The Royal Academy of Engineering

The 2006 Hinton Lecture

Redesigning African Economies

The Role of Engineering in International Development

Speaker: Professor Calestous Juma, FRS

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

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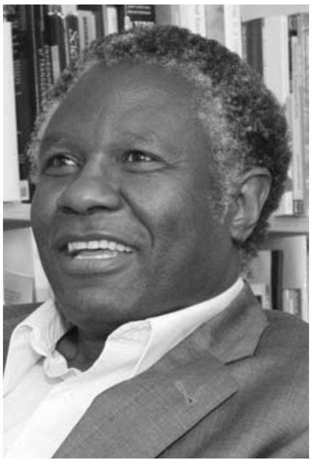

Speaker and Author:
Professor Calestous Juma, FRS

At a time when the Academy has been expanding its international activities, especially in seeking to establish how engineering can assist in tackling world poverty and help achieve the UN Millennium Development Goals, we are delighted to announce a timely and important lecture by Professor Calestous Juma.

Calestous Juma is an internationally-recognised authority in the application of science and technology to sustainable development. He is currently Professor of the Practice of International Development and Director of the Science, Technology and Globalisation Project at Harvard University's Kennedy School of Government. Professor Juma is a lead author in *Innovation: Applying Knowledge in Development*, the final report of the UN Millennium Project's Task Force on Science, Technology and Innovation. He holds a DPhil in Science and Technology Policy Studies from the University of Sussex. Formerly, he was Executive Secretary of the UN Convention on Biological Diversity and founding Director of the African Centre for Technology Studies in Nairobi.

Furthermore, he has served on numerous boards of international agencies and advises several heads of state and government on science, technology and innovation. Professor Juma has made significant contributions to understanding the dynamic role of technological innovation in economic transformation in developing and developed countries. His work on the implications of biotechnology for sustainable development in Africa is widely cited and his achievements have been honoured by his election to several scientific academies as well as numerous awards he has received in recognition of his original work.

Africa's ability to meet human needs, participate in the global economy and protect the environment will require considerable investment in the engineering sciences. More specifically, building capacity in the engineering sciences should be directly linked to infrastructure projects. Academies of engineering will need to play a central role in helping to shape a new vision for the role of the engineering sciences in international development.

Introduction[1]

Development is easier done than said. This inversion of the old maxim reflects the end of an era in which Africa's development was defined largely as a matter for discourse rather than accomplishment.[2] Focus is now shifting from emergency and relief operations to long-term endogenous solutions based on building endogenous technical competence and stimulating local entrepreneurship.[3] In a crucial statement about the future of Africa, *Our Common Interest*—the report of the Commission for Africa chaired by UK Prime Minister Tony Blair—notes:

> "Growth will also require a massive investment in infrastructure to break down the internal barriers that hold Africa back. Donors should fund a doubling of spending on infrastructure–from rural roads and small-scale irrigation to regional highways, railways, larger power projects and Information & Communications Technology (ICT). That investment must include both rural development and slum upgrading without which the poor people in Africa will not be able to participate in growth. And policies for growth must actively include–and take care not to exclude–the poorest groups. There should be particular emphasis on agriculture and on helping small enterprises, with a particular focus on women and young people. For growth to be sustainable, safeguarding the environment and addressing the risks of climate change should be integral to donor and government programmes."[4]

This statement represents a departure from conventional approaches by placing specific emphasis on the importance of investing in infrastructure and the associated human capital development.[5] The term "infrastructure" is used here to mean the facilities, structures, associated equipment, services, and institutional arrangements that facilitate the flow of goods and services between individuals, firms, and governments. Infrastructure therefore includes: public utilities, such as energy, telecommunications, water supply, sanitation and sewage, and waste disposal; public works, such as irrigation systems, schools, housing, and hospitals; transport sectors, such as roads, railways, ports, waterways, and airports; and research facilities, such as laboratories and related equipment. Infrastructure services include the provision, operation, and maintenance of the physical facilities of the types of infrastructure listed above. Infrastructure represents a foundational base for applying technical knowledge in sustainable development and relies heavily on civil engineering. Other economic activities require contributions from other fields, making engineering an interdisciplinary field.

The traditional focus on relief and emergency activities is being replaced by a new focus on competence building to enable Africa solve its own problems. "We know that despite increased aid, trade and debt relief, coupled with improvements in economic growth and governance in Africa, those opportunities will not be realised unless and until the foundations of economic growth—sustained investment, innovation, education, skills, science and technology—are in place and built on over the long term."[6] In other words, development partners need to pay more attention to investing in people and promoting technological innovation rather than simply providing short-term palliatives aimed at reducing the visible symptoms of low levels of economic productivity. This shift will involve building capabilities in key areas related to production, project execution, and technological innovation.

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1 I want to thank Keith Davis and Philip Greenish (Royal Academy of Engineering, London) for inspirational conversations that helped shape this paper. I also want to thank Wm. Wulf and George Bugliarello (National Academy of Engineering, Washington, D.C.), Lee Yee-Cheong (World Federation of Engineering Organizations, Paris), Tony Ridley (Imperial College London), Graham Allison, John Holdren, Henry Lee, Robert Frosch, Bob Bell, Sharon Wilke and Katie Bartel (Kennedy School of Government, Harvard University), Alice Amsden and Apiwat Ratanawaraha (Massachusetts Institute of Technology, Cambridge), David Curry (davidrcurryAssociates, Philadelphia, Pennsylvania), Romain Murenzi (Office of the President, Kigali, Rwanda), Silas Lwakabamba (National University of Rwanda, Butare) and Caroline Wagner (Georgetown University, Washington, D.C.) for their guidance and valuable contributions to this paper. I am also grateful to Lorna Butler (Iowa State University) and Wilf Stevenson (Smith Institute, London) for giving me an early opportunity to outline some of the ideas developed in this paper.

