innovation systems' increasingly operate on a global scale. They involve research and development, including basic research, translational research in which various component tools and processes are developed, and the integration of these components into final products and services (Figure 1).

Note such systems are not linear. Innovation is driven as much by demand and by the inventions of translational research as by the discoveries of fundamental science and engineering.

Innovation systems have other characteristics in addition to R&D:[3]

1. competence building, including formal and non-formal training in educational institutions and training of technical labour force in firms and organisations;
2. supply of inputs, particularly finance for production and innovation, and for the development of a scientific, technical and managerial labour force, including flow of foreign direct investment, venture capital and loans;
3. provision of regulatory frameworks and measures, standards and quality functions (such as product quality tests), and provision of incentives to develop new products and services;
4. facilitation of the exchange and dissemination of knowledge and information;
5. stimulation of demand and creation of markets; and
6. reduction of uncertainties and resolution of conflicts through appropriate institutions, such as industrial arbitration.

'Malaria prevention, Kenya'. Picture: Crown Copyright

A good example of such innovation is the development of insecticide-treated bed nets. These have greatly reduced the incidence of malaria in many countries by killing malaria-carrying mosquitoes as they come to feed at night on sleeping adults and children. The basic science lay in the development of synthetic pyrethroid insecticides based on a natural compound, pyrethrum, which is lethal to mosquitoes. The translational research involved a large number of researchers testing nets in various locations and developing ways of impregnating resins with the insecticide. Medical Research Council laboratories in The Gambia were largely responsible for the former and the Japanese company Sumitomo for the latter. Eventually, factories were built in Africa using Chinese engineering experience to produce the nets, ensuring they are cheap and easy to maintain. The nets have been distributed free or at a subsidised cost.

Many similar global innovation systems exist, developing medical diagnostic tests, genetically modified crops, water purification systems, photovoltaic cells, and carbon capture and storage systems. These systems can be likened to great ocean-going liners crisscrossing the oceans, involving scientists and engineers from many nations but surrounded by lawyers, financial and operations managers. They are generally powered by the industrialised countries in order to meet their needs. The challenge for developing countries is to gain access - continuing the analogy, to board, find out what is going on and what, if anything, is relevant to their needs.

For this to happen developing countries have to build their own innovation systems that can identify and interrogate the global systems. This means they have to put in place their own appropriate implicit and explicit policies (including intellectual property policies), education systems that provide a good technical workforce, and indigenous R&D systems based on universities and government research laboratories. Although the emerging economic powers, such as China, South Africa and India, have built such systems, most of the less-developed countries have few if any elements in place. Often too they mistake investment in universities and in trained scientists and engineers as the key to success. Experience has shown that by itself such investment does not work. The other elements - policy frameworks, education systems and so on - have to be in place and this takes time and considerable financial input.

There is a special role for the emerging economic powers. They have the capacity to become involved in many of the global innovation systems, can contribute expertise from their own laboratories, but also can ensure that the global systems produce innovations with real benefits for less-developed countries. They can, to continue the ocean liner analogy, readily get on board and modify the direction of travel.

Another consequence of poorly developed national innovation systems is that they leave countries largely restricted to 'technology catch-up'. This process takes time and involves cumulative learning in which earlier, more simple capabilities and activities provide the basis for developing more advanced capabilities and activities. It is essentially a step-by-step process, which has to be accompanied by the development of innovating policies as business capabilities and domestic knowledge systems develop and as the structure of the national economy changes. The typical learning and innovation trajectories provide the basis for identifying how strategic priorities, incentives and institutions of innovation policy can change over time as technological catch-up occurs.[4]

At the same time, in some cases developing countries can 'leapfrog' old technologies and immediately adopt advanced technologies - as already seen in the extraordinary uptake of mobile phones in Africa. There are today some 150 million mobile phones in Africa, compared with only 50,000 ten years ago. This equates to an average of one per family. Uptake has been driven in part by the lack of fixed line capacity, but poor people have also seized on the technology as a means of making their lives better, allowing them, for example, to connect to markets and to converse with distant relatives facilitating transfer of remittances. An innovative banking system based on mobile phones has been developed by Safaricom in Kenya and already has 1.6 million people signed up. It is

Solar panel, Sunderbans, India

called M-PESA, which means mobile money in Swahili.[5]

The uptake of mobile phones is unlikely to be a one-off phenomenon. There has been rapid and widespread adoption of genetically modified cotton in India and China because of reduced costs of pesticides and higher yields.[6] Poor people and poor communities are desperate to gain access to electric power. Solar panels are now becoming more common in developing countries but cost is a factor. The development of new photovoltaic cells, such as thin-film cells, could bring the price down and, if that happens, uptake could be rapid. Another potential lies in the use of nanotechnology for water purification and sanitation - either as filters or as bactericidal coatings for toilets.

One of the keys to technology adaptation and innovation is the existence of a vibrant small and medium-sized enterprise (SME) community with access to venture capital, either indigenous or foreign. Banks and other financial institutions are critical. SMEs, however, also need supportive economic incentives and government inputs in the form of support for technology incubators, export processing zones and production networks, as well as help with skills training.[7]

Allied to SMEs is the need for a class of entrepreneurs. These may be scientists or engineers with strong experience of the practicalities of applying inventions to real life problems. But often they are individuals with a business background, a sense of the market opportunities and a capacity to understand the essentials of the technologies on offer. In other words, they have a certain flair for spotting winners and seeing the process through from embryonic stages to production and sale.

Such entrepreneurs may be indigenous but not necessarily 'home grown'. Often some of the most energetic entrepreneurs are working abroad, in industrialised countries. India has made significant efforts to lure such entrepreneurs back, at least on a part-time basis.

The diaspora of Rwanda are bringing income and capital funds into the country, contributing to a construction boom. Examples of entrepreneurial skills include the production of high-value coffee exports based on coffee-washing machines and the export of hand-woven baskets and bowls, which command high prices in up-market western retail outlets. In both cases the processes are led by energetic, visionary individuals. Generally, the technologies are imported but there are significant local variations, which add greatly to the value of the processes. Two aspects are key to success. One is quality control, itself a technology, and the other is access to international markets. The Rwandan diaspora have developed contacts and skills, making them well placed to access global innovation systems and business networks.

The private sector is thus critical to innovation. Nevertheless, in many cases the targets of innovation essentially take the form of public goods where the market is not well developed or is insufficiently profitable in the short term for private sector investment. An example is the need for new medicines and vaccines to combat such diseases as HIV/AIDS, malaria and TB. The approach here has been the creation of a variety of public-private partnerships, which combine the political power and will of the public sector with the entrepreneurship and innovative capacities of the private sector. Examples include the International Aids Vaccine Initiative and the Medicines for Malaria Venture. Such partnerships aim to share the costs and risks and hence attract private sector investment into research and innovation relevant to poor countries.

In this category falls the recent announcement by the UK government of a competition to construct the first commercially viable coal-fired power plant with carbon capture and storage capacity. If this is successful it could enable China and India to reduce their carbon emissions significantly.

For Africa, science and engineering are increasingly seen as central to future development. In January 2007, the African Union Heads of State and Government signed an Addis Ababa declaration stating that: 'achievement of these goals [the MDGs] depends on our countries' ability to harness science and technology for development and also on an increased and sustained investment in science, technology and innovation.'

The Heads of Government have also endorsed a Consolidated Plan of Action for Science and Technology in Africa (the CPA) developed by the New Economic Partnership for Africa's Development. The plan is based on three interrelated areas of support: capacity building, knowledge production and technological innovation. To deliver these outcomes the CPA identifies the need for support for 12 prioritised 'flagship' research programmes, underpinned by support for the development of national science policy capacity monitored by effective science indicators.

The underlying assumption is that national policies for the promotion of science and technology will be improved through pan-African strategies that encourage the sharing of experience, joint programming, and mutual learning from good policy and practice. It is hoped that this will enable African countries to mobilise and share their scarce R&D resources, improve the quality of national science, technology and innovation policies, and hence hasten the delivery of the Millennium Development Goals.

Sir Gordon Conway is Chief Scientific Adviser to the UK Government's Department for International Development and a former President of the Rockefeller Foundation. He is President of the Royal Geographical Society and has written a number of books on agriculture and technology.

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Profile: Dato Lee Yee-Cheong

Dato Lee Yee-Cheong is the founding President of the ASEAN Academy of Engineering and Technology (AAET), Chairman of the Governing Board of the UNESCO International Science, Technology and Innovation Centre for South-South Cooperation in Kuala Lumpur, and Special Advisor on Sustainable Energy to the Co-Chairs of the InterAcademy Council (IAC). He has been President of the World Federation of Engineering Organizations (WFEO; 2003-2005), President of the Commonwealth Engineers Council (1993-2000) and Vice President of the Academy of Sciences Malaysia. With Calestous Juma, he was co-coordinator of the UN Millennium Project 'Science, Technology and Innovation' Task Force (2002-2005).

What attracted you to engineering? What has been the highlight of your career to date?

There was no university in British Malaya and my family could not afford to send me overseas.

My love was mathematics, but there was no scholarship on offer for that subject so I ended up studying electrical engineering.

In my professional career as an engineering consultant, I regard my election as a partner of the British consultancy firm Ewbank Preece of Brighton as the highlight. I was the first non-British and non-Caucasian partner in its history of ninety odd years.

In professional service, my roles in WFEO and the IAC led to my involvement in the International Science and Technology Community major group of the UN Commission on Sustainable Development (2000-2006), which in turn helped raise the profile of engineering in UN circles. As a result, I became engaged with the UN Millennium Project. I am continuing to work with the Millennium Project Director Jeffrey Sachs in global poverty eradication endeavours.

What did the Science, Technology and Innovation Task Force achieve?

We were able to identify the key factors countries need to lift themselves out of poverty - basic infrastructure and a thriving industrial sector based on small and medium-sized enterprises. We were able to find many case studies showing how this works in practice and established well-supported models of best practice. A major challenge now is for countries to establish the policy frameworks for adopting these models.

One point we made strongly is that that scientific knowledge per se does not create wealth and employment. It is the application and commercialisation of knowledge, scientific or otherwise, into useful devices, installations, services and systems through engineering and technological innovation that creates wealth and employment. Therefore there must be much more balanced resource allocation between science and engineering and technology in line with national needs.

What can be done to maximise the contribution that engineers make to reducing global poverty and promoting sustainable development?

Economic growth in developing countries is predicated on indigenous human resources and institutional and enterprise-related capacity. Since institutions and enterprises are run by people, it all boils down to human resources capacity building.

Education must therefore be a high priority. Universities must re-orientate themselves to serve the development needs of their region and their nation. Universities in developing countries need to produce job creators rather than job seekers.

R&D in developing countries should enhance indigenous advantages in niche areas. For example, R&D in rubber, oil palm and forestry technology in Malaysia has added value to the global production chain and contributed to economic growth in Malaysia.

Universities in the developing world benchmark themselves against the best in the developed world. A better assessment would be their relevance and success in meeting their country's critical development challenges. Such 'fit for purpose' measurements would be much more meaningful for employment creation and economic development, and governments should reward such 'fit for purpose' universities and their faculty members.

Innovation is born of the inquisitive and creative mind. If the inquiring spirit is lost by the child in primary school, it will be difficult to restore later. With inquiry-based primary science education, children learn to doubt and to query. They learn not to follow 'prophets' blindly, but look to have opinions verified by experiment and evidence-based experience. It will help develop future citizens that are conscious of the importance of evidence-based decision making as stakeholders in the political and social life of their countries. This initiative must be anchored by affording teachers the proper training, financial reward and social recognition.

There is also an important role for military engineers. Kenya suffered a severe drought in 2004/05, yet half the money allocated for water storage for irrigation projects was returned to the Treasury unspent due to lack of implementation capacity in engineering consultancy and contracting. In any developing country, military engineering units are among the best equipped for basic infrastructure construction and rehabilitation. There is little difference between their role in disaster relief in the construction of access roads, bridges, jetties, temporary shelters, provision of safe drinking water and electricity supply and the implementation of basic infrastructure in remote areas. Yet such invaluable capacity remains idle in a sea of need.

How important is South-South cooperation in engineering, technology and innovation?

There is great potential for least developed countries to benefit from the emerging economies of Asia and Latin America. Developing countries struggle to produce enough scientists and technologists and suffer a constant brain drain to the North. Yet China alone produces 400,000 graduate engineers every year. Developing countries must look to fellow countries in the South like China, India, Mexico and Brazil to offset their science, engineering and technology brain drain.

More generally, countries can draw inspiration from what has been achieved in Asia Pacific and South-East Asia, where macroeconomic stability, self-reliance, hard work, thrift and investment in education have transformed the economic landscape in three decades. The 'Look East and Look South' principle is central in my continuing advocacy for Africa. We cannot ignore the scientific and technological strength in the North nor their willingness to help the South. However, countries in the South should commit to help themselves through genuine South-South cooperation before reaching out for assistance from the North.

Are you optimistic or pessimistic about the future?

The Chinese phrase for 'crisis' comprises two characters: 'danger' and 'opportunity'. In a world of desperate need, the opportunities for entrepreneurial enterprises are immense. So I am positive and optimistic, especially if the engineering profession and my fellow engineers have the vision to help the world to help themselves. The current 3 billion poor and the additional 3.5 billion poor to 2050 offer a tremendous market for technology-based products and services if their economic circumstances improve, as has been seen in China in the last ten years. On the other hand, we have to make sure that future enterprise is not simply linked to extravagant consumption - that won't be sustainable. We need to focus on quality of life, not quantity of living.

Engineering, wealth creation and disaster recovery: The case of Afghanistan

M Masoom Stanekzai and Heather Cruickshank

Most developing countries face significant development challenges, but those recovering from conflict or natural disasters have also to contend with the consequences of significant destruction and loss of life. Engineering and engineers have a key role to play in the recovery process, but regeneration must also take account of future needs as well as immediate priorities, and be based on sound, sustainable principles. Work in Afghanistan highlights some of the opportunities and pitfalls.

Least-developed countries emerging from conflict face many challenges. Their citizens suffer many hardships, including poor security, extreme and persistent poverty, weak and volatile economic growth, low capacity, and non-functional or limited infrastructure (often largely destroyed by the conflict), inadequate social services, and poor governance. The latter, as well as undermining the rule of law, is also an obstacle to the application of engineering norms and standards.

In the last decade, more than 200 million people annually have been affected by natural disasters such as flooding, drought, tsunami or earthquake - seven times more than the numbers affected by conflict. Extreme natural events have a particularly serious impact on vulnerable countries with low institutional capacity, poor infrastructure, and few financial resources. Increasingly, climate change appears to be exacerbating the frequency and scale of extreme events, while higher population densities are increasing their impact.

In countries heavily dependent on natural resources, and where poverty is widespread, there is an established link between environmental degradation and worsening standards of living. Overuse of natural resources, without any investment for regeneration or preservation of some of the most precious natural resources for the future, poses threats to the environment and to future survival.

We need to generate wealth to address the development needs of people today, but also people in the future, while recognising emerging new challenges. Among these, climate change is a global challenge that the entire world has a responsibility to tackle. It is up to engineering and science to find appropriate solutions, balancing the need to foster wealth creation with the obligation to protect the environment from further damage.

The role of engineering in wealth creation

Engineering has a role to play by capturing and exploiting global knowledge and experience, and through application of innovative approaches and technologies. Crucially though, engineers need to understand the economic, social, political and international context within which engineering is practised, in order to be able to meet the challenges and develop solutions that are suitable to the local context, appropriate, cost-effective and reliable.

Poor countries emerging from conflict often suffer from inadequate basic infrastructure (water, sanitation, roads, electricity, telecommunication, housing and irrigation systems) because of damage caused by the conflict, decay due to lack of maintenance, or an absence of investment. Whatever the cause, inadequate infrastructure presents a major obstacle to social and economic growth.

Relief, recovery and reconstruction efforts after conflict or natural disaster rely heavily on engineering and engineers to improve the well-being of affected people, through provision of safe drinking water, shelter, access to services, jobs and economic opportunities. Reconstruction efforts in Afghanistan illustrate how engineering can contribute to wealth creation and improving the living condition of people in post-conflict and disaster-prone countries.

The case of Afghanistan

By the end of 2001, after the Bonn agreement, Afghanistan's needs were recognised by the international aid community and work began on reconstruction. A comparison of social and economic indicators immediately after the peace agreement and in 2006 highlights the progress that has been made over the past five years in sectors where engineering has had a role to play (Table 1).

Table 1: Development in Afghanistan 2002-6

Socioeconomic indicator	2002	2006
GDP	US$4 billion	US$7.3 billion
Income per capita	US$173	US$306
Access to safe drinking water	13%	32%
Access to sanitation	11%	23%
Access to basic health services	9%	82%
Access to basic education	9%	62%
Access to communication	1 telephone per 1,000 pop.	100 telephone (mobile) per 1,000 pop.

Source: Joint Coordination and Monitoring Body. Annual Monitoring Report 2007.

These improvements have depended on the rebuilding of related infrastructure in different sectors and use of enabling technologies (wireless digital technology and improved techniques) based on engineering knowledge and services. The importance of this progress is not only greater access to these services but also the additional benefits that greater access brings. Child mortality figures, for example, have improved dramatically. Some 85,000 children who would otherwise have died are now alive. Many people today enjoy better living conditions than five years ago.

In 2003, before the road between Kabul and Kandahar in the south was repaired, it took three days by car to travel between the two cities. In 2004, after reconstruction work was completed, travelling time had been reduced to five hours. As a result, the cost of travelling and transporting goods has been reduced by two-thirds. This has also had an impact on fuel consumption, carbon emissions and improving access to market for farmers, who can bring their products on the same day in good condition.

As illustrated in Figure 1, between 2004 and 2010, US$28 billion of international assistance will be committed for reconstruction programmes in Afghanistan. Nearly 62% of this investment will be spent on projects requiring engineering expertise to build the infrastructure needed for service delivery across different sectors.

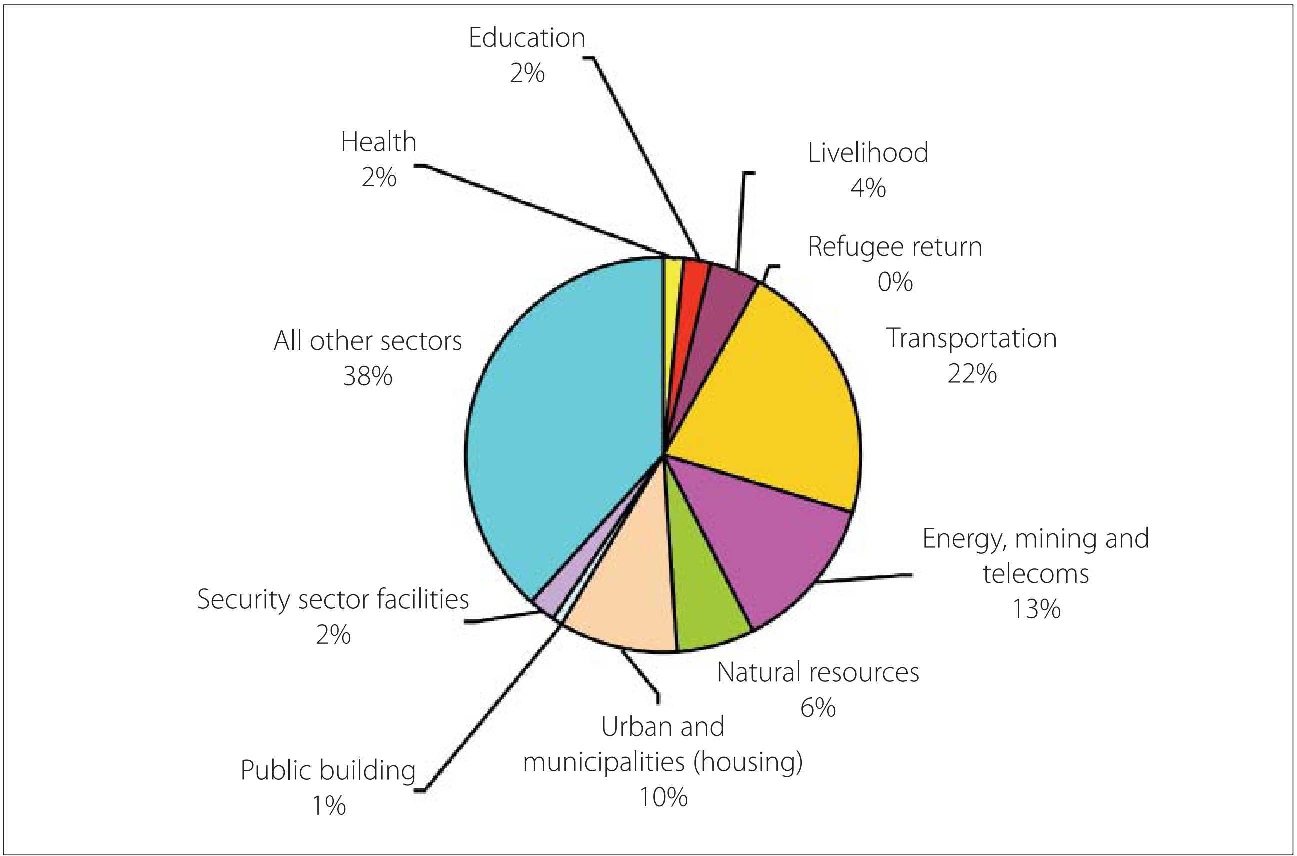

Figure 1: Share of infrastructure investment across all sectors (2004-2010)
Source: SAF-2004, Stanekzai (2006)

As a result of recent investment, thousands of large- and small-scale projects have been implemented in areas of civil engineering, including infrastructure development, urban planning, water supply, homes, sanitation, roads, bridges, buildings, public works (labour-intensive projects), structures, watershed management, land planning. Electrical and computer engineering and services have also been developed, such as energy, communication computer technologies, information technology, a national grid and decentralised electricity systems. Agricultural engineers have enhanced farming technology and soil maintenance. Industrial engineers have provided infrastructure support, logistics planning, and support to initiate production inside the country. And mechanical engineers have been involved in many areas, including micro-hydro systems, locally produced small-scale machinery and water-pumping stations. These initiatives have generated thousands of new jobs and stimulated small business and service industries, creating millions of additional days of labour.

In addition, through the National Solidarity Program, rural infrastructure has been improved in more than 25,000 villages. This has helped increase agriculture productivity, improved use of water resources, enhanced access to markets, reduced water-borne diseases, and promoted the use of alternative sources of energy (solar and microhydro) - all of which have enhanced the country's asset base and improved the living conditions of the rural population.

The constraints

Although engineering activities and resulting services need to be a central focus of reconstruction and development initiatives in developing countries, and despite international donors' commitment to significant increases in infrastructure investment since 2005, there are major constraints on the ability of engineering to deliver wealth creation and sustainable development.

To start with, reconstruction tends to focus on quick-impact, high-visibility projects, and initial costs rather than long-term affordability and sustainability. A further issue is that new elements of built infrastructure are usually left without adequate maintenance provision due to poor life-cycle costing and lack of ongoing resources.

In the absence of mechanisms to adopt and apply relevant norms and standards, design and planning is often based on outdated or inadequate data. This may lead to poor quality infrastructure or engineering products and services. For example, as illustrated in Figure 2, a, b, c in 2005 the reconstruction of the highway connecting the north to the capital Kabul was completed, including several new bridges. A minor flooding event caused severe damage to the newly reconstructed road and bridges. This damage could easily have been avoided during the design and planning phase, by allowing for controlled losses (sacrificial elements), at much lower cost than that subsequently needed to repair the damage.

Figure 2a: The highway connecting the north to the capital city, Kabul. The reconstruction of this highway was completed in 2005 but several sections of this road have being severely damaged by flooding after a year due to poor design.

Figure 2b: A section of the highway near Salang damaged by flooding in May 2007.


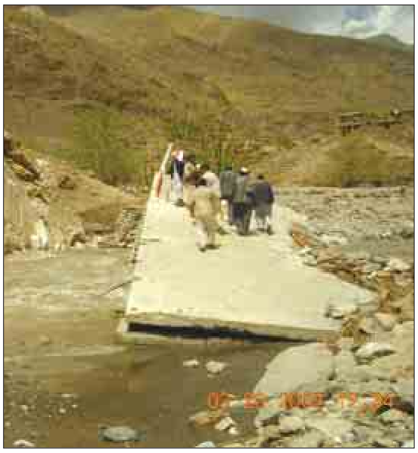

Figure 2c: Collapsed bridges in Kolomai and Salang district in Parwan Province.

A further important point is that, due to a lack of knowledge of sustainable development among engineers, traditional engineering approaches are still being applied, even though the world is facing 21st century challenges such as climate change that will affect the lives of millions in poor countries, including Afghanistan.

In-depth analysis of post-conflict reconstruction shows that, alongside the availability of resources, professional and institutional capacity are the key factors to successful regeneration. Economic growth in developing countries can be stimulated by building the technical capacity of their workforces. Economists have consistently stressed that investments in science and technology are among the highest yielding investments that a nation can make. A competent technical workforce can provide several paths to economic development. It can help attract technically oriented multinational companies that can invest in a developing country once a pool of qualified employees is available. Effective use of foreign aid needs technically competent people to operate and maintain the infrastructure built. And technically competent entrepreneurs can create wealth by launching small business start-ups.

Conclusion

To enhance the awareness and knowledge of engineers in developing countries, there is a need for special capacity-building support, with long-term commitments to build local capacity of both people and institutions. Only a strong and broad knowledge base will promote innovation - transforming raw data into wealth through engineering processes and procedures.

Engineers in poor countries well understand the 'time, cost, and quality' approach to engineering practices, but they need to be equipped with up-to-date and broader knowledge to go beyond these basic concepts. For example, a sustainability framework for civil engineering that integrates values, process and constraints, developed by an expert group at the Centre for Sustainable Development at the University of Cambridge, is one model for broadening the vision of engineers to maximise the benefits of engineering services for sustained wealth creation.

Today, engineers and engineering services are in high demand in the developing world, and an engineering degree is seen as a great honour and a passport to lifelong well-being for an individual and his or her family. Furthermore, in any post-disaster situation, engineers are in the frontline, helping to alleviate people's suffering and restore normal life. There is no greater honour and satisfaction than to be at the service of people who need help.

But we must realise that what we do today to solve one problem should not be at the cost of suffering to others or future generations. This is why we need more investment in engineers and engineering capabilities that enable them to provide innovative solutions to today's challenges. This requirement should be reflected in international aid policies, in order to enable poor countries to get maximum benefit from resources provided by developed nations as part of their global commitment and responsibilities.

M. Masoom Stanekzai is an electronic/communication engineer. He is a graduate of Kabul Military Academy and completed a Master of Philosophy in Engineering for Sustainable Development at the University of Cambridge, UK, in 2006. He is an adviser to the President of Afghanistan, vice-chair of the commission responsible for the disbandment of illegal armed groups, and is involved in monitoring infrastructure projects in Afghanistan. **Heather Cruickshank** is a Senior Research Associate in the Centre for Sustainable Development, University of Cambridge, Cambridge, UK.

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Untapped potential: The role of women engineers in African development

Joanna Maduka

Women began to participate formally in engineering and technology after the First World War, when they were first admitted onto engineering courses in higher education around the world. Nevertheless, it took more than five decades for women to establish themselves in the profession, and even now women make up less than 20% of engineering graduates in many western countries and around 10% in most developing countries. So how can women engineers contribute to the development and growth of Africa?[1]

'Naturally, the African culture relegates the girl child to the background, so imagine what it is like when it comes to engineering that is perceived as a male profession. A lot of people see the issue of women involvement in science, engineering and technology as one of those unnecessary gender issues, and it is not!'[2]

Long-standing cultural traditions, and an adherence to well-established gender roles, are significant barriers to the integration of women into engineering professions in Africa. On the one hand, women may be highly respected: in several traditional African societies, a woman may hold any position except that of ultimate ruler. She may even be the priestess who is consulted by the chief on serious societal issues. This would happen usually when the woman has passed the child-bearing age, when she is assumed to be equal to a man.

On the other hand, girls are often brought up to be passive and submissive in traditional African societies. They are groomed to be mothers and home-makers, so a father does not feel obliged to send a girl to school: it is argued that she would not be useful economically. Education is considered an investment, enabling offspring to look after their families, since few countries provide old-age pensions or social welfare facilities in the modern sense. Therefore, many fathers consider it an economic waste to invest in training female children. In addition, the male child traditionally carries on the family lineage.[3]

Although no laws prevent women from progressing, they encounter considerable prejudice that holds them back. They are likely to encounter sexist attitudes in men, and even in some women and children. It may be difficult for women to feel that they are taken seriously. In this atmosphere, a woman may have to work twice as hard as her male counterpart to be given equal recognition, and career development is likely to be slow.

UN and the Millennium Development Goals

In 1946, the United Nations established the Commission on the Status of Women, to promote women's rights in political, economic, civil, social and educational fields.[4] At the United Nations Millennium Summit in September 2000, global targets were set by the world's leaders - the Millennium Development Goals. Two of these goals are of particular relevance for gender issues:

- Achieving universal primary education by 2015 so that children everywhere, boys and girls alike, will be able to complete a full course of primary schooling. The indicators to be used are: the net enrolment ratio (NER) in primary education; the proportion of pupils starting grade 1 who reach grade 5; and the literacy rate of 15-24 year olds.
- Promoting gender equality and empowering women, so that gender disparity in primary and secondary education will be eliminated, preferably by 2005 and in all levels of education no later than 2015. The indicators to be used are: the ratio of girls to boys in primary, secondary and

tertiary education; the ratio of literate females to males of 15-24 years olds; the share of women in wage employment in the non-agricultural sector; and the proportion of seats held by women in national parliaments.

In his assessment visit to Nigeria in April 2008, Director-General of the United Nations Industrial Development Organisation, Kandeh Yumkella, concluded that Nigeria was not on course to achieve the Millennium Development Goals (MDGs) by 2015. Yumkella said he was concerned that even in 2008, at the half-way review of the MDGs, no tangible progress had been recorded. His view was that "There are very strong institutional challenges in the country to meeting the MDGs, but they can be surmounted".

Engineering education for women

Tanzania: Women's vocational education

In Africa generally, school attendance among girls in primary and secondary schools is high and sometimes greater than among boys. In Botswana, for example, at primary school level 83% of children of school age attend school and over 50% of these are girls, while 53.5% of secondary school intake are girls. Yet women are still not well represented in scientific and technological careers. For instance, women represent 3.5% of engineers and 11.3% of technicians in Mali, while Sudan has the highest percentage of women engineers with 15.8%.[5] Less than 10% of professionally active engineers in Nigeria are female. Women are slightly better represented in higher education, making up one in six engineering students in Nigeria.

In the late 1960s through to the early 1980s, women were rare participants in engineering in Nigeria. This had its roots in the history of Nigeria's academic institutions. Engineering education in Nigeria dates back to the early 20th century, when the Yaba Higher College in Lagos was established to train engineering assistants to work in the colonial civil service. No woman was ever admitted to the College. Then, when the first university was founded in 1948 (a College of the University of London), engineering was not included in its programmes. It took another 14 years before engineering was introduced into the Nigerian university system.

Substantial efforts have been made during the last 15 years to get more women into engineering education. At the 1999 World Conference on Science in Budapest, the Framework for Action included strong calls for access of women and girls to STEM (science, technology, engineering and mathematics) education and employment, collection of gender-disaggregated statistics, more women in leadership positions, and the establishment of an international network of women scientists and engineers.

Then, in 2003, the International Network of Women in Engineering and Science (INWES) was established formally, with a key objective of attracting young women into engineering and science. Other international networks exist, such as the Global Alliance for Diversifying the Science and Engineering Workforce, and the GASAT (Gender and Science and Technology) Association. In Nigeria, the Association of Professional Women Engineers of Nigeria (APWEN) was formed in 1982 to enable female engineers to share work experiences and act as a pressure group, as well as encouraging girls to study science and mathematics. APWEN celebrated its 25th anniversary in 2007, and its membership has grown from six in 1982 to more than 1,000 graduates and about 1500 student members today.

An analysis of first degree and postgraduate degrees does suggest that women are gaining ground (Tables 1 and 2). However, the proportion of women is still low, particularly at postgraduate level. And engineering and technology is lagging behind other disciplines.

Table 1: Number of degrees, diplomas and certificates awarded at Nigerian federal universities [6]

	First degree							
	1993/94		1995/96		1996/97		1997/98	
Discipline	**M**	**F**	M	F	M	F	M	F
Education	4,011	2,767	4,908	3,748	4,325	3,186	4,136	3,395
Engineering and technology	1,800	107	2,192	211	3,141	491	3,058	396
Law	624	133	916	304	1,140	349	1,137	548
Medicine	1,097	269	1,180	362	1,367	434	1,186	467
Science	3,428	844	3,898	1,130	4,529	1,233	4,705	1,480
Social science	3,639	816	3,828	1,392	4,380	1,452	4,249	1,556

Table 2: Number of postgraduate awards at Nigerian federal universities[6]

	First degree							
	1993/94		1995/96		1996/97		1997/98	
Discipline	**M**	**F**	M	F	M	F	M	F
Administration	464	34	431	87	537	85	1,201	328
Agriculture	289	93	283	72	473	130	465	109
Arts	359	65	398	113	530	117	583	168
Education	913	331	1,010	576	939	469	1,243	899
Engineering and technology	274	10	345	41	436	51	424	39
Environmental science	69	5	93	9	86	16	79	5
Law	93	41	136	71	200	11	203	40
Medicine	104	20	131	61	158	57	142	76
Pharmacy	32	6	27	10	40	3	39	12
Sciences	629	77	467	139	603	117	655	164
Social science	1,446	117	1,545	416	1,885	410	2,623	752
Veterinary medicine	15	2	22	7	25	6	25	5

The Beijing Declaration and Platform for Action and outcome document, 'Gender Equality Development and Peace in the 21st Century', adopted at the 23rd special session of the UN General Assembly, highlighted the potential of information and communication technology (ICT) to contribute to the advancement and empowerment of women.

A key component of APWEN's programme is therefore to organise computer seminars and training for secondary schools, especially as computer appreciation and literacy is still low in Nigeria. In addition, APWEN organises career talks and the 'Girl Day Campaign', designed to encourage girls to study science and mathematics.

Women engineers and the labour market

African women have always been active in agriculture, trade and other economic pursuits, but most are in the informal labour force. In 1985, the proportion of women in the labour force ranged from 17% in Mali to 49% in Mozambique and Tanzania. African women are traditionally seen as guardians of their children's welfare and have explicit responsibility to provide for them materially. They are the household managers, providing food, nutrition, water, health, education and family planning to an extent greater than elsewhere in the developing world. This places a heavy burden on them, despite developments such as improved agricultural technology, availability of contraception and changes in women's socioeconomic status.

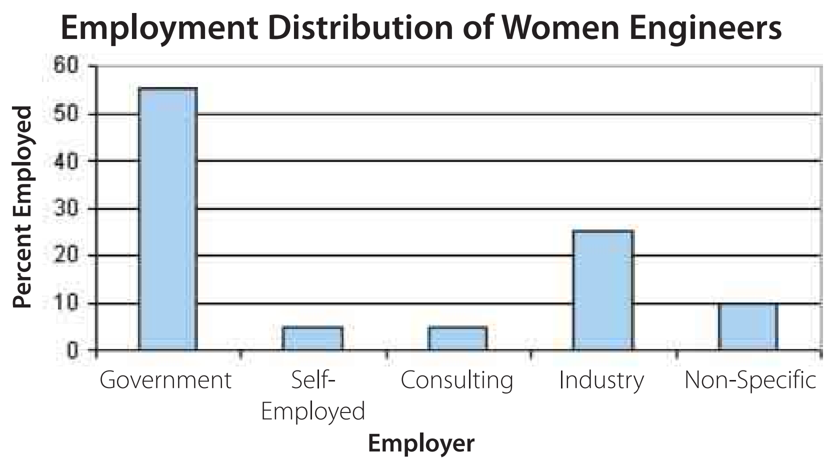
Engineering training is widely considered long and arduous and girls tend to choose studies with short curricula that rapidly lead to employment. Of those who pursue the engineering adventure, many decide to change direction after several years of study or professional practice. In fact, many graduate engineers find the financial and management professions much more attractive than engineering.

Other reasons why girls turn their backs on science and technology are well-known:

- Lack of equality between the sexes or equal opportunity in studies and careers;
- Difficulties reconciling family demands and those of a demanding engineering education or career;
- Insufficient number of female role models to inspire girls to choose an engineering career;
- Lack of financial backing needed to study engineering.[5]

Employment

African governments and their agencies have always been the largest employers of engineers, but as the state-owned enterprises are privatised and more private sector businesses are established, engineering positions for women may became more difficult to obtain.



Source: Association of Professional Women Engineers of Nigeria, 2001

Employment Distribution of Women Engineers by Employer

The private sector and multinational corporations typically prefer to employ male engineers, who are assumed to be more likely to work long hours or more able to be moved easily or relocated to different offices at short notice. Women employees are considered more transitional, on the assumption that they will eventually prioritise family life over their career.[7]

Success stories

Despite the difficulties, many women in Africa have managed to develop successful careers in engineering. A career in engineering can also serve as a gateway to other rewarding careers - such as government, business, medicine and law.

They have applied their engineering skills to tackle some of the world's most challenging problems, including pollution, hunger and human rights. In doing so, they have made a difference. Their lives stand as shining examples of how an individual woman, empowered with the proper skills, can help improve the dignity and prosperity of all the world's people.

In Nigeria, over the last 40 years women engineers have risen to senior positions. Women engineers have become Permanent Secretary in the Federal Civil Service (Ebele Okeke) and State Commissioners. Women engineers are also to be found in the private sector, especially in ICT and banking. The Group General Manager of the Nigeria LNG Division and Engineering Project Division of the Nigeria National Petroleum Corporation are both women (Fabiyi Amakiri and Tokunbo Somolu, respectively). Other women engineers run their own businesses in construction or consultancy.

In addition, there are now a growing number of women engineers in academia, especially chemical engineers, who act as role models for aspiring female engineers and help to overcome discrimination against female students by male engineering lecturers.

Case studies

Gloria Reef, a civil engineer, was the associate administrator of the US Federal Highway Administration in 1993 when the apartheid system crumbled in South Africa. President Bill Clinton asked Gloria to head a technology transfer initiative to support a new road-building programme in rural areas of the country.

The African Technologies Studies Network honoured Judith Owigar, a computer science student at the University of Nairobi, as the Best Woman Engineer of the year in 2007. Judith's winning entry, 'Mobile Blogging', allows users to update and visit websites using mobile phone technology. The technology is designed to allow users to send information from remote rural areas to the web, so could be used to publish stories rapidly, enhancing the flow of information around the country.

As well as being an electrical engineer and engineering consultant, I have helped to establish a group called the Friends of the Environment (FOTE), to empower women and promote sustainable energy. FOTE is affiliated to ENRGIA, a network of NGOs in sustainable energy development, poverty eradication and gender issues, based in The Netherlands. FOTE's projects include the construction of biogas plants for farmers using piggery waste to save firewood, and the provision of cassava-processing plants for women's cooperatives. Seminars are also organised on environmental issues, including climate change and renewable energy.

Conclusion

Academics and women's engineering organisations need to go out to young students with a message about what engineering involves and the fact that women can succeed in engineering by bringing different perspectives, qualities and skills.

Generally, more needs to be found out about the experiences of existing female engineers and engineering students, so more effective ways can be found to attract and retain women in engineering in the future. Real change will only happen when the abilities of women engineers are fully recognised and they become visible in decision-making positions, where they can act as role models for the next generation. This will require a social environment that allows women engineers to reconcile their family and their professional commitments. It will also be important to achieve a critical mass of women engineers. Without such moves, the considerable potential of women of the African continent will remain untapped.

Joanna Maduka graduated with a BSc (Hons) in 1965, became Grad IEE in 1966, and obtained an MSc (Engineering) in 1969 from Trinity College, Dublin. Joanna was the first woman to be registered by COREN (Council for the Regulation of Engineering in Nigeria), and the first woman Fellow of the Nigerian Society of Engineers and Nigerian Academy of Engineering. She is the founder President of the Association of Professional Women Engineers of Nigeria (1982), and Friends of the Environment (1993). She has also served on many boards including the Nigerian National Petroleum Corporation (NNPC).

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Scarce skills or skills gaps: Assessing needs and developing solutions

Allyson Lawless

Faced with increasing development needs and workloads, countries need to ensure that adequate training and capacity development is taking place. This calls for a good understanding of the supply and demand of trained workers. In South Africa, accelerated development has led to a shortfall in engineering capacity. A comprehensive research programme identified the extent of this shortfall and outlined the interventions required to rebuild the skills base.

> *'Scientists discover the world that exists; engineers create the world that never was …'*
> Theodore Von Karman, aerospace engineer

The World Summit on Sustainable Development, held in Johannesburg in 2002, focused world thinking on quality of life and the environment. Many of the goals have fallen to engineers to address. These include halving the number of people without access to safe drinking water or basic sanitation; developing and manufacturing more environmentally friendly chemicals; and implementing poverty reduction strategies. Clearly, the first two are the domain of the civil engineer, and the third falls squarely on chemists and chemical engineers. The link between poverty reduction and engineering is not so obvious. However, J F Kennedy offered a clue when he said, 'It is not wealth which makes good roads possible, but good roads which make wealth possible.' Indeed, roads - again the domain of the civil engineer - offer access to education and the job market and make it possible to trade. Job creation, the escape from poverty, is also dependent on the availability of energy and machines, the domain of the electrical and mechanical engineer. Thus a sound engineering skills base is critical to the wellbeing of any nation.

Yet in the latter part of the twentieth century, engineering has been neglected - in the developed as well as the developing world. As well as a shortage of trained staff, many countries are beginning to see the impact of decades of inadequate maintenance. In the USA, following the collapse of the Minneapolis Bridge, the American Society of Civil Engineers calculated that an investment of US$1.6 trillion was needed over five years to bring the nation's infrastructure to a good condition.[1]

The world is starting to understand again that engineers are critical for infrastructure service delivery, operations and maintenance, because the growth that countries seek is dependent on good infrastructure. Much of the infrastructure in developing economies is holding back growth and capacity constraints are increasingly being cited as the most significant hindrance to development.

The challenges facing the post-1994 democratic government of South Africa have been exacerbated by the enormous development backlogs caused by the policy of apartheid, because of which more than half the population has limited or no access to basic services. The country now faces a public sector infrastructure development of some R500 billion (US$80 billion) to ensure the desired 6% growth required to stimulate job creation and alleviate poverty. The poverty relief cycle (Figure 1) outlines the need for bulk and economic infrastructure to stimulate growth, and for improved domestic developments to address food security and education and health facilities to build the workforce.[2]

However, glib references to shortages of engineers do not provide a complete picture. Can countries simply poach from others? Is it a matter of placing bigger, better and more adverts in the employment pages or is it a global challenge? Should new engineering faculties be opened? Or is there a systemic problem that must be addressed? Without detailed research these questions cannot easily be answered.

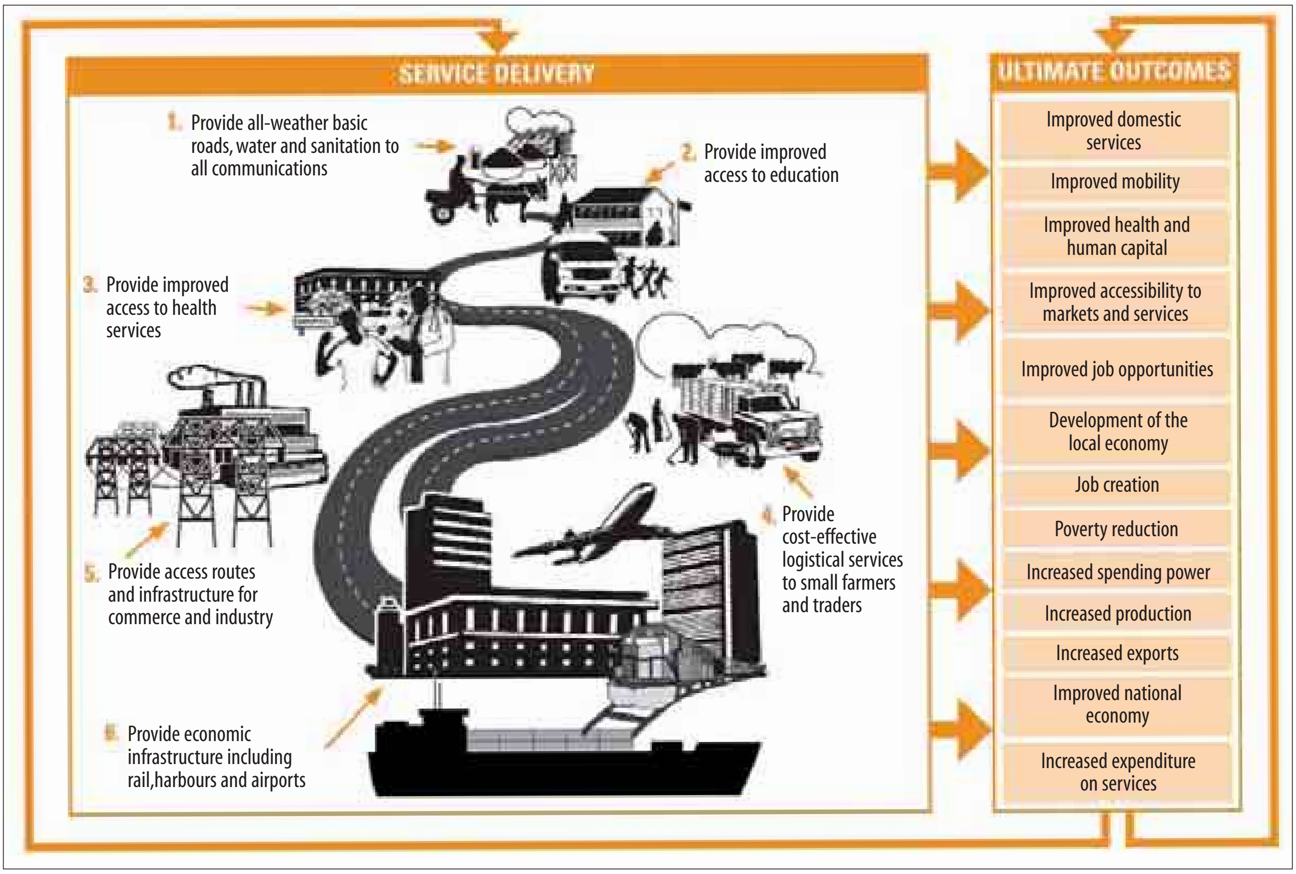

Figure 1. Escaping the poverty trap.

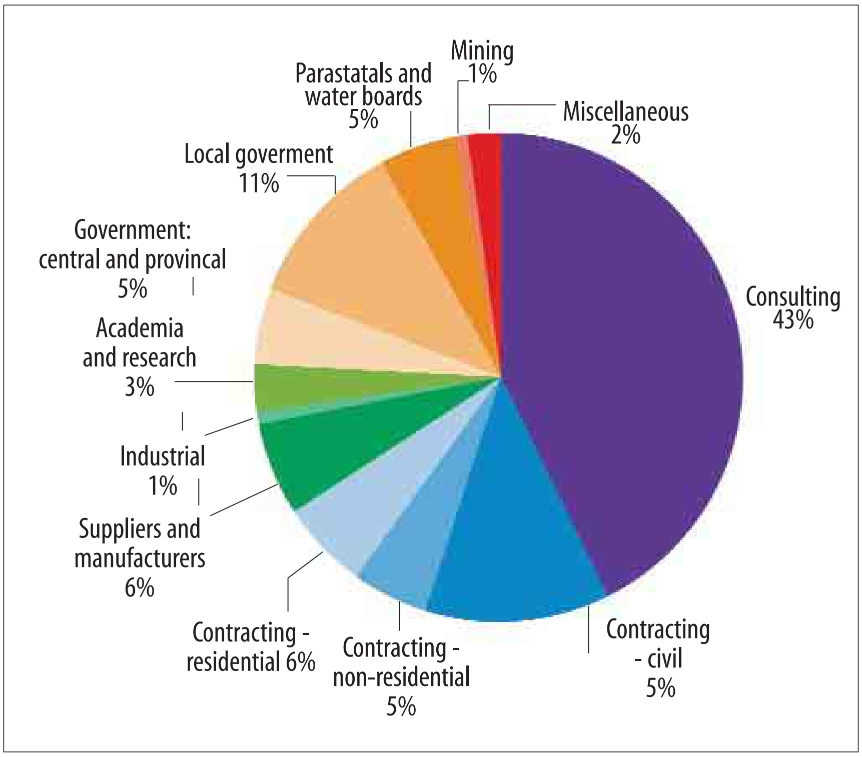

Figure 2. The distribution of civil engineering professionals in South Africa, April 2005.

A research programme

In 2003, the South African Institution of Civil Engineering embarked on a comprehensive research programme to determine the numbers, age, gender and racial profiles of all civil engineers, technologists and technicians in South Africa - some 15,000 people (Figure 2) - in a bid to understand the constraints and to develop solutions to this vexing challenge. The analysis was published in 2005 in book form.[3]

One way to assess demand is to look at use of a commodity such as cement, which is a proxy measure of construction activity. In 1998 a study was carried out to determine the future demand for cement,

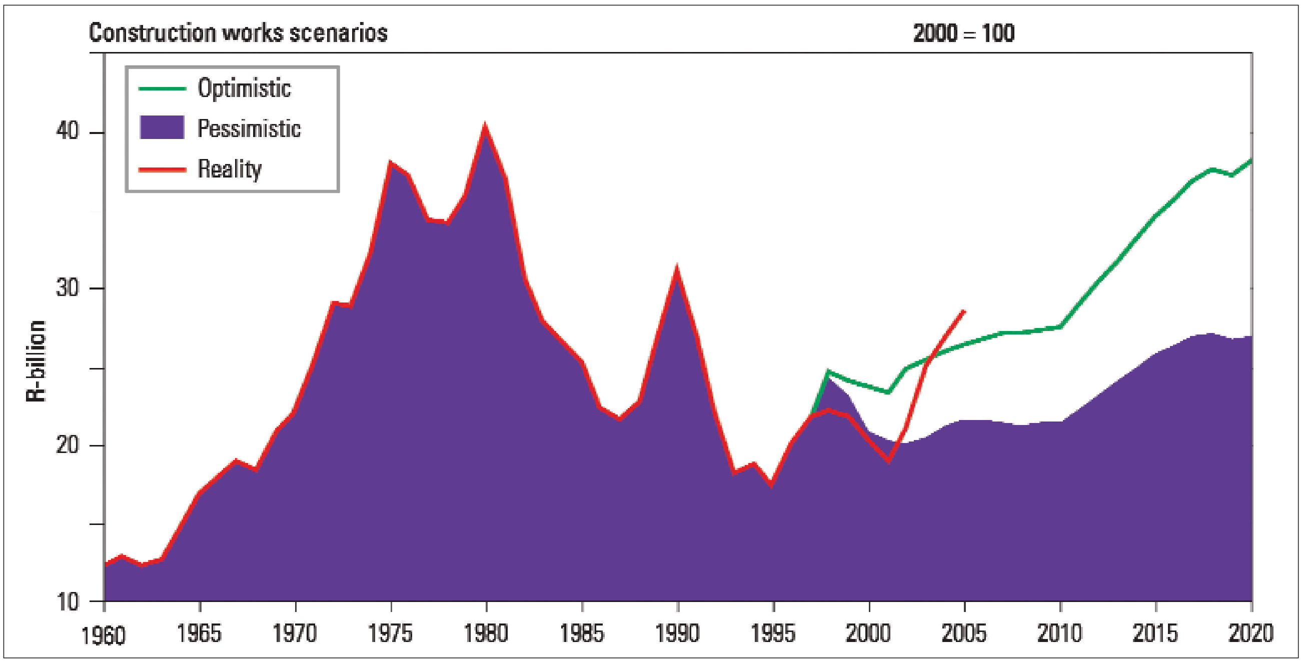

Figure 3. Civil engineering spending and projected spending in South Africa.

identifying optimistic and pessimistic scenarios (Figure 3). The red line shows the actual figures to September 2005.

After a 20-year decline in construction activities, many of the engineers and technicians who trained for the boom of the 1970s and early 1980s have left the industry and often the country. Those trained in that era who are still in the industry have started to retire, and will continue to do so in significant numbers in the next five to eight years.

Many factors limiting supply were identified. The nature of the home environment, parental guidance and schooling limited the pool of learners entering tertiary institutions. In a bid to increase numbers, entrance criteria were lowered, resulting in high drop-out rates and in students taking much longer than the minimum period to complete their studies. Underfunding of tertiary institutions resulted in the appointment of fewer, and in some instances inadequately qualified or experienced, lecturing staff and inadequately equipped departments. Further, the structure of the diploma course for technicians required that students spend a year in industry before completing their final semester(s). Industry, being so short of engineers, is reluctant to take on anyone with fewer than five years' experience, creating a catch-22 situation that is preventing students from graduating.

Figure 4 superimposes the graduation patterns over 40 years on civil spending. With the huge increase in spending shown in Figure 3, it is clear that a commensurate increase in the number of graduates is required. Sadly, inadequate workplace training, sexist attitudes, posts being reserved for previously marginalised groups (the black population, who had no access to engineering education until the early 1990s) and low starting salaries resulted in poor attraction and retention of graduates.

Experienced technical staff were found to be leaving the industry for a host of reasons, including frustration (see below), better prospects in other fields, or the lure of lucrative international contracts.

Drivers for development

Key drivers for development are economic growth, availability of finance, supportive policy, favourable interest rates and other economic variables, and institutional capacity.

Although the first four items are favourable in the public sector in present-day South Africa, the same is not true of the changing institutional environment. While central support departments have been

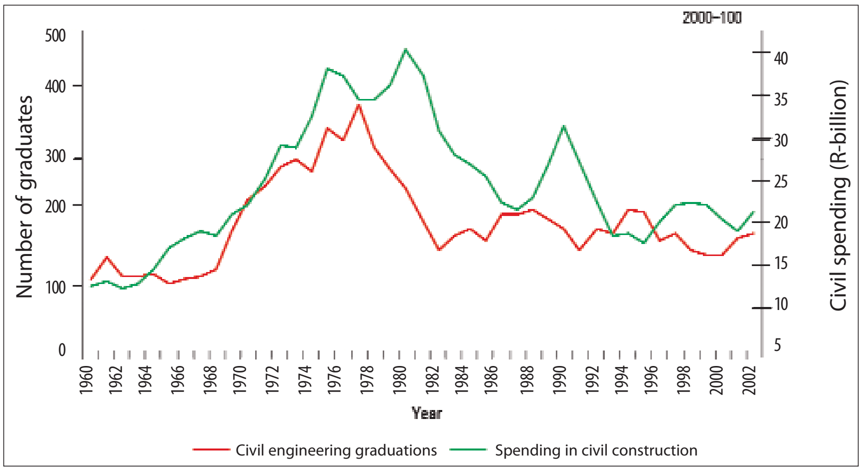

Figure 4. Civil engineering spending and civil engineering graduations in South Africa.

set up to assist technical staff, many engineers complain that these departments have gained too much power and lack technical understanding. 'Political interference' and excessive reporting is felt to be stifling creativity and efficiency. Frustrated by the undermining of their professional skills, there has been a slow but steady migration of engineers from the public to the private sector and beyond.

What is to be done?

It is important to differentiate between scarce skills and skills gaps. A scarce skill is one for which the skill is simply not available, whereas a skills gap exists where there are qualified people but they do not have appropriate experience. Civil engineering in South Africa suffers from both problems.

If nothing is done to increase the number of civil engineering graduates coming into the industry, numbers in 2020 will hardly be different from the current inadequate figure. Gains from tertiary institutions will be balanced by losses due to emigration, people leaving the industry, retirement and death (Figure 5). To increase the capacity of the industry, many scarce skills must be developed or enticed back into the industry, and those who have the education but lack experience must be developed to take their place in the industry.

Education

A change in teaching at schools is clearly needed. The London Mathematical Society,[4] has argued that students who need to continue mathematical training after school no longer receive an adequate maths education. The Society highlighted 'a marked decline in analytical powers when faced with simple problems requiring more than one step…', as students are led through set questions step by step rather than being taught fundamental principles. This message has been communicated to South African educators, but changes will take many years to be felt.

Having estimated the number of extra civil engineering graduates required to rebuild the skills base, it was suggested to the South African government that the total number of engineering graduates per annum should be increased from 1,500 to 2,500. It has been gratifying to see this recommendation taken very seriously. Most tertiary institutions have received substantial contributions to enhance their engineering departments. Enrolments have increased, which augurs well for the future supply of graduates.

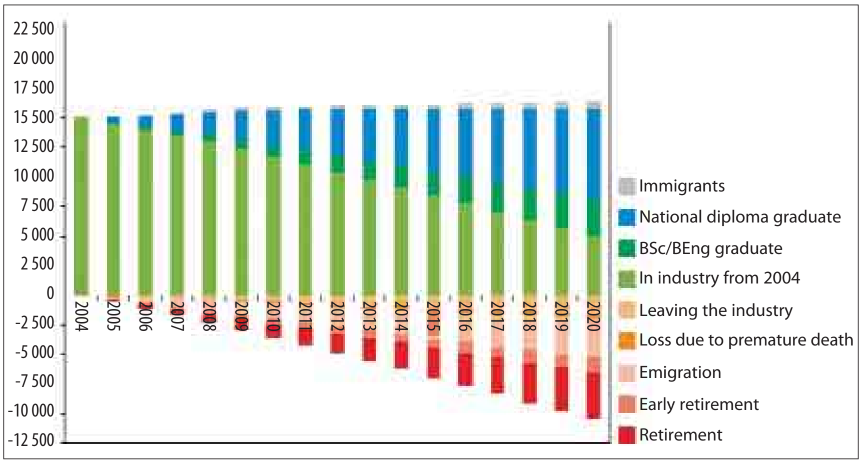

Figure 5. The 'do nothing' approach to skills development in civil engineering.

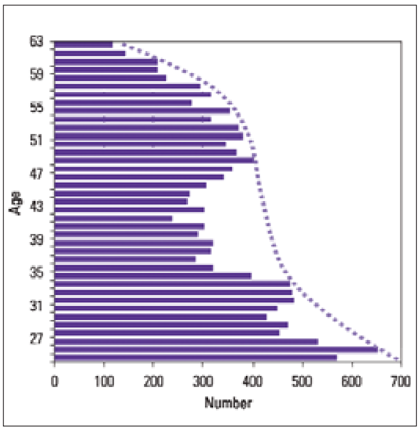

Figure 6. The age distribution of civil engineering staff in South Africa in 2005.

Box 1: Learning the tricks of the trade.

The best way to become proficient in the workplace is to gain practical experience under the guidance of a seasoned professional. The development of professional skills requires comprehensive formal instruction, preferably on a one-on-one basis. Below students and graduates paired with mentors hone their civil engineering skills in the workplace.

Skilled workers

Major campaigns such as the 'homecoming revolution'[5] have been mounted internationally to encourage those who have left to return. Through promotions and seminars organised in London, across Canada, the USA and Australia, many large engineering organisations have reported success at repatriating staff who left during the uncertainty of the early 1990s.

Possibly the quickest wins are achieved by redeploying those who have left the industry or retired. The former can generally be encouraged to return 'if the price is right'. Salaries have increased dramatically over the past three years, tempting many engineers back into the field.

Engineers who have retired present the most interesting opportunities. Many keep up with technical innovations, and have a strong desire to share their knowledge. Institutions can email retired members, offering projects that appeal to their interests, and many can be persuaded to return on a part-time or short-term contract basis.

Retired staff can help tackle another significant problem - the lack of young people gaining adequate workplace training, due to the shortage of experienced civil engineering staff (Figure 6). With their skills in such demand, few of these people have time to oversee the work of trainees. Many retired engineers were relatively young, fit and ready for new challenges. A major project was therefore mounted to recruit retired engineers and pair them with two or three students and graduates in order to tackle outstanding projects. This win-win model is helping to accelerate service delivery while also growing a new generation of engineering professionals (see Box 1).

Because the start date of many projects was flexible, calculations suggested that if all the above initiatives were successful and projects were staggered, the country would have sufficient capacity to cope with its development challenges. If projects were brought forward or the number or size of projects increased substantially, however, foreign skills would have to be harnessed, either on a short-term basis or through dedicated immigration programmes.

Clearly, the continued loss of staff from the public sector needs to be addressed. Some degree of autonomy for engineering departments, a reduction in the volume of reporting, more efficient methods of measuring performance and collecting statistical data, and efficient support staff are essential to allow engineers to get on with the business of engineering. Employers need to consider issues such as salary reviews, the working environment, incentives, and so on. It is critical for the adequate management of service providers that the public sector should rebuild a pool of proud civil servant engineering managers.

The overall effect

Figure 7 shows the predicted impact of these new initiatives on the number of civil engineering professionals in both the short and the long term. The additional long-term capacity will be gained from high-quality education of an increased intake into tertiary institutions and systematic workplace training under the mentorship of seasoned professionals.

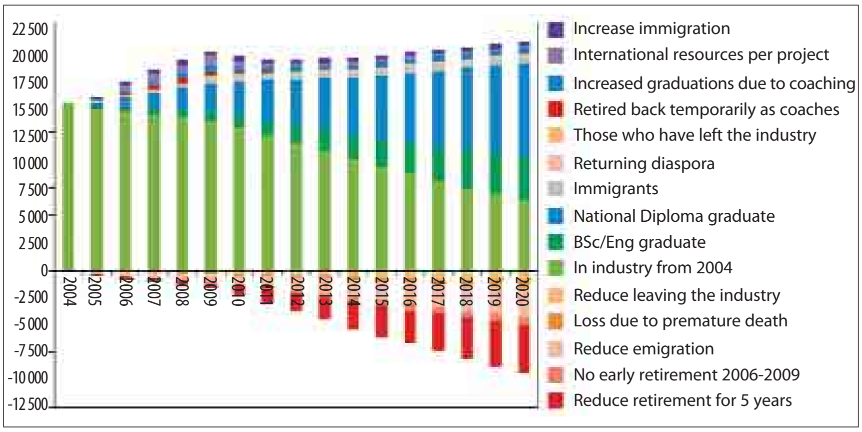

Figure 7. Short-term and long-term skills development interventions.

The short-term shortfall will be made up by repatriation, redeployment and reducing losses - that is, by aggressive attraction and retention strategies for those who already have the expertise. It was initially estimated that about 6,000 more civil engineering professionals were required to meet the challenges of development to 2010. Conversely, some 6,000 had left the industry during the slowdown. Hence there is good reason to believe that, with suitable employment policies and inducements, the short-term gap can be managed until the young generation has been groomed to take over.

Conclusion

'Unless you measure, you do not know where you are going or how you are going to get there' - Maria Ramos

To address any skills challenge, every aspect of the supply and shortfall needs to be measured and understood, suitable strategies developed, and capacity rebuilt. Without having carried out detailed research, few if any changes directed at engineering education and training would have taken place, South Africa's young people

Electrical students and graduates assist with revenue enhancement.

In Gauteng, structured local government deployments extend beyond civil engineering and include building science and electrical students and graduates. The graduate below is recalibrating the meter box of a major consumer. As a result of their interventions, under the watchful eye of a senior electrical engineer, income in a relatively small municipality was increased by some R7 million over a 15-month period.

Participating in Women's Build.

Female civil engineering students and graduates in Gauteng participated in Women's Build 2006 to celebrate Women's Day. Women keen to contribute to housing development volunteered to build 50 low-cost houses during the week to kick off a major housing project, with guidance from experienced engineers.

The participants learned a lot, as outlined by an enthusiastic Carolyn Maphanda, from Randfontein Local Municipality:

During the course of the five days of the project I learned that building is not all about having completed the job, but also thinking about the people [who] will be using the structure on a daily basis.

I would recommend that the NHBRC [National Home Builders Registration Council] insist on contractors keeping plans on site. This will enable anyone coming to inspect the buildings to check that the contractors are doing the right thing - building quality houses.

Access, the key to poverty alleviation.

Poor road maintenance and rains always present rural communities with major access problems. When the Njekeni stream flooded, the road became impassable, cutting off access to supplies, markets, schooling, health services and job opportunities. A new bridge has now solved the problem.

Another community in the same region was faced with an even more challenging situation. Their road was in such poor condition that it took eight hours to traverse 44 km in a 4x4. Households at the end of the road were virtually cut off. A project to upgrade the road provided 1,700 jobs over a 20-month period. Now some 100 vehicles a day allow communities to travel in and out of the area and children can attend school. Income in the area has increased because communities can sell excess crops. In addition, each household along the road is now paid a small fee by the municipality to maintain about 300m of the route.

would have continued to battle for workplace training opportunities and the institutional knowledge of the retired would not have been harnessed.

As the South African minister of science and technology, Minister Mosibudi Mangena, put it:

'Science and technology are considered central to creating wealth and improving quality of life for all … the Millennium Development Goals … can be better serviced by growing the engineering sector and by fighting the declining status of the field.'

With the facts and figures at our fingertips, the skills development initiatives now taking place have enjoyed support from both the public and private sector, which are both now intent on rebuilding the engineering skills base for the benefit of South Africa's future.

Allyson Lawless holds a master's degree in structural engineering from Imperial College, London, and is active in the fields of IT and civil engineering in South Africa. In 2000 she became the first female president of the South African Institution of Civil Engineering. She was the author of two reports for the South African Institution of Civil Engineering, both of which stressed the need to rebuild civil engineering capacity in the private and public sectors in order to address service delivery.

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Profile: Irenilza de Alencar Nääs

Irenilza de Alencar Nääs is a Professor at the Agricultural Engineering College, State University of Campinas, Brazil, and the first woman to be elected president of the CIGR, the International Commission of Agricultural Engineering. She received her PhD in Agricultural Engineering at Michigan State University in 1980 and is a former president of the Brazilian Society of Agricultural Engineering and President of the Latin American and Caribbean Society of Agricultural Engineering.

What is the main focus of your work at the moment?

The main theme of our group is agricultural buildings and the environment. Over the last 20 years, we have worked with poultry and pig producers to develop housing and equipment that can cope with high environmental temperatures. I am also involved in teaching and advising students and consultancy work for major companies and the Brazilian government.

What attracted you to engineering and what has been the most rewarding aspect of your career so far?

I was always fascinated by applied maths and physics and enjoyed solving engineering problems during undergraduate course work.

Teaching and doing research has been very rewarding. At the beginning of the 1980s environmental thinking in agricultural housing was very new, and I had the opportunity to change this situation. Some of my former graduate students are now in leading positions, helping to spread knowledge.

What kind of skills or qualities do you need to be a successful engineer?

I think that skills in applied mathematics are important, but you also need to exercise creativity and innovation.

Why is agricultural engineering important?

New trends in life support systems are focusing on the challenges of producing food, fibre and bioenergy from crops and animals to supply the world's growing population in a sustainable way. So the main challenge for the future is achieving high crop and animal densities with limited emission of effluents and minimum use of water.

We need to review the techniques and trends that can be applied in life support system research, emphasising the important role of agricultural engineering. In the coming years agricultural production will need to increase to meet demands, and new engineering solutions will be needed to achieve sustainability. Specialist knowledge will also be required for product processing and in the development of infrastructure to support production.

Developing countries are increasingly contributing to the global growth in demand for food and are becoming a more important destination for countries exporting goods. Emerging economies are showing relatively high income growth, and changes in food consumption patterns. Although developing countries still have a large amount of arable land and water, this needs to be used in a sustainable way, and this requires sound application of engineering principles.

Growth rates in Asia are projected to be about 5% for the next decade. While some slow down is likely, China's growth is expected to average above 7% over the next decade. India's projected growth is around 6% a year but it is still among the low-income countries, with a per capita income of less than US$600 per year. This projected growth rate will therefore move a significant number of people out of poverty over the next decade. With the need for more food, fibre and bioenergy, there is a huge opportunity for developing countries to invest in expanding agricultural production.

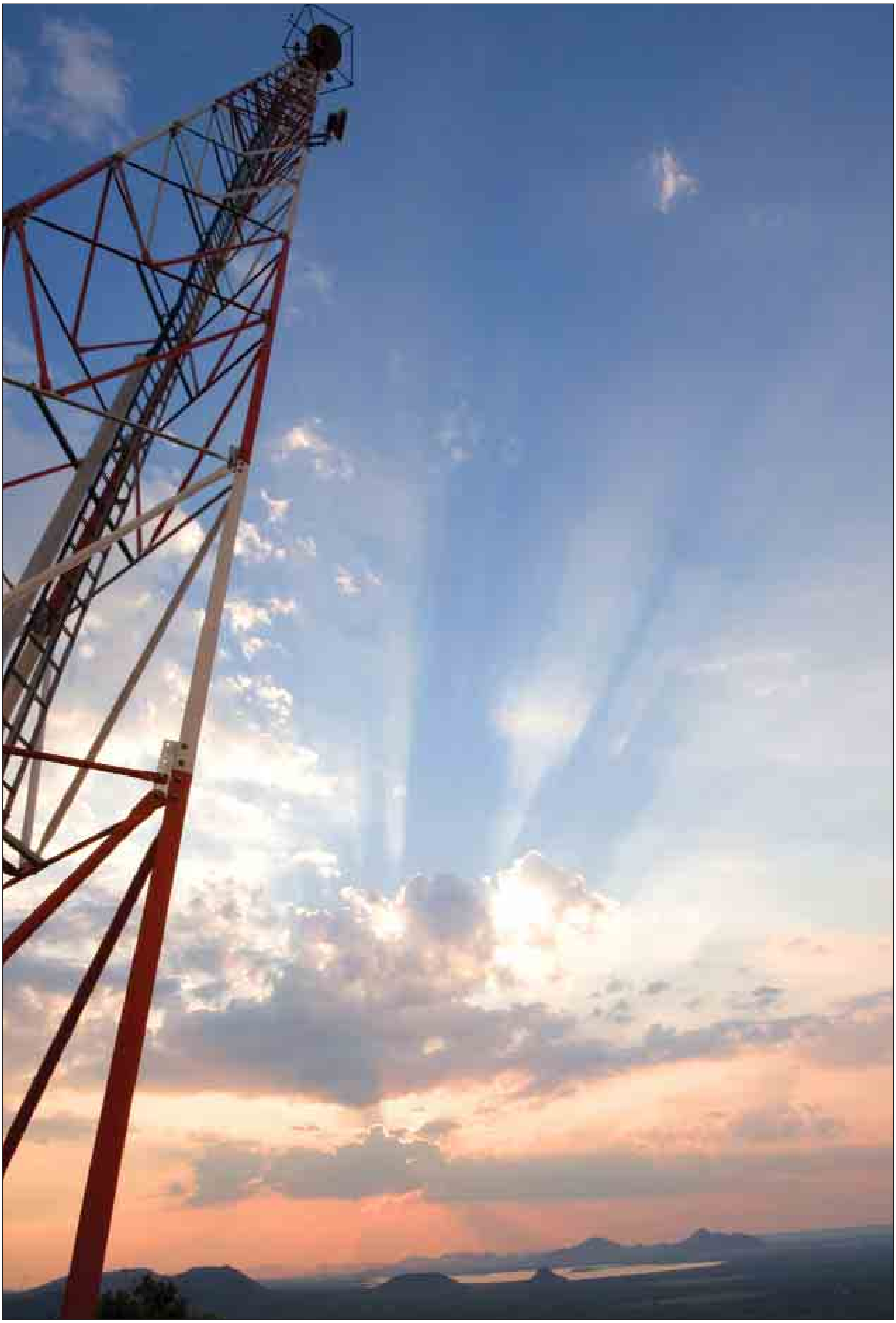
What are the key challenges and obstacles that you face in your work?

As a mother of three boys, it has been difficult to combine the roles of professional, mother and spouse, especially as I faced the loss of my husband when my youngest son was just one month old. But this had the benefit of building strong ties in my family and we always made the most of the limited time we had together. Today my sons are grown up and I am the proud grandmother of a lovely girl.

I owe much of my professional success to the advisers I had in my masters program (Ed Carnegie) and my doctoral program (Merle Esmay), who strongly believed in my talent, innovation skills and teaching ability. They gave me much of the drive and courage I needed to forge new frontiers throughout my professional life.

What plans do you have for the future?

I hope to teach in graduate school, do research and advise students as long as I can, as well as helping in transfer of technology through the Association of Technology Transfer - *Technology for all* - which I helped start a few years ago.



Bootstrapping infrastructure: The driving force for sustainable development

Paul Jowitt

Lack of infrastructure may be the single biggest factor holding back the development of poor countries. A concerted effort is now needed to put in place infrastructure that will spur economic development, while also ensuring that the process of construction yields benefits - directly to local suppliers and indirectly through enhancement of local capacity and institutional learning.

Nature is a great leveller. We only have to look back at Hurricane Katrina and the Boxing Day tsunami of 2004 to see that. The fragile coastal communities of Indonesia, Sri Lanka and parts of India were torn apart by a freak act of nature. The devastation of New Orleans showed how the advanced infrastructure of a major city in the world's richest and technically most advanced nation could easily be reduced to chaos.

For many people, it is not rare natural disasters that threaten infrastructure - because there is little infrastructure anyway. Many have little or no access to even the most basic of infrastructure, education and healthcare, and little, or at best tenuous, legal tenure to land or property. Communities are marginalised, outside and unsupported by the official economy and local government systems.

In the massive Kianda-Kibera township in Nairobi, community groups are bettering their community by constructing toilet blocks and running a maternity unit, assisted by aid funds and personal subscriptions of a few Kenyan shillings per month. Their daily life is largely disconnected from the official economy, and equally disconnected from the basics of infrastructure and services. But even in Kibera the mobile phone is ubiquitous and TV aerials sprinkle the shantytown skyline. In the schools the children are there in their overcrowded classes, attentive and smartly turned out. In her schoolbook an 8-year-old girl writes in neat handwriting that cutting down trees is bad because it leads to soil erosion, and yet much of Kibera relies on fuel wood for cooking.

And even in an emerging economy such as India, there is scant evidence that the underclasses are benefiting significantly from the country's transformation into a technologically driven economy. Most are still living in what are euphemistically called 'unplanned settlements': slums. From Mumbai to Nairobi, Cape Town to Rio de Janeiro, the urban landscape is scarred by amorphous, slum-grey shanty towns, built from whatever materials come to hand, with water courses polluted by sewage and solid waste. These settlements are simultaneously distinct from and - however reluctantly officialdom acknowledges it - part of their wider urban and national economies.

The solutions today are deceptively straightforward - the provision of basic urban infrastructure and effective infrastructure services. But infrastructure delivery also requires investment. Internal economic regeneration is important but insufficient. External public and private investment are also needed - as is assistance from the engineering community. Politicians and economists have never delivered infrastructure. But they can will the means. Ultimately, it is down to the engineers working with and within the communities in need.

The UN Millennium Development Goals

In one way or another, all of the Millennium Development Goals (MDGs) depend critically on the delivery of underpinning infrastructure, to provide decent shelter, transport links, affordable energy and, perhaps most critical, access to safe water and sanitation systems. The point has been eloquently made by Calestous Juma:[1]

'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.'

His words were reinforced by Sir David King, the UK Government's former Chief Scientific Adviser:[2]

The Good Hope Hotel, Kibera


A typical lane in Kibera

'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.'

There are certain prerequisites for development, without which attempts to improve livelihoods in the developing world will be unlikely to succeed. These include reasonable governance structures; a functioning civil society; and freedom from persecution, conflict and corruption. Nobel Laureate Amartya Sen has suggested that development must involve an expansion of choice for individuals and societies.[3] On the other hand, as Thandika Mkandawire, Director of the UN Research Institute for Social Development, recently noted,[4] it would be the height of irony if external aid funds were used to push for democratic reforms yet resulted in choiceless democracies. Instead, he argues, they must lead to effective institutions to manage that aid better. African politics is changing rapidly, and is still a state of flux, as witnessed by recent events in Kenya and Zimbabwe.

The impact of global politics, trade and conflicts on development is immense. These include trade rules, tariffs and developed world subsidies, local and regional conflict, oil diplomacy, governance, and the roles of multinational companies. A thriving local private sector (large and small) is equally critical. A climate in which individual traders and small businesses can flourish 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.
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.

An engineering vision for MDG implementation

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, 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 per se, 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 that are excluded by virtue of illegal/disputed property rights. The sheer scale of some of the 'unplanned' settlements sited on land pockets within and on the fringes of major cities in the developing world demands a more constructive response than simply declaring them to be illegal, and using this as the pretext to ignore their infrastructure needs.

Emerging technologies will play a role, perhaps not central but nevertheless important. For example, renewable energy provides a means of local access to power, and wireless communication enables access to knowledge and services, and indirectly promotes gender equality. The limiting factors are not usually 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 it 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. Engineering for international development is not an apolitical activity.

This is exemplified by the work of Ron Watermeyer (former President of the South African Institution of Civil Engineering, SAICE). Watermeyer was seconded to the South African government in 1995 to lead a three-person team tasked with reforming 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 and the development of local engineering businesses and enterprises. Watermeyer's view is that, 'it is simple to develop the concepts and much more difficult to implement them' - but it can be done.

In his SAICE Presidential Address, Watermeyer 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.'

Nevertheless, Watermeyer's view on infrastructure provision in slum areas is that 'green sustainability' might have to give way to 'brown sustainability' in the immediate term -infrastructure for poverty reduction must come first.

Capacity building and institutional learning

As demonstrated by Watermeyer, and supported by people such as Professor Calestous Juma, Professor Tony Ridley (former ICE President), Dato' Ir Yee-Cheong Lee (former President of the World Federation of Engineering Organisations) and Sir 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. Conway describes an example from Uganda:

> '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.'

Ridley and Lee have made a similar point:

> '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.'

But how can this actually be implemented?

First, by building professional and technical engineering capacity where it is needed most, and, where it is requested, with the help, support and partnership of the engineering institutions and the engineering community in the developed world.

Secondly, by strengthening the links between local engineering educational and professional institutions and their industrial and municipal counterparts engaged in infrastructure delivery.

Thirdly, by encouraging greater partnership in delivery between the community, municipalities,


An 8 year old school girl in Kibera learns about the environmental impacts of soil erosion

NGOs, local businesses (large and small), and the international engineering business community.

And fourthly, by using all these delivery partnerships to press relentlessly - using every available avenue - for the means to deliver the ends.

It is worth exploring how these partnerships might be established and managed and to whom they would be responsible and accountable. Are there any successful precedents that could be used to inform this process? There have been attempts - often at the behest of external aid funding agencies to impose the privatisation model used in the developed world to deliver and manage infrastructure and major utility services. However, the privatisation models of the developed world were established primarily to deal with a much narrower and less complex set of problems, specifically the perceived inefficiencies of the public sector and the need to raise private capital in order to reduce public sector borrowing. Delivering effective and sustainable infrastructure in the developing world is vastly more difficult and involves additional factors such as affordability, good governance, skills development and so on. The track record of privatisation in international development is not strong. Are there other development models that have successfully dealt with issues more akin to those of the developing world? Perhaps there are. For example, in many deprived inner city areas in the developed world, the issues are broadly similar - rundown infrastructure, high unemployment, an economically disadvantaged local population, high crime rates and drug use, and a dysfunctional local economy. The solution to such cases has been the establishment of special purpose development corporations, independent of the local municipality and separately accountable. Such a model could embody all four of the requirements outlined above, whilst also offering accountability, independent scrutiny and financial transparency.


Solid waste management in Kibera

And if successful, the lessons learned by that 8-year-old girl in Kibera will have been worth it and put into practice. She might still be at school in her teens, her family part of a recovering local economy, the community less at risk from disease from poor wastewater disposal and fetid solid waste. Perhaps she will go on to college and be part of the process of technological learning, ultimately working for the delivery authority.

The MDGs viewed as an engineering project

The scale of delivering the MDGs is immense. Inadequate infrastructure affects some 2 billion people. Solutions will require systems for constructing, managing, maintaining and paying for new infrastructure, while also developing local skills.

Combined with other political and economic barriers, the task looks nigh on impossible. But is it? Certainly not from an engineering perspective. Building the infrastructure to deliver the MDGs is not about a single project, but about the delivery of very many. Each one complex in itself - but at the right scale and with the right planning, perfectly feasible. Each project delivery plan developing surplus skills and resources that can be rolled out to the next series of projects - scaling up the response.

And the barriers? Well, as a delegate from Papua New Guinea said recently in a different context in Bali: 'Either lead, follow or get out of the way.'

Professor Paul Jowitt is Vice President of the Institution of Civil Engineers (ICE) and Executive Director of the Scottish Institute of Sustainable Technology, Heriot Watt University. He chaired the ICE Presidential Commission - Engineering without Frontiers - examining the engineer's contribution to meeting the UN Millennium Development Goals, and the ICE Council Task Group to embed sustainable development into civil engineering curricula and professional development. He chairs the ICE's Expert Panel on Climate Change. Paul is also a Trustee of Engineers Against Poverty.

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Good business: Mobilising the engineering industry to tackle global poverty

Petter Matthews

Industry has the potential to make an enormous contribution to development goals - not least because of the financial resources at its disposal. But in addition to its monetary investments, industry can be a force for good in other ways, for example by insisting upon and contributing to good governance practices. Moreover, by aligning its business activities with countries' or regions' development goals, industry can not only meet its corporate and social responsibilities but also protect and enhance its long-term business interests.

The private sector has the skills, technology, economic power and global reach to make a decisive contribution to the UN Millennium Development Goals (MDGs). It is now larger than the public sector in almost all but a handful of developing countries and for every US$1 in net long-term flows to the developing world from official sources, the private sector now invests close to US$3. As a result of this and other changes, the global economy is expected to grow from US$35 trillion in 2005 to US$72 trillion in 2030, with an increasing proportion being driven by activities in developing countries.[1] Harnessing this extraordinary potential, whilst protecting the environment, represents what is probably the single greatest opportunity to step-up the fight against poverty. However, the conditions needed to realise this potential have not previously existed, but this could be changing.

In recent years, businesses have begun to contribute to a range of development goals in ways that were previously unheard of. This includes pharmaceutical companies providing affordable drugs to combat HIV/AIDS, software companies using information and communication technology (ICT) to link rural schools, and utility companies creating jobs by preferencing disadvantaged sections of the community through their supply chains. Is this new corporate interest in social responsibility a temporary aberration? Or is it a sign of a more fundamental shift in the relationship between business and society? Could we be witnessing the end of the purely profit-seeking company and the emergence of an enduring corporate commitment to the public interest? For many of the world's poorest people, the answers to these questions could be a matter of life and death.

The sheer power and influence of the private sector provides it with the moral imperative to act. If it is seen to have this power but chooses not to use it, then it can expect to face increasing levels of opposition and protest, and in the long-term it will probably suffer the disruptive social, economic and environmental consequences. But in addition to the moral case for action, there is an increasingly convincing business case.

The private sector will benefit directly if the MDGs are achieved by having access to a healthier and better educated workforce, a more stable investment climate, and a reduction in the business risks that accompany poverty-related problems such as global insecurity, climate change and ethnic conflict.[2] It will also benefit from the vast new markets that will be created by drawing the 4 billion people that currently live on less than US$2 per day into economic life.[3]

The engineering industry, as a subset of the private sector, is in a particularly strong position to contribute to the MDGs and to benefit from the associated economic opportunities. It is present in most developing countries and the goods and services that it provides, for example in relation to infrastructure and the exploitation of natural resources, directly affect efforts to achieve the MDGs.

But there is not even a remote possibility of this contribution being realised, or of the commercial benefits being obtained, if it continues with 'business as usual'.

There is an urgent need for a searching reappraisal of the ways in which the engineering industry does business. This includes positioning itself to influence global governance, rethinking established business management systems and developing new business models. The commercial interests of the engineering industry need to be aligned with the development priorities of developing countries, to produce outcomes that are better for business and better for society.

Balfour Beatty 'Lot 3' overhead power transmission line project in Indonesia

BP 'Tangguh' LNG project in West Papua

Governance

Global governance refers to the efforts of state, business and civil society sectors to work together and deal with problems - such as mitigating the effects of climate change, fighting corruption and maintaining biodiversity - that affect more than one state or region and that are beyond the capacity of any individual sector to solve alone. Governments have traditionally been responsible for determining the rules that govern economic interaction, but the growing power and influence of multinational corporations has highlighted the need for a global governance framework to regulate their activities. Mechanisms have also been developed to involve companies themselves in maintaining that framework. Examples include the UN Global Compact, the Extractive Industries Transparency Initiative and the International Labour Organisation Tripartite Declaration of Principles Concerning Multinational Enterprises and Social Policy.[4]

Global governance is particularly relevant to infrastructure because corruption (a symptom of weak governance) has become so ingrained. Public works and construction are identified by Transparency International as the business sector most likely to demand or accept bribes.[5] Oil and gas construction, telecoms, power and mining, all of which have large infrastructure components, also appear in the top 10 list of worst offenders.[5] Corruption not only increases the cost of infrastructure, it also reduces the quality of the assets built and the services delivered, and severely limits the impact of investment on growth and development.

Engineering service providers are in a strong position to improve governance in infrastructure. They are involved at most of the critical junctures where corruption can occur, including policy development, contract preparation, design, procurement, supply chain management, project management, and operations and maintenance. And engineers, through their professional institutions and representative bodies, have a history of participating in collective action to improve professional standards and promote the positive impact of engineering on society.
But there are still very few examples of industry-led actions that have actually made a difference. It is important to understand some of the reasons for this if we are to avoid repeating the mistakes of the past.

First, the 1980s and 1990s saw a loss of confidence in the public sector as a provider of infrastructure and services and an ideologically driven move towards privatisation and various forms of public-private partnerships (PPPs). Policy-makers naively assumed that corruption would simply disappear with private investment, and the ideological nature of the debate reduced the policy space for alternatives. The private sector fulfilled a narrowly prescribed role and its reputation suffered as a result of some of the high-profile projects that failed.[6]

Secondly, the relationship between less corruption on the one hand and progress on development goals on the other is still poorly understood. We tend to apply binary thinking to issues of corruption. The problems are framed in terms of good and bad, right and wrong, leading to 'absolutist' solutions that prescribe improvements across all aspects of institutional life. Given the inevitable constraints on time and resources, it is unrealistic to believe that all areas of reform can be pursued simultaneously.

Governance reforms are more likely to succeed if we identify the range of possible institutional improvements and prioritise those that are more likely to accelerate growth and development. Work undertaken recently by Engineers Against Poverty (EAP) and the Institution of Civil Engineers has identified procurement as an important lever to improve the developmental impact of infrastructure.[7]

Thirdly, earlier interventions rarely benefited from cross-sectoral collaboration. The rationale for cross-sector (or multisector) partnerships is that each sector, state, business and civil society has distinctive core competencies - the things they do best and that are integral to their primary purpose - which, when combined with those of other sectors, can help to solve complex problems more effectively than individual sectors could on their own.[8] Efforts to overcome problems such as corruption, which often have complex social, political, economic and cultural dimensions, are more likely to succeed if the partners developing the solutions include a range of perspectives and expertise.

The fourth factor inhibiting industry-led action is the failure of the UK Government to put in place effective legislation and enforcement to regulate the practices of UK companies working overseas. Firms that have maintained high standards of corporate ethics have found themselves at a competitive disadvantage when bidding against others who see little prospect of having to face any legal consequences for their actions.

These barriers to industry-led solutions may not have been entirely overcome, but they have been weakened. There is a new pragmatism regarding the respective roles of the public and private sectors in infrastructure delivery, the tools available to analyse corruption and shape our responses to it are more sophisticated and potentially more effective, partnership-based solutions have entered the mainstream of corporate thinking, and the UK Government is coming under increasing pressure to improve the legislative framework.

These changes provide a platform for a new generation of initiatives, such as the UK Anti-Corruption Forum (UKACF),[9] which brings together many of the UK's leading engineering services companies, business associations, professional engineering institutions and civil society organisations to develop industry-led actions to fight corruption. Between them, the members represent more than 1,000 companies and over 200,000 engineers and technologists. Soon after it was launched in 2004, the UKACF published an 'Anti-Corruption Action Statement' that set out a series of recommended actions for all those working in infrastructure.[10] It subsequently established a series of working groups to focus on specific issues - including debarment, professional standards, developing countries and transparency - and entered into dialogue with governments and international agencies to offer support, advice and pressure where necessary, to stimulate action.

The UKACF encapsulates many features of good practice in corporate engagement in global governance, and shows how the engineering industry can position itself to provide an informed and responsible voice in governance debates. The size and diversity of its membership ensures that it is accountable and its cross-sectoral composition provides a high degree of legitimacy. But like other global governance initiatives, the UKACF must be judged on the difference that it makes. If it were to become narrowly focused on advancing the interests of business, it would lose its legitimacy and its right to influence international debates. If, however, it continues to respond to society's demands that the corporate sector transcend purely profit-driven motives and demonstrate a commitment to the broader public interest, then it is likely to remain relevant and effective.

New business models

If global governance initiatives such as the UKACF can help develop a 'level playing field', where companies that maintain high standards of corporate behaviour are rewarded and those that do not are punished, then it is more likely that companies will seek to establish competitive advantage through contributing to development goals. This alignment between the commercial interests of industry and the development priorities of poor countries is key to unlocking the potential of the private sector. Regulation is important, to ensure that minimum standards of corporate behaviour are maintained, but incentives are also needed to scale-up the impact of the sector and maintain it over time. EAP's work with engineering service contractors in the extractive industries shows how this can be achieved.

In the next 30 years, US$16 trillion will be invested in energy-supply infrastructure, almost half of it in developing countries.[11] This represents an enormous development opportunity. But the developmental impact of the extractive industries tends to focus on the revenues that governments receive through royalties and taxation from oil, gas and mining companies. Although this income generates significant development opportunities, countries with abundant natural resources also tend to suffer lower rates of growth, greater market volatility, and more corruption and conflict than countries that are not similarly endowed.[12] While it is vital to improve revenue management, it is also important to look at other opportunities.

The extractive industries are capital-intensive and require substantial investments in infrastructure. In fact, the amount spent by oil, gas and mining operators on infrastructure and services often exceeds the value of revenues paid to governments.[13] Given that most of this expenditure (sometimes up to 90 per cent) is managed by the main contractors, it is surprising that their activities, and the construction, operation and maintenance processes that they are responsible for, have received so little attention.

EAP's work on Shell's Malampaya Gas-to-Power Project in the Philippines revealed that operations and maintenance contractor AMEC had a range of competencies that could be aligned with local development priorities.[14] For example, it had developed a systematic approach to supply chain development, so that it could source goods and services locally, secure cost efficiencies and improve its competitiveness. Thanks to the support provided by AMEC to its catering supplier, that company secured additional contracts with a mining company and with local hospitals. AMEC's support transferred technology, provided training, created jobs and put money into the local economy and, importantly, made good business sense for the company. AMEC was encouraged to look at its core competencies, repackage them and incorporate them into a business development strategy based in part on offering a high standard of social performance to potential clients. It subsequently emerged that this approach had helped the company to secure a similar operations and maintenance contract in Timor Leste, providing firm evidence of the elusive 'business case'.[15]

Malampaya Offshore Platform (credit: AMEC)

In addition to business development opportunities, maximising local content can also help companies manage the costs and risks of doing business by developing a 'social licence to operate' - the passive or active support of the population in the areas where it works. The implications of a company not securing such a licence can be seen in the Niger Delta, where almost a third of Shell's production has been regularly 'shut in' in recent years. If a company can demonstrate that it is environmentally responsible, that it creates decent jobs and supports local enterprise development, it is less likely to suffer these adverse consequences.

The MDGs are still achievable, but the window of opportunity is narrowing. Increasing the quantity and quality of aid and writing off debt are necessary but not sufficient to deliver sustainable and cost-effective solutions. Societal demands of business will continue to increase and the days of the ruthlessly self-interested and purely profit-seeking company are numbered. At the same time, the market for engineering services is shifting towards developing countries and the companies involved have to contend with a range of new and unfamiliar challenges. The companies most likely to prosper in this changing environment are those that are able to adapt their business models to these new circumstances and align their commercial drivers with the development priorities of the countries where they work.

Petter Matthews is Executive Director of Engineers Against Poverty, an independent NGO that works with industry, government and civil society to fight poverty and promote sustainable development. He is a senior international development specialist with expertise in areas including social policy, infrastructure, the extractive industries and governance. He is currently Chairman of an Institution of Civil Engineers/Engineers Against Poverty Expert Panel on Promoting Development through Procurement, a member of the Natural Sciences Committee of the UK National Commission for UNESCO and a technical adviser to the Construction Sector Transparency Initiative.

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Profile: Himanshu Parikh

Himanshu Parikh graduated from Cambridge University in engineering sciences and practised in England for ten years. In 1982 he moved to India where he has done innovative work in urban planning, environmental upgradation and infrastructure design, with an emphasis on low-income urban and rural areas. He has held various positions outside his practice, including professor at the School of Planning, CEPT University, Ahmedabad, member of Governing Council of Department of Science and Technology and member of working group on poverty alleviation of Planning Commission, Government of India. Mr. Parikh has received several awards including the SOM Fazlur Khan Fellowship for excellence in structural engineering in 1985, the United Nations World Habitat Award for Urban Development in 1993, the United Nation Habitat II Best Practice recognition for Slum Networking in 1996 and 2006, Aga Khan Award for Architecture in 1998 and a Citation by Government of India in 1998. In 2005 he was invited to become a Fellow of the Royal Society of Arts.

Why did you choose to get involved with slums?

Around a billion people live in slums in abysmal conditions, and the numbers are likely to double in the next two decades. In lieu of inadequate and piecemeal interventions generated by the 'poverty' mindset, I felt that good engineering could bring holistic and affordable solutions to improve and assimilate slums into the formal urban fabric instead of isolating them as islands. The concept of Slum Networking has thus managed to transform slums in Indore, Baroda, Ahmedabad and other cities of India. The concept has now spread to villages of Andhra Pradesh to demonstrate its applicability to rural areas, where the majority of the Indian population lives in equally poor conditions. We've seen that engineering can make a difference to the quality of life of the poor.

What did the Slum Networking Projects achieve?

The tangible impact on health has been obvious. In Ahmedabad infant mortality dropped from 6% to 1%, working days lost to illness reduced from 64 to 9 per year per person and medical expenses almost halved. The monthly expendable income increased by 50%. However, the larger knock-on impact on poverty alleviation in terms of improvements in education, incomes and social conditions has been both dramatic and surprising. For example, the number of children attending school in Ahmedabad has jumped from 41% to 72% and the incomes, particularly of women, have almost doubled in five years.

Rather than building houses for the poor, at a fraction of the cost, Slum Networking focuses on infrastructure - roads, water, sanitation, lighting and so on to transform the environment and the quality of life of not just the rundown areas but the city as a whole. The work so far has covered a million people and slums are no longer seen as liabilities but as catalysts of change. It is an example of how engineering can change lives. More importantly, the work has shown a way out of aid dependency for pro-poor development.

What role was there for innovation in your project?

What inspired me to start with was the realisation that slums always tended to follow natural watercourses, rivers and streams. It struck me that water services could mimic natural topography, so for example we could use gravity rather than pumps to move water. We needed a range of innovative techniques to make it work - holistic computer modelling, earth management, constructive landscaping, using roads as storm channels - but we managed to deliver not just better performance but also lower cost.

As well as technological innovation, we introduced radically different social models. Our first project in Indore was based on aid, but that tended to promote a dependency culture and was not sustainable - responsibility for maintenance was a real issue. For our follow up work, we brought together slum-dwellers, the commercial sector and government, encouraging them to work together in partnership. The slum-dwellers weren't just 'beneficiaries' - they had to make a financial contribution, literally to buy in to the project.

What was important was that people ended up benefiting financially. What I think also surprised a lot of people was that, once the environment had been improved, the overwhelming majority of people found the money to improve their own housing themselves.

What factors underpinned the success of slum networking project?

Engineering expertise was important - the system we developed was cost-effective, providing quality services at low cost. But good engineering on its own would not have been sufficient.

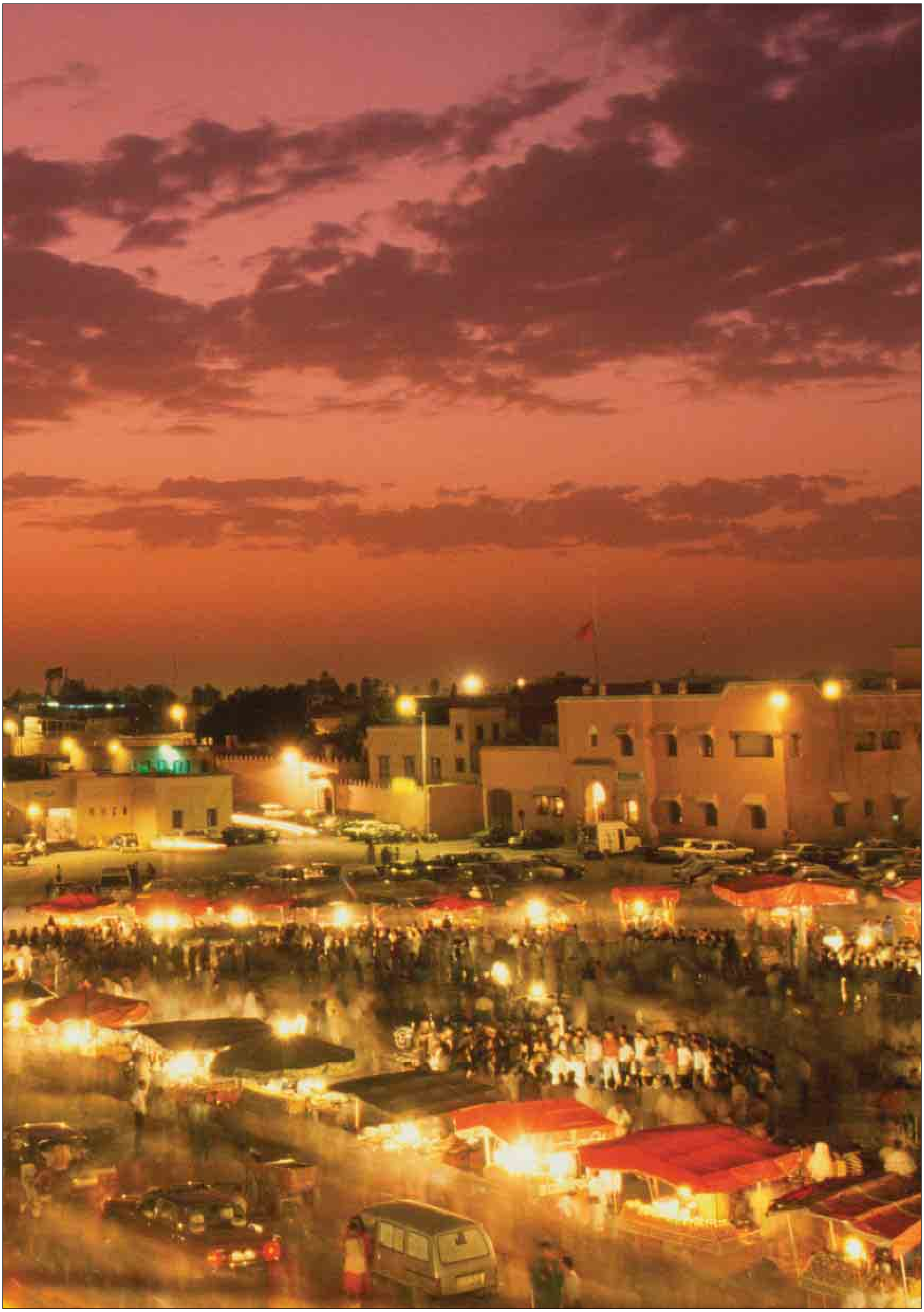
Involving people, making them partners, was crucial. Engaging with the corporate sector was also important, as it helped wean everyone off a dependency culture and ensure that solutions were economically sustainable. We also had to make sure that local authorities gave an undertaking that they would not demolish the housing during the next ten years, which gave people the confidence that improvements would be worthwhile. It was also important that the community could see the improvements for themselves and gain real benefits, as well as reaping financial rewards from their initial investment.

What are the lessons for development more generally?

One point is that water and sanitation should be seen as primary interventions, as they catalyse so many other benefits - not just health but education, incomes and social conditions too.

Our work so far has covered a million people and questions our basic assumptions about 'poverty' and the resourcefulness of the 'poor'. Conventional pro-poor development tends to see disadvantaged people as 'recipients', and locks them into a particular kind of solution. We need to see people not as beneficiaries but as capital partners and, therefore, clients and consumers.

Community investment is also an acid test of the efficacy of the solutions. As aid is not sustainable or adequate to meet global needs, the challenge can only be met from the internal resources of nations through constructive partnerships. The business and banking partners replace aid and assist with implementation on a business model. The government's role is to establish a financial, administrative and legal framework that enables all the different groups to participate. Slums are seen as blights on the landscape, but really they can catalyse the most amazing changes.



Computing for the future of the planet

Andy Hopper, Andrew Rice and Alastair Beresford

Computers have transformed western society and look likely to do the same in the developing world. The challenge for the future is to harness the enormous power and potential of computing technology to generate a better understanding of the Earth and its environment and to provide low-impact alternatives to humankind's current activities. Simultaneously, both academia and industry must seek to minimise the environmental impact of computing so that the sheer abundance and energy consumption of technology does not threaten the goals of sustainable development.

The human species is living an unsustainable existence. The scientific consensus is that our planet will be unable to provide long-term support for us if we continue depleting the natural environment as we have over the past century or so. And since the global population is expected to grow from 6 billion today to 9 billion by 2050, and living standards are predicted to increase, managing our environmental impact is going to be vital to the future of society.

Over the last 60 years computers have transformed many aspects of our lives, and it seems likely that this transformation will continue, particularly in the developing world. Computing confers numerous benefits, but consumes a lot of natural resources.

Here we describe how computing could become be a positive force for reducing the environmental impact of humankind. First we consider the environmental impact of computing itself and the challenge of reducing resource consumption and waste. Secondly, advances in computing and networking will enable us to collect the sensor data needed to understand our world - providing crucial information for managing our planet in a sustainable manner. Thirdly, better models of the world will allow us to make more accurate predictions about our future. Finally, we believe that computing has the potential to offer less environmentally damaging alternatives to many of today's profligate consumer activities.

An optimal digital infrastructure

The power-inefficient nature of modern computers is apparent in their generation of waste heat and the costs of dispersing it. A large data centre must typically expend an additional watt of power on cooling for every watt of power supplied to a machine. Furthermore, around half the energy used over the typical three-year lifetime of a desktop computer is consumed in its manufacture, even if it is running 24 hours a day for its entire working life. The energy used by computers must be minimised throughout the lifecycle of manufacture, operation and disposal.[1] Chip manufacturers are already adopting green computing initiatives which seek to reduce the resource consumption and pollution of chip manufacture, and many charities now refurbish computers and mobile phones for reuse in the developing world.

Servers in large data centres typically operate at utilisation levels of 10-50%,[2] so for much of the time a machine has significant unused capacity. Some of this wastage is deliberate, enabling the system to cope with a sudden peak in load. Wastage also occurs because mission-critical software systems may interact in unusual ways and are therefore installed on separate physical machines. Virtualisation technologies offer a solution to both these problems by dividing a single physical machine into a number of virtual machines.[3] Multiplexing a number of existing servers onto a single physical machine leaves operators free to switch off unneeded hardware, while applications that have variable workloads can be scaled dynamically so that the resources an application uses depend on the current service load. Virtualisation of the popular types of server machines has only recently become viable and further hardware and software facilities are needed before it is ready for the desktop. However, industry is rapidly moving to adopt this technique in server infrastructure wherever appropriate.

Not all tasks require high-performance computing. A huge range of consumer electronics devices now exist - mobile phones, personal digital assistants, MP3 players - many of which are equipped with small, embedded processors. Whilst these processors are very efficient at performing the kinds of applications we typically use today, they are not very adaptable to possible applications of the future. They would not, for example, be suitable for the huge numbers of sensors needed to gather comprehensive data about the health of our planet. This type of application requires highly parallel processing - where lots of data can be processed independently and concurrently. Meeting these goals will require new computer architectures that can efficiently and dependably collate, process and distribute sensor data.

All computers need power. Currently the demand on our electricity grid varies massively depending on time of day, weather conditions, and even what is on television: a nationwide boiling of kettles often occurs during the adverts in popular soap operas. In addition, renewable energy sources often have variable supply levels, wind power being a particularly good example. Due to their significant energy demands, modern data centres are often built in areas of cheap electricity supply, such as near hydroelectric dams, rather than in areas of good digital connectivity. This reflects the fact that it is more efficient to transmit digital data than power over long distances. We believe that placing data centres next to renewable energy sources can exploit the flexibility of power control and virtualisation to smooth an increasingly variable supply and demand. Recently there has been interest in constructing data centres in Iceland due to its plentiful geothermal energy and naturally cold climate. Perhaps in the future every windmill will have a server farm attached, and every village in sunny parts of the world will provide low-cost hosting services.

Charging mobile phones at the village power centre in Kiangombe using hybrid renewable energy

There has been a huge uptake in broadband internet connectivity in developed nations. Yet, while 66% of the UK population has internet access, globally the figure is only 19% .[4] Efforts are being made to reduce this gap. Mobile phone technology has emerged as a valuable technology for many countries with low levels of access. In these regions fixed-line infrastructure is often inadequate, and electricity supply is unreliable, so battery-powered mobile phones are the only feasible means of long-distance communication. Street businesses that recharge phones from car batteries have been quick to spring up to support this new activity. Fixed broadband wireless systems have the potential to deliver high bandwidth data connections over large distances without the need for expensive and environmentally damaging laying of cable - an ideal technology for connecting remote and isolated regions. Research is ongoing to improve data rates, reduce power consumption and overcome interference between radio signals.

Nigeria: Phone vendor

Delay-tolerant networks are another way to improve access to digital data.[5] Such networks operate under the assumption that communicating nodes are mobile, unreliable and are frequently disconnected - as mobile phones are in weakly provisioned areas. Delay-tolerant networks could be used to deliver email to destinations with unreliable network connections. Alternatively, vehicles could be used as carriers. With delay-tolerant networks, deliveries to outlying areas can include both physical and digital resources - the local bus service can now deliver passengers, email and web pages. One form of this idea is already operated in rural India, Rwanda, Cambodia and Paraguay, where buses cache website data and relay it to computers with no direct internet connection.

Another example of the challenges of delivering computing to people in developing countries concerns the management of pictures from camera phones. Many people in Africa have a mobile phone with a camera, but no means of printing or displaying these pictures. In response, researchers at the University of Cape Town developed a distributed photo presentation application which allows sharing of photos between phones. In addition to being highly popular, this might be useful for people meeting in public places in developed countries. Similarly, 'ruggedised' low-power phones or computers designed for Africa have also generated significant interest in other continents. As researchers strive to minimise the power and resource consumption of our digital infrastructure, its very likely that technology and solutions inspired by the challenges present in the developing world will eventually be deployed more pervasively, helping us all do more with less.

Sensing the planet

We live in complex societies constructed within complex ecological systems. A detailed understanding of these systems can help us make informed choices about how to protect or improve them. Crucial to this understanding is the collection, dissemination and analysis of sensor information about the physical world.

One small-scale application of this approach is seen in 'sentient computing', which attempts to improve human-computer interactions by providing machines with information about people and their surroundings.[6] This can help the computer model the outside world and anticipate to some extent what will happen in the future. Sentient computing applications often rely on an internal model containing details about the current state of the world: in an office environment this might include the positions of walls, doors, desks and computers. Keeping this model up to date is increasingly difficult as its size and fidelity increases. Privacy can also be an issue: for example, location data collected from GPS receivers attached to vehicles can be used to assess road congestion, but can also reveal which hospital clinic you have visited or where you went after work.

Testing a G3 Communication device, Khartoum

Transportation is another area that can benefit from remotely collected data. Prototype intelligent vehicles incorporate numerous communications mechanisms, low-level sensors, cameras and touch-screen displays. These have the potential to improve in-vehicle satellite navigation systems. Mapmakers face an ever-increasing struggle to maintain the quality of their data: incorporating new routes, deleting closed roads and providing information about road quality and size. Appropriate processing of GPS position traces from augmented vehicles may make it possible to build these maps autonomously: raw journey traces from many journeys (and vehicles) can be aggregated to form a working map of the road network.[7]

Sensing has the potential to play a huge role in the developing world. Widely distributed autonomous sensors could collect and relay detailed information about water or soil quality, or use of such resources, to support effective planning. Sensors could be used to provide a clearer picture of illegal logging, or even a way to locate felled timber. Researchers have tackled diverse projects ranging from tracking the habits and movements of wild animals to enhancing water management using satellite imagery.

These projects are a step along the way to sensing the entire planet,[8] something which would enable ecologically minded consumers to find out the true cost of their purchases, the impact of emissions-changing initiatives, and improve our general understanding of the world in which we live immeasurably. Online mapping services already include real-time congestion information of our road networks and research projects such as TIME at the University of Cambridge and SenseWeb at Microsoft Research aim to integrate a plethora of additional sensed data. In the future, global sensor information might provide new data layers for these services, such as an infrared layer showing heat loss from buildings and a pollution layer showing current air quality conditions.

Nevertheless, there are substantial technical obstacles to global deployments of sensor technology, ranging from the environmental impact of sensor construction and deployment to power requirements and recovery of data. It will also be a challenge to exploit this technology without compromising privacy or individual rights.[9]

Modelling the planet

While it is now generally accepted that increasing levels of greenhouse gas emissions are altering the climate, determining the consequences of emissions is a difficult task reliant on large-scale computer models of the climate. These models are only destined to get more complex as they are refined and the amount of sensor data collected increases.

An important and largely unexplored question is whether the implementation of the model correctly captures the intent of the engineer. The impact of some nuance in the model could be masked by a programming error. Theoretical computer science has long investigated techniques for improving the reliability of software and for ensuring that it meets the intent of its designers. Examples include model checking, in which one specifies certain properties about a program and then verifies that they always hold. In the context of physical models, a programmer might wish to check that the program can never generate a state known to be impossible or that global properties such as conservation of energy are preserved by the system. Resolving these issues is a current research problem. We aim to explore how these techniques can be applied to the implementation of physical models to make sure that we can discover the effects of natural processes rather than the effect of a programming error.

Digital alternatives

The rapid evolution of computing has produced a huge change in our society, particularly with the emergence of the internet. It has done so principally by competing with traditional activities and providing compelling new alternatives. Digital activities potentially have a much smaller environmental impact than similar activities in the physical world.[10] At the same time, a shift from physical to digital is often preferred by consumers. This is a win-win situation: our environmental impact is reduced and our convenience increases.

Morocco: Cyber Café

Consider music sales from a conventional store or via the internet. With the latter, there is no physical storefront to maintain and no physical media to manufacture or transport. Online music is also undeniably popular, with an estimated US$2 billion spent on downloadable music online in 2006.[11] Online grocery shopping also compares favourably to visits to the supermarket in a car: deliveries to the same neighbourhood may be consolidated and the shop itself no longer requires any facilities to support the consumer. Digital alternatives are already emerging in the developing world too, where mobile phone networks are erected instead of fixed-line services, and air-time is used as the basis of trade in lieu of traditional currency.

Of course, the digital infrastructure has an environmental and economic cost, but this should become less significant with improvements in efficiency and as the number of online activities increases. The interesting fact about online shopping is that it is rapidly growing in popularity without environmental legislation. For many people, the online option is simply more compelling than the conventional alternative - the environmental benefit is an unexpected bonus. However, a new technology can also have a negative impact on the environment. For example, many companies have seen the use of teleconferencing increase the demand for travel because people have a desire to meet their co-workers in person. Computing is a tool which can reduce our impact or allow us to increase it. We must be vigilant, and examine in detail how computing is used and measure the emergent effect.

The shift from physical to digital is not restricted to goods, but can also be applied to people and services. Online virtual worlds have recently experienced explosive growth - by April 2008 Second Life had 13 million registered residents. Large corporations are exploring the use of virtual worlds to help employees collaborate and communicate without leaving the office. Some run their own worlds within their private networks, others rent space in worlds such as Second Life. The virtual worlds of the future may well provide an immersive environment in which we shop, socialise, travel and create wealth without significant burden on our planetary resources. A virtual world might even be able to support virtual tourism - for example, a local guide could take a mobile computer together with a high-resolution video camera and give a personalised tour of a distant place of interest.

Conclusion

The Cambridge EDSAC (electronic delay storage automatic calculator), one of the world's first computers, ran its first program in 1949. Since then, computing has changed itself and society beyond all recognition. Our vision is of another revolution, which we hope will benefit every person on the planet: with an optimal digital infrastructure we seek to improve the efficiency of our existing computing platform but also to manage the demands of computing to meet the constraints of our future energy supply. We envisage global sensor networks that help us optimise our use of resources. Theoretical analysis of computer models should provide scientists with a more accurate and trustworthy view of the future. And compelling digital alternatives to current activities could reduce mankind's environmental impact while providing equally rewarding experiences.

Computing provides the opportunity for an unbounded upside. If everyone can shift their activities to a virtual world then there is huge potential for growth and innovation whilst reducing environmental impact. To achieve this we must ensure that the world's computing platform is efficient, effective and appropriately applied.

Andy Hopper, Andrew Rice and Alastair Beresford are in the University of Cambridge Computer Laboratory, Cambridge, UK. Andy Hopper was the founder of Acorn Computers and has launched numerous high-tech start-up companies. He is a Fellow of The Royal Academy of Engineering and was made a Fellow of the Royal Society in 2006.

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Profile: Ayisi Makatiani: Engineer turned entrepreneur

Ayisi Makatiani is head of Fanisi Fund Management LLC, a fund management company to be established in 2008 to invest in small and medium-sized enterprises (SMEs) in East Africa. Previously he was head of the African Management Services Company (AMSCO), founded by the International Finance Corporation - the World Bank's private-sector arm - the UN Development Programme, and the African Development Bank. Mr Makatiani obtained a degree in engineering from Massachusetts Institute of Technology (MIT) before setting up Africa Online, which became the continent's largest internet service provider. Mr Makatiani is also an adviser to the President in Kenya and was a member of the UN Secretary General's Taskforce on ICT. Voted one of the top 10 CEOs in East Africa several times, Ayisi Makatiani is both a Global Leader for Tomorrow and a Young Global Leader at the World Economic Forum.

What's the main focus of your work at the moment?

My focus at the moment is a new African business investment fund, Fanisi, which I am establishing with European and American partners. Our aim is to persuade all potential investors to provide additional funds, in recognition of the tremendous opportunities that now exist in Africa.

We will be concentrating on the SME sector, which suffers from a financing gap. Investors have tended to focus on large-scale investments - US$10 million or more - and on micro-enterprises at the lower end of the market. We will be targeting the 'missing middle', the small businesses that are looking to grow. We will be looking to invest around US$0.5 million to $3 million in SMEs in Kenya, Uganda, Tanzania and Rwanda.

Why is this sector important?

We know that there are many growth-oriented small businesses with good ideas and good prospects, particularly in technical areas. These SMEs can make a significant contribution to a country's economy. They help upskill labour forces and provide many economic and social benefits. What they have not been so good at is interacting with the investment community - that's where Fanisi comes in.

Where do you think the major challenges lie?

Many SMEs are based on good ideas and are run by innovative and driven individuals. But they often lack the business skills that would enable them to develop and grow. Their organisation and approach to corporate governance may be lacking. They don't yet appreciate what investors are looking for and don't fully understand how to work with investors.

Fanisi is a general fund, so we will be investing in the full range of sectors, including engineering and technology. Our aim will be to work with talented and driven entrepreneurs and work with them to bring them up to speed, helping them to grow their businesses and build value. We'll be supplying expertise and technical assistance, when needed, as well as financial support.

My previous company, AMSCO, supplies business services to SMEs in Africa. We wanted to help small firms to become competitive at home and abroad by offering management help and on-the-job training. Many businesses are founded on good ideas but struggle because they lack management skills and experience.

AMSCO sources relevant management expertise, from Africa and elsewhere, and puts them in place in companies for extended periods, up to several years. This kind of input can make a huge different - at Omnium Mali, a firm that makes environmentally friendly batteries, an AMSCO manager was able to increase production by 45% and reduce the product failure rate from 5% to less than 1% in a few months, by training workers and improving procedures. Those skills are passed on and survive in the company.

How did your career get started?
I was studying at MIT and wanted to stay in touch with my home country, Kenya. A couple of friends and I set up an email system by linking a machine in Kenya with one in Boston. We soon realised there was a big demand for web-based services and went on to establish Africa Online, which was eventually bought by Prodigy.

Information technology has the potential to make a huge impact in Africa, by enabling companies to join the digital economy at low cost. We need to plug Africa into global broadband networks as rapidly as possible and make sure we have enough trained engineers to maintain, grow and exploit digital resources.

What kind of skills or qualities do you need to be a successful engineering entrepreneur?
Technical knowledge is important but on its own it is not enough to make a business successful. Business skills are just as important. Unfortunately, those skills are not yet well developed across Africa. So as well as enhancing capacity in science and engineering skills we need to make sure that this is accompanied by a corresponding development in entrepreneurship and small business management.

How important do you think engineering is to development?
It's crucial. Engineering and innovation are at the heart of wealth creation, and sustainable wealth creation should be at the heart of development. By making profitable companies, you develop countries.

Africa from space

Who's teaching whom? Opportunities for two-way learning in South-North engineering partnerships

Paul L Younger

Technology transfer in international development is generally assumed to be a one-way street: industrialised nations of the North export their supposedly superior technologies and organisational priorities to the under-developed nations of the South. However, there is much that engineers in the North might learn from their colleagues in the South. Moreover, there is a pressing need to encourage such two-way learning if engineering is to play its part in tackling the impending global crises in natural resources management.

Pro-poor engineering aims to deliver infrastructure and services to individuals and communities in a manner that yields obvious and significant net benefits to the poorest people. Successful pro-poor engineering projects are generally characterised by the following three hallmarks:[1]

- They can be used by small communities and enterprises as well as larger ones;
- They require only modest capital investments and are not dependent on costly external inputs;
- They are relatively simple to use.

Where these hallmarks are absent, system failure often ensues, usually for want of expensive spare parts or realistic maintenance programmes. Sadly, many donor-funded engineering projects in developing countries fail in just this way. Nevertheless, numerous well-funded international aid programmes have delivered genuine pro-poor engineering solutions - the activities of the UK charity WaterAid being a well-audited example.[2] Successful programmes typically have an unswerving commitment to embedding development projects within the communities they are intended to benefit. As such, they build upon self-help principles that are still the norm in parts of many poor countries.

Self-help versus technocratic dependency

Self-help approaches often have deep roots in local cultures. A good example is the traditional social arrangement known as 'cargo' which flourishes in the Andes of Bolivia and Peru.[3,4] Cargo is a system whereby communities develop and maintain their own local public works. Cargo is based on a reciprocal principle known as 'hayma' - where entire communities voluntarily work to the benefit of other communities, on the implicit understanding that the favour will be returned at some time in the future.

The continued vigour of hayma and cargo in the Andes has, ironically, been bolstered by the historic weakness of formal governmental and commercial structures. Having little faith that governments based in urban areas will do anything significant on their account, the rural peoples of the Andes have maintained their ancestral practices as the principal means of providing infrastructure at a scale beyond that manageable by individual families.

In most countries of the North, models of social organisation similar to hayma did exist historically. The inter-community collaboration that persisted until recently in the Outer Hebrides is one example. However, this approach has more or less disappeared. Population growth, coupled to the ascendancy of centralist models for social and political organisation, led to the development of large state bureaucracies which promised citizens cradle-to-grave provision of all of life's necessities: shelter, food, water and health care. The direct participation of individuals and communities in the development of infrastructure was replaced by a dependency on centrally managed public services.

While social welfare provision has yielded innumerable benefits in public health and education, it has also led to the development of what may be termed a 'technocratic dependency culture', in which individuals no longer have any formal role in the provision and management of essential infrastructure - except occasionally visiting polling stations to elect representatives. When the centralised provision of life's necessities fails, individuals have two obvious courses of action: they can harbour their resentment and vote against their representatives at the next election (possibly years away); or they can write letters of complaint and hope their elected representatives will exert pressure on the ultimate decision-makers. Neither action has any guarantee of success; both are inherently slow. By contrast, in communities of the South which still have traditions such as hayma - or its better-known South African counterpart ubuntu - a third possible course of action exists: do it yourself.

Hand-augering new well near Mariscal Santa Cruz

DIY development

Bolivia is the poorest country in South America.[5,6] More than two-thirds of the Bolivian population still live in severe poverty,[7] with nearly 30% of the population subsisting on less than US$1 per day. Some 23% of the Bolivian population are malnourished (compared with an average of 12% for Latin America as a whole), and infant mortality is very high, averaging 75/1,000 live births (2001 figures), with even higher figures in rural areas.

It is within this unpromising context that the subsistence-farming communities of Aymara people in the central Altiplano region have sought to improve their living conditions. The immediate spur was the major drought of 1983, which caused acute food shortages and led to the death of more than 90% of livestock. Many people migrated to the cities to avoid destitution. However, living conditions for the urban poor are also grim, with inadequate accommodation, sewerage and medical services. As a result, several voluntary initiatives were launched to improve living standards in the rural areas. One such initiative is the programme of village-level development run by an Aymara non-governmental organisation (NGO) known as YUNTA, with which I had the privilege to work in the early 1990s.[8]

YUNTA's programme is based on the development of local ground water resources for both potable and agricultural uses. Its modus operandi is based on the principles of hayma and cargo. Only where a local community is sufficiently organised and dedicated to take the initiative in seeking to develop more secure water supplies will YUNTA become involved. Conversely, where internal cooperation within communities breaks down, YUNTA will withdraw its support. The golden rule is: no community commitment, no YUNTA involvement.

Final stage of comissioning a new well, drilled by YUNTA in a school playground in Papel Pampa, Provincia Villarroel

YUNTA facilitates locally led development in several ways. Firstly, it will broker external funding (principally obtained from international aid charities) to supplement local economic inputs. YUNTA has a strict rule that it will never provide 100% of the resources of any engineering project. Rather it insists that partner communities provide substantial contributions, both monetary (where possible) and 'in kind' (labour, materials and land). YUNTA also provides the engineering expertise and equipment needed to develop water and irrigation systems that the communities have themselves championed. Once an engineered system is established, the community elects a dirigente who holds primary responsibility for organising maintenance, in accordance with the principles of cargo and hayma.[4]

Working in this way, within ten years of the 1983 drought YUNTA had helped more than 60 communities in the Villarroel Province of the Altiplano to develop water and irrigation infrastructure. Having spent a year working in this programme as a groundwater engineer, I returned to the UK with a transformed conception of what communities can achieve, even in the total absence of help from centralised public authorities.

My native district is the North-East of England, and in particular the region formerly known as the Great Northern Coalfield. Immediately after my return to the UK, the national government announced that it intended to close the last five collieries in this coalfield. Furthermore, closure of the collieries would be rapidly followed by the demolition of nine pumping stations which prevented water inundating the last working mines. The mine workings would therefore be left to flood - even though this would inevitably lead to extensive water pollution.[9] Such pollution was already in evidence in the western parts of the Durham Coalfield, where the last working mines had closed in the early 1970s. In that area, the key issue was remediation of local watercourses contaminated by discharges from already abandoned mine sites.

Polluted water at the Quaking Houses site, heavily contaminated with aluminum

Such was the case at Quaking Houses, a village that lost its source of income with the closure of the nearby Morrison Busty Colliery in 1972. Although ravaged by unemployment thereafter, the village retained a lively community spirit. However, just when the pit heaps had been grassed over, and the noise and dust of mining days had begun to fade in people's memories, the local stream became very visibly contaminated due to rejuvenated run off from the pit site. The water was strongly acidic, with very high concentrations of iron, aluminium, zinc and sulphate. As in most similar cases, the stream bed became heavily coated with orange-red ochre (ferric oxyhydroxide), with floating masses of white froth (aluminium hydroxide spume). Generations of children had played around the stream where it flows past Quaking Houses village. Now the ochre in the stream indelibly stained children's shoes and clothes. The situation was exacerbated by occasional sewage discharges from a decaying drainage system near the old mine.

Residents of Quaking Houses wrote letters of complaint to the relevant public authorities. However, because of a clause in the relevant legislation, inserted by the UK Government when it was (through the National Coal Board) the largest mine owner in the country, public authorities had no obligation to address mine water pollution.

At this point I mentioned my experiences with YUNTA in Bolivia. My challenge to the residents of

The completed full-scale wetland treatment system at Quaking Houses built by local community volunteers

Quaking Houses was thus: if we can obtain the necessary resources to tackle the pollution of the Stanley Burn, would you be prepared to put down the pen and pick up a spade? The residents responded in the affirmative. The engineering solution that we finally developed was the first of its kind in Europe: it was based on the principles of pro-poor engineering, and finally took the form of a wetland (in which the most important processes occurred not in the visible parts of the system, but in the subsurface). In addition to the wetland construction activities, an allied programme of public arts and education work was undertaken, successfully drawing in local schools, youth clubs and interested individuals in the common endeavour of restoring life to the Stanley Burn.[10] The project as a whole won the UK Conservation Award for 1998, and gave rise to a sustained programme of research that eventually won the Queen's Anniversary Prize for Higher Education for Newcastle University in 2005.

In a particularly satisfying epilogue, lessons learned about mine water remediation at Quaking Houses were later taken back to Bolivia, where similar problems exist in former tin mining districts.[11] The key message here, however, is that South-North transfer of concepts of community-led engineering interventions proved key to breaking the inertia which had developed due to the disempowerment of communities within the framework of natural resources management in the 'mature' democracy of the UK.

Facing the coming crises together

Is the example given above an isolated case, or is there really scope for two-way learning in South-North partnerships in engineering? Not only is there scope - it is an increasing necessity. Humankind faces unprecedented challenges as our population grows and the consequences of centuries of laissez-faire attitudes to natural resource stewardship finally come home to roost. Conflicts over access to, and conservation of, sensitive habitats grow ever more intense.[12] And it is precisely the poorest communities who are most vulnerable to even modest changes in, for instance, the availability of water, fish stocks, or soil fertility.

While much discussion in the media lately has focused on 'peak oil',[13] it is also becoming increasingly apparent that un-mined reserves of several crucial metals will be significantly depleted within a few decades.[14] An important recent study reached the alarming conclusion that 100% deployment of all existing or reasonably foreseeable renewable energy technologies will not be sufficient to support a consumer society for even the present world population, let alone for the 50% greater population that is expected later this century.[15]

The corollary of this important finding is that, in addition to working with the world's poorest communities to enable them to achieve decent standards of living, we must also begin to address social transformation in the consumer societies of the North. It is impossible to see how the challenges of the future will be met by anything other than a re-establishment of a more geographically distributed, community-focused, 'self-help' approach to the creation and management of essential infrastructure. As this realisation spreads amongst engineers in the North, it will be to our engineering colleagues in the South that we will need to turn, to re-learn from them important lessons on genuine participatory approaches and appropriate technologies that have long since been forgotten in the throw-away cultures of Europe and North America.

Paul L Younger is Pro-Vice-Chancellor (Engagement), University of Newcastle, UK. He is an environmental engineer, with more than 20 years' experience in groundwater engineering in five continents. In 2005, the work of his research team won for the University of Newcastle the Queen's Anniversary Prize for Higher Education. He was elected a Fellow of The Royal Academy of Engineering in 2007.

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Pollution solution: Clean-up of contaminated sites in developing countries

H R Thomas, A M Koj, M Eisa and A O Ajani

Protection of the environment is recognised as an increasingly important aspect of sustainable development. Many countries, developing nations among them, now face the legacy of past generations' industrial and domestic activities, in the form of contaminated land and stockpiles of hazardous chemicals. Careful disposal of such materials is essential, yet few developing countries have either the resources or technical expertise to tackle disposal. A project linking a centre of excellence in Cardiff, UK, with sites in Ghana and Nigeria aims to build capacity in these countries - and to act as a regional model for other countries facing similar problems.

The preservation of a sustainable geo-environment is an issue of major concern to governments and environmental agencies. The pursuit of economic development, for the benefit of a nation's population, may not always be compatible with the pursuit of environmental preservation. Past problems range from the contamination of land and groundwater due to industrial activity, to inefficient and ineffective waste disposal. Much research is now being pursued worldwide to address these problems.[1]

The extent of the challenges faced differs from country to country. Typically, developing countries face not only acute problems but also high costs and a lack of capacity to deal with their environmental issues.

One problem of concern to all nations is that of persistent organic pollutants (POPs). In the early 1960s, mink ranchers in the northern parts of the USA and Canada noticed that their animals were dying or suffering reproductive complications. This was found to be linked to maternal consumption of salmon contaminated with polychlorinated biphenyls (PCBs) from the Great Lakes. At the same time, polar bears around Svalbard were found to be contaminated with PCBs at levels greater than those linked to reproductive failure in the mink. These and other observations were captured in Rachel Carson's landmark book Silent Spring.[2] Carson drew an association between the large volumes of DDT sprayed in the USA in the 1950s and 1960s and the decline of songbird populations - hence the 'silent spring'. Carson's book did much to focus the world's attention on these environmentally ubiquitous and persistent pollutants.

Worldwide, the World Health Organisation (WHO) has estimated that as much as 24% of global diseases could be attributed to environmental factors, including exposure to chemicals.[3] The World Bank has highlighted how management of chemicals can contribute to several Millennium Development Goals.[4] Poor people are particularly vulnerable to chemical risks, and areas as diverse as agriculture, fishery, health, energy, mining, water and sanitation may involve exposure to POPs covered by the Stockholm Convention.

As an indication of the scale of the problem, Ethiopia has one of the largest stockpiles of obsolete pesticides in Africa, with approximately 3,000 tonnes stored at 1,000 sites.[5] In Arjo, a small Ethiopian village, some 5.5 tonnes of old pesticides, such as malathion, DDT and other POPs, are stored in boxes, drums and bags, some of which have been breached and begun to leak. Similarly, in Mexico, it has been estimated that, between 1969 to 1979, 3,900 tonnes of DDT and 2,500 tonnes of endrin were produced per annum.[6] A recent study in Slovakia concluded that, of 4,000 tonnes of PCBs produced, 960 tonnes remain in use and 2,700 tonnes are unaccounted for.[7] Therefore, there is potential for significant community exposure to POPs.

Box 1: Industrial and other processes generating persistent organic pollutants

- **Manufacturing,** including chemical manufacturing (e.g. chlorinated chemical production oil refining and catalyst regeneration, pulp and paper processes) and the manufacturing of products that involves the use of materials contaminated with Persistent Toxic Substances - for example textile manufacturing.
- **Thermal processes,** including municipal (non-hazardous) waste incineration, coal combustion, metallurgical processes such as sintering of iron ore for blast furnaces and cable burning, coke production and carbo-chemical processes, mineral processing such as asphalt mixing, and uncontrolled processes such as forest fires.
- **Product use,** including pesticides and herbicides, preservatives for wood, leather, textiles, industrial bleaching processes, especially using chlorine, and solvent use e.g. dry-cleaning, de-greasing.
- **Recycling processes,** such as paper, metal, electronic scrap and circuit board, refrigerator and waste oil recycling, solvent recovery processes
- **Waste disposal** (non-thermal), including landfills, storage/stocks of transformers containing PCB-oil, ocean dumping of solid/sludge/liquid wastes

Although there are some natural sources of POPs, such as volcanoes, by far the most significant sources are industrial production and the by-products of combustion and other industrial processes (such as waste incineration, the metal industry, transport and home heating). Accordingly, the United Nations Environment Programme (UNEP) has developed a list of the main processes, by sectors, likely to be sources of POPs (Box 1).

Aware that POPs pose a major and an increasing threat to human health and the environment, in May 1995 the Governing Council of UNEP requested that an international assessment process be undertaken of an initial list of 12 POPs - the 'dirty dozen' (Box 2).

To minimise the impact of POPs and protect the environment, a number of control programmes have been implemented, including the Stockholm Convention on Persistent Organic Pollutants, a legally binding global environmental agreement adopted in May 2001 in Stockholm, Sweden.[8] The Stockholm Convention, signed by 151 countries, provides a framework to reduce or eliminate the production, use, import and export of the 'dirty dozen', as well as guidelines on their safe handling and disposal. The Convention also contains a mechanism for including additional chemicals subsequently identified as persistent organic pollutants.

Signatory countries are obliged to prepare national implementation plans - formal planning documents that

Indonesia: volcano emitting hot ashes and gases containing dioxins and furans into the atmosphere define a country's commitments, current situation and the actions it plans to undertake in POPs management.

The importance of POPs-related problems is well recognised in most developed countries, which have the legal, financial and technical solutions needed to implement the Stockholm Convention. Most developing countries, by contrast, lack both the necessary resources and institutional structures. These countries require significant assistance, especially in capacity building, to enable them to develop legal frameworks and financially sustainable mechanisms for addressing the problems posed by POPs.

Box 2: Persistent organic pollutants targeted by the United Nations Environment Programme

1. Aldrin	7. Chlordane
2. DDT	8. Dieldrin
3. Dioxins	9. Endrin
4. Furans	10. Mirex
5. Hexachlorobenzene	11. Heptachlor
6. PCBs	12. Toxaphene

Financial support to enable countries to implement their national plans is provided by the Global Environmental Facility, part of the World Bank System.

A West African example

While most developing countries banned the use of POPs decades ago, they are still burdened with obsolete stocks of POPs pesticides. These may be lying in unattended warehouses or buried underground, without proper records or protective or monitoring measures. As well as disposing of stockpiles, countries face the related problem of cleanup of POPs-contaminated sites. If redeveloped or redeployed for agricultural or housing purposes, such sites could pose significant threats to human and animal health.

Ghana and Nigeria are two countries that have attempted to address these issues. Both are signatories of the Stockholm Convention, and both have developed national implementation plans. Inventories in both countries identified several hundred metric tonnes of stockpiled or obsolete pesticides, which may include POPs pesticides. Sites of stockpiles need to be investigated for possible soil and groundwater contamination.

There are several potential sources of POPs in Ghana and Nigeria. These include locations where electrical equipment, particularly transformers and capacitors, were serviced, poorly designed and maintained storage sites, and places where POPs wastes might have been dumped, along with other hazardous or domestic waste. Waste discharges from chemical plants using elemental chlorine may also release POPs into the environment, as may former organochlorine pesticide manufacturing or formulation plants. Sewage sludge treatment plants are a further potential source of POPs. Finally, POPs may also be produced by Ghana and Nigeria's vibrant mining and oil-producing industries and other chemical industries.

On the basis of the ongoing national implementation plans, Ghana and Nigeria approached the United Nations Industrial Development Organisation to assist them to:

- develop policies and regulations for the rehabilitation of contaminated sites;
- build capacity in identifying contaminated land and in the selection of methodology for site remediation;
- establish a public education programme;
- set up an information management system;
- at a later stage, through public-private partnership and support from other donors, promote proper clean up of sites, using remediation technologies conforming to best available techniques and best environmental practices

The project

The Geoenvironmental Research Centre at Cardiff School of Engineering is acting as a technical partner in the project, making available its expertise and technical facilities to centres in Ghana and Nigeria.

The project aims to build capacity in Ghana and Nigeria, so the two countries can develop strategies to identify and deal with sites contaminated with POPs. As well as enhanced technical capacity building, enabling policy and legal frameworks need to be established, and systems put in place to enforce new legislation. Information collection and dissemination is an important feature, so an information management system is also being developed. This system will also include social economic indicators affecting human health and the environment, which will enable the countries to assess the socio-economic impact of POPs-contaminated sites. A regional monitoring and evaluation plan is also being developed.

POPs-contaminated land (and other sources of exposure, such as stockpiles) will be identified and monitored, and samples analysed. Finally, model experiments will be set up to explore possible environmentally and economically acceptable remediation technologies. This work will feed into the development of a 'toolkit' to guide choice on suitable approaches for remediation in different circumstances.

A key feature of the project is the establishment of Geoenvironmental Centres in both Ghana and Nigeria. These in turn will be linked to the Geoenvironmental Research Centre at Cardiff. The Centres will play a key role in enhancing Ghana and Nigeria's technical capacity to identify contaminated sites, develop environmental indicators to support priority setting based on risk assessment and management, and develop capacity to select suitable low-cost technology for remediation of POPs-contaminated soil.

Special emphasis will be given to particularly badly affected sites in both Ghana and Nigeria, where pilot-scale studies of low-cost remediation technologies will be carried out. Past experience in the US 'Superfund' exercise, and lindane decontamination in The Netherlands in the 1960s, suggests that land remediation is an expensive undertaking, particularly for developing countries. Remediation costs are around €100-300 (US$150-450) per metric tonne, depending on the degree of contamination, technology used, and the extent of clean up required.[9] This project will investigate whether these costs can be lowered while still delivering remediation technologies that are usable and environmentally acceptable. The project will also assess whether such low-cost technology deployment would be affordable in the context of private-public sector participation.

Throughout the planning of the project, considerable emphasis has been placed on stakeholder participation. This will continue throughout the project, through workshops, the use of the information management system and ongoing dissemination of information. Public awareness and environmental education programmes will be organised by NGOs and government ministries. Participation of stakeholders and environmental education in the two countries should help to ensure that there is a good public understanding and awareness of POPs contamination and remediation of POPs-contaminated sites.



Remediation of POPs contaminated site, DDT spraying for insect vector control, PCB-contaminated creek

Conclusions

POPs are a significant problem in developing countries. The project discussed here reviews one possible regional solution. As well as the commitment of the countries themselves, the United Nations Industrial Development Organisation has an important role to play, as a regional catalyst. Also crucial is the Geoenvironmental Research Centre at Cardiff University, which is helping to build capacity through links to two new Geoenvironmental Centres in Ghana and Nigeria. These new Centres will act as focal points for the development of technical and other expertise in each country.

Most countries with developing economies lack the technical capacity to dispose of obsolete stocks of POPs and remediate POPs-contaminated soils. The criteria and guidelines established in this project therefore provide a model that could be applied in other countries in the region.

H R Thomas and **A M Koj** are in the Geoenvironmental Research Centre, Cardiff School of Engineering, Cardiff, UK; **M Eisa** is at the United Nations Industrial Development Organisation and is a Visiting Professor at the Geoenvironmental Research Centre, Cardiff School of Engineering, Cardiff, UK;, **A O Ajani** is at the United Nations Industrial Development Organisation.

H R Thomas is professor of Geoenvironmental Engineering and Founder Director of the Geoenvironmental Research Centre. He was elected a Fellow of The Royal Academy of Engineering in 2003.

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Engineering resilience: Disaster risk reduction in the developing world

Jo da Silva

Engineers have a crucial role to play in disaster recovery, helping to get a region or country back on its feet as quickly as possible. Traditionally, engineers have been drafted to help because of their practical skills, yet they can potentially offer much more. And rather than just being part of a reactive response to disaster, engineers can play a much bigger role in preventing disaster, by reducing exposure through planning and design and by providing access to essential infrastructure. The goal is more resilient communities better able to cope with environmental challenges and change.

Earthquakes, volcanic eruptions, cyclones and hurricanes, tsunamis, landslides and flooding can be sudden and devastating. As well as the immediate loss of life, destruction of infrastructure and loss of agricultural land can lead to a second wave of hardship, including loss of livelihoods, mass displacement of people and epidemics of infectious disease.

Although not restricted to the developing world, poor countries are disproportionately affected - 97% of deaths from natural disasters are in the developing world[1] - and often lack the resources to mount large-scale responses. International aid can be mobilised to provide emergency relief, and engineers can be an important part of this response. But is this the limit of our involvement, or should we be looking to play a more active role, particularly to prepare communities for extreme events?

In the beginning…

More than 25 years ago, Professor Peter Guthrie OBE FREng, Professor of Engineering for Sustainable Development at Cambridge, was among those who realised that engineers had valuable skills and experience that could be applied in post-disaster relief efforts. He founded Registered Engineers for Disaster Relief (RedR),[2] which provided a way in which humanitarian agencies could access trained and experienced personnel after disasters. At the time the value of engineers in relief efforts was not widely recognised, but is often crucial. By providing clean drinking water and sanitation in refugee camps, such as Goma, which housed more than a million people fleeing the Rwandan genocide, engineers have saved thousands of lives by preventing spread of infectious disease. Engineers are responsible for reconstruction of roads so aid conveys can reach devastated areas with food and medical supplies. They have also contributed through development of emergency shelters, including makeshift hospitals, schools and distribution centres

Valuable though these activities undoubtedly are, there is a tendency to pigeonhole engineers primarily as technicians, offering practical skills. But engineers have much more to offer - particularly their planning abilities. Engineers are not just theorisers: they are skilled in problem solving and project management, from inception to delivery. Inherent in this is their ability to build effective teams and to drive operations around common goals. All these skills are immensely valuable in crisis situations.[3]

By the mid-1990s, thanks to the work of RedR and others, engineers had come to play a valued and respected role in disaster relief efforts. But the whole area of disaster relief has been undergoing a sea change, for several reasons. Foremost is the increasing number, complexity and scale of disasters - a result of heightened vulnerability due to population growth, urbanisation and environmental degradation, as well as changing patterns of extreme events, particularly those linked to weather.

Moreover, natural disasters have become more directly linked to the broader development agenda.

Earthquake Reconstruction, Pakistan, Kashmir Schools Rebuilding project © Arup

As well as the loss of life, the economic costs of disasters can be considerable, not just directly through loss of infrastructure but also indirectly, for example by their effects on employment and trade. A disaster can set back development by years and slice off several per cent of GDP. Dealing with a disaster can also divert funds away from much-needed longer-term development projects to tackle immediate emergencies. In Bangladesh, for example, dealing with the effects of Cyclone Sidr has led to money being channelled away from efforts to provide clean drinking water in other areas. Disasters can also lead to conflict and a loss of social cohesion. They may promote inequity, with affected regions lagging behind those less badly affected, or foster simmering resentment if some areas are thought to be receiving special treatment.

The Hyogo Agreement

In January 2005, world leaders gathered in Japan to sign the 'Hyogo Agreement', in some ways disaster relief's equivalent of the Millennium Development Goals.[4] The agreement placed disaster risk reduction at the heart of development. Disaster risk reduction took the process one step back - the emphasis was not just on emergency relief but also on prevention and mitigation, awareness and preparedness: what can be done to ensure natural hazards do not become human catastrophes?

Earthquake Resistant Construction, Pakistan © Arup

In the developed world, the engineering community has had considerable experience designing around powerful natural forces. Coastal defences protect seaside communities, buildings in seismically active zones are designed to withstand earthquakes (or, failing that, to collapse in controlled ways). In The Netherlands, the realisation that building on flood plains was inevitable has led to the development of floating buildings - analogous, perhaps, to the stilt houses of the Mekong delta in Vietnam.

Traditionally engineers have adopted 'hard' engineering solutions, which attempt to keep nature at bay, through use of solid structures or brute force. The danger of this approach is that when design

UNHCR Post-Tsunami Shelter Programme, Sri Lanka © Arup

forces are exceeded, failure can be catastrophic - as seen with the levees in New Orleans following Hurricane Katrina. Also, since design parameters have been based on historical data, they may become out of date because of changing trends and the unpredictability of climate change. By contrast, 'soft' solutions try to work more with nature than against it, for example using sand dunes or mangrove plantations to ameliorate impact. Somewhere in the middle are strategies that allow for a degree of damage, for example with sacrificial elements that preferentially fail but allow the bulk of a structure to survive. There are stilt houses in the Mekong delta which also have woven raffia walls which can be rolled up when a severe storm is expected, so winds blow through houses rather than blowing them away.

Typically, protective infrastructure is expensive and the impact of a natural hazard can be greatly reduced much more cheaply by ensuring people are forewarned. When the great tsunami of Boxing Day 2004 hit the island of Simeulue, just seven people out of 78,000 living in predominantly coastal communities were killed, even though hundreds of thousands of people lost their lives elsewhere. So few lives were lost because the population fled to higher ground when they saw the sea retreat - a sign that a tsunami was on its way. This folk knowledge - 'smong' - had been passed on from generation to generation following a catastrophic tsunami in 1907.[5] Today, there is an increasing emphasis on the importance of schools in disaster preparedness, ensuring they are designed to withstand extreme events and that awareness of natural hazards forms part of the curriculum.

Early warning systems can thus save thousands of lives - and don't necessarily need to be expensive high-tech solutions. In Bangladesh, the deaths of 300,000 people in 1970 led to the establishment of a network of Red Crescent-trained volunteers who cycled around the country warning residents of the arrival of a cyclone. Thanks to their efforts, just 3,500 people died when Cyclone Sidr hit land in November 2007. Two million Bangladeshis were protected within 1,800 cyclone shelters and 440 flood shelters. In stark contrast, Cyclone Nargis resulted in at least 130,000 fatalities when it hit an unprepared Mynamar in May 2008.

Using knowledge

A greater understanding of natural hazards, when they are likely to strike and how to mitigate their impact is critical to reducing the risk of disasters. The El Niño Southern Oscillation, for example, periodically brings severe weather to tropical regions, and an awareness of when it is likely to strike can enable vulnerable populations to take steps to mitigate its effects.

Industrialised countries have developed a significant body of knowledge of how to reduce losses - of human life and infrastructure - because of natural disasters such as earthquakes. The value of this knowledge is well illustrated by a comparison of the impact of the 1906 San Francisco earthquake

(3,000 dead, half the city destroyed) and the Loma Prieta earthquake of 1989 (63 deaths, 1,018 buildings lost). Although Loma Prieta was a less extreme event, it was the significant advances in seismic engineering, leading to the progressive development and application of effective building codes, that led to the collapse of so few buildings and loss of so little life.[6]

Equally important are the advances in technology that now allow detailed hazard mapping, information that can be overlaid on numerous other data sets to identify vulnerable groups and locations and inform strategic planning. In Hong Kong, for example, maps of seismic vulnerability have been overlaid with patterns of housing stock to identify vulnerable buildings and prioritise a replacement programme, as well as influence planning policy. Remote satellite imagery was used after the Pakistan earthquake in 2005 to assess the extent of damage in remote valleys and inform the relief and reconstruction effort.

Although building codes and planning policy are both recognised as effective mitigation tools, there are critical gaps in their availability and use in many hazard-prone countries. Where they do exist, they vary substantially in their quality and how rigorously they are enforced. When Hurricane Louis hit the Caribbean island of Saint Martin in 1995, the French part of the island suffered less than the Dutch side, even though it bore the brunt of the storm, because building codes had been more strictly enforced. Codes are often imported and frequently do not reflect local circumstances and building technologies. In Indonesia, for example, seismic codes were introduced for the growing numbers of concrete and steel multi-storey buildings, but exclude single-storey constructions such as housing or schools - which are far more common and vulnerable to earthquake damage. The same is true in Peru, where a survey by the Earthquake Field Investigation Team of the Institute of Structural Engineers following the 2007 earthquake found that there are no standards for the design of traditional adobe buildings.[7]

Much of the discussion following Hyogo has centred on innovative financial mechanisms, ranging from micro-insurance for home-owners to macro-insurance schemes such as the Caribbean Catastrophe Risk Insurance Facility to transfer or share risk. There is scope to provide financial incentives through reduced premiums which promote compliance with planning policy, good practice design and construction quality and actually reduce risk.

Ironically, disasters provide an opportunity to improve infrastructure quality - the key principle of reconstruction is 'build back better'. It is vital that reconstruction integrates local people and practices, so that key knowledge is transferred and embedded in future practice. As far as possible, reconstruction should plan for the future - but also learn from the past. In Montserrat, a hospital was re-built in 1989 after Hurricane Hugo hit the island. It was located in Plymouth, even though the town had been known for decades to be at risk from volcanic activity. It was destroyed during an eruption just six years later. This illustrates the need to recognise multiplicity of risk, but also the window of opportunity after disasters when there is an incentive to minimise the impact of other hazards. Rebuilding in Aceh after the 2004 tsunami, for example, has in some instances included measures to reduce the risk of earthquake damage and considered evacuation routes, drainage, elevated structures and site selection to protect against floods - both more likely in the future than another tsunami.

Countries can therefore take steps to minimise the impact of severe events. But to do so they need to be equipped to take advantage of available knowledge. Unfortunately, local training is not always geared to local needs. In Pakistan, for example, engineering is seen as a high-status professional field but rarely involves any practical experience, limiting engineers' ability to offer practical advice or willingness to work in the field. In Indonesia, undergraduate engineering education omits design for seismic activity despite this being a major risk. Enhancing the capacity and capability of the engineering community locally through appropriate education and professional certification, and ensuring this includes disaster management, are critical components of disaster risk reduction. The emphasis is on local knowledge, response and ownership, rather than countries being the passive recipients of emergency aid involving international staff.

Recent events in Gujarat, Bam, Pakistan, Indonesia and now China have highlighted the challenges associated with reconstruction, particularly of rural and urban housing. Engineering companies typically have experience in strategic planning and large-scale project management, required for reconstruction. What they may often lack is a detailed knowledge of the local people, culture and environment - something that non-governmental agencies and local governments specialise in. Hence cross-sectoral partnerships present a mechanism to combine respective strengths, and potentially offer a better solution in the future.

The future…

The emphasis in disaster management has thus shifted from reactive response to proactive preparation. Yet a further shift is underway, with a growing awareness that there are significant limitations to formalised planning and preparedness. The impact of any severe event will depend not just on the extent of a hazard and the likelihood that it will happen but also on the vulnerability of the populations affected. Poorer nations and communities are most vulnerable; in the USA the impact of Hurricane Katrina in the USA was felt most severely by low-income populations in New Orleans.

The risk to populations is greatest when they are already stretched. To cope with severe events, communities need to be resilient, so that in the aftermath they can be, as far as possible, 'self-healing'.

Earthquake Reconstruction, Pakistan, Kashmir Schools Rebuilding Project © Arup

Social systems need to be flexible and robust, and to have the capacity to develop strategies for themselves - recovery does not have to be a centralised, top-down thing. Communities generally have their own coping strategies to deal with hardship, and these need to be nurtured and strengthened.

This view brings 'disaster relief' into the territory of classical development. All the things that make a society more resilient are those that have long been advocated by the development community, including access to essential services. Disaster risk reduction needs to be fully integrated into the humanitarian and development agenda, so it is seen as an essential aspect of a country's infrastructure and not as an expensive add-on. The engineering community globally has a significant part to play but this will require innovative ways of working which bring together global expertise and local knowledge.

The future is likely to see an increase in the frequency of extreme environmental events - perhaps not the major catastrophes but more smaller scale yet still damaging challenges. There will still be a need to respond quickly when catastrophe does strike, and to put in place effective monitoring systems and plans to deal with emergencies. But with an uncertain future ahead for the climate, predicting which communities are at risk is going to be difficult. Ensuring as many as possible thus have the power to shape their own futures is absolutely crucial.

Jo da Silva is Director, International Development, Arup. She is a member and former Chair of RedR and a Trustee of Engineers Without Borders UK. She was named Young Consulting Engineer of the Year in 1995, Cosmopolitan Woman Achiever of the Year in science and technology in 1999 and British Expertise Individual of the Year 2006 for her work with UNHCR in Sri Lanka following the tsunami . She is a Fellow of The Royal Academy, and Visiting Senior Fellow at the Centre for Sustainable Development at the University of Cambridge.

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Acronyms

APWEN	Association of Professional Women Engineers of Nigeria
CIGR	International Commission of Agricultural Engineering
CPA	Consolidated Plan of Action for Science and Technology in Africa
DDT	Dichloro-diphenyl-trichloroethane
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
HIV/AIDS	Human Immunodeficiency Virus / Acquired Immune Deficiency Syndrome
IAC	InterAcademy Council
ICT	Information and communication technology
IPCC	Intergovernmental Panel on Climate Change
ISAE	Institute of Agriculture and Animal Husbandry
KIE	Kigali Institute of Education
KIST	Kigali Institute of Science and Technology
MDGs	Millennium Development Goals
NGO	Non-governmental organisation
PCBs	Polychlorinated biphenyls
POPs	Persistent organic pollutants
PPPs	Public-private partnership
R&D	Research and development
SAICE	South African Institution of Civil Engineering
SME	Small and medium-sized enterprise
STEM	Science, Technology, Engineering and Mathematics
TB	Tuberculosis
UKACF	UK Anti-Corruption Forum
UNEP	United Nations Environment Programme
UNHCR	United Nations High Commissioner for Refugees
WFEO	World Federation of Engineering Organizations
WHO	World Health Organisation

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The Royal Academy of Engineering
3 Carlton House Terrace, London SW1Y 5DG

Tel: 020 7766 0600 www.raeng.org.uk

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