2 "Africa" is used in this paper to mean "Sub-Saharan Africa."

3 "Competence" denotes the ability to perform specific tasks and is used in this paper to reflect the practical nature of Africa's sustainable development challenges. It is a subset of the larger concept of "capacity development." The word "capacity" is often defined by the United Nations to mean the "ability of individuals, organizations and societies to perform functions, solve problems, and set and achieve goals." Anne Whyte, *Landscape Analysis of Donor Trends in International Development*, Rockefeller Foundation Series, No. 2 (New York: Rockefeller Foundation, 2004), p. 24.

4 Commission for Africa, *Our Common Interest: Report of the Commission for Africa*, (London: Commission for Africa, 2005), p. 13.

5 Moses Oketch, "Determinants of Human Capital Formation and Economic Growth of African Countries," *Economics of Education Review*, Vol. 25, No. 5 (October 2006), pp. 554-564.

6 Gordon Brown, "Forward," in Calestous Juma, ed., *Going for Growth: Science, Technology and Innovation in Africa* (London: Smith Institute, 2005), p. 5

Much of the work to build local competence entails training in engineering and related management fields.[7] In the area of industrial production, for example, African countries need to strengthen their production engineering and management capabilities. In other words, the challenge for Africa lies largely in its ability to harness the world's scientific and technical pool and using it to solve local problems. To effectively execute investment projects, African countries need to enhance competence for personnel training, preinvestment feasibility studies, and project implementation. Finally, the countries need to focus on innovative work related to creating new products and processes. Most of the effort involves engineering and its associated management practices.[8] Current investments in infrastructure offer a strategic starting point for building capacity in engineering.

The aim of this paper is to explore the technological implications of the transition to a competence-based development cooperation strategy for Africa. The paper argues that this transition will entail a clear recognition of the role of infrastructure in Africa's sustainable development and focused investment in the associated engineering fields. It departs from traditional approaches (to capacity building) that have focused on independent, short-term training activities; instead, it proposes that new engineering programmes be directly linked to strategic investments in infrastructure development.

This focus on infrastructure is not intended to exclude other economic activities and their associated engineering fields. Similar strategies could be adopted in manufacturing as well. This paper uses infrastructure both as a strategic opportunity, given renewed interest in this field, and as an illustration of the linkages between engineering and sustainable development. The paper concludes by calling for a major global effort to review the key lessons learned in development cooperation in the post-war era, and makes a plea for serious efforts to emphasize the role of engineering in Africa's sustainable development strategies.

This paper is divided into five sections. The first section outlines the role of science and innovation in sustainable development. This is followed by a discussion and specific information of the status of infrastructure in Africa. Section three offers case studies on the role of infrastructure in sustainable development. This is followed by an overview of strategic opportunities for using engineering as a set of tools to reinvent African economies. The paper concludes with specific options for action by academies of engineering and other knowledge-based institutions.

1. Mapping the Terrain

Development cooperation has often been driven by diplomatic considerations that are devoid of serious operational content. Much of what passes for development cooperation is focused on "discourses" about a variety of possible options for development, rather than development action. Even critical issues such as the importance of infrastructure in sustainable development have been the subject of extensive rhetorical debates. These debates have also affected the role of the engineering profession in international development.

Engineering has been marginal to international development practice in the last two decades. This is partly because earlier designs of major infrastructure projects ignored a wide range of critical social, economic, and environmental factors. Large dams, for example, were associated with corruption, ecological harm, and social dislocation, among other problems.[9] Irrigation projects became breeding grounds for vectors of a variety of diseases. Large projects were also linked to macroeconomic distortions, especially those related to lending for questionable infrastructure projects.

This experience led to wholesale rejection of conventional development paradigms by some, and to the rise of a corresponding transnational activist community.[10] Development agencies shied away from such projects, and gradually came to be dominated by policy proposals that underplayed the critical role of infrastructure in sustainable development.

7 "Engineering" means the application of scientific and technical knowledge to solve specific problems.

8 Alice Amsden, *The Rise of 'The Rest': Challenges to the West from Late-Industrializing Economies* (New York: Oxford University Press, 2001), p. 3–4.

9. World Commission on Dams, *Dams and Development: A New Framework for Decision-Making*, Report of the World Commission on Dams (London: Earthscan, November 2000).

10. See, for example, Sanjeev Khagram, *Dams and Development: Transnational Struggles for Water and Power* (Ithaca, N.Y.: Cornell University Press, 2004).

The failure of subsequent sustainable development strategies has forced the international community to rethink the role of infrastructure and the associated engineering fields in sustainable development. At the Millennium Summit in September 2000, world leaders adopted the Millennium Declaration, a landmark statement for promoting peace, improving human welfare, encouraging international trade, and protecting the environment. The statement led to specific strategies later adopted as the Millennium Development Goals (MDGs), which became an international reference standard for tracking improvements in human welfare in developing countries.

Engineering plays an important role in addressing the challenges associated with eliminating poverty and hunger, as illustrated by the experiences of Latin America and Asia. The field's contributions can reduce poverty by contributing to sustainable development (for example, by creating job opportunities and raising agricultural productivity); and alleviate hunger by providing the physical infrastructure needed to advance agriculture.[11] These technological measures themselves, however, do not solve the challenges of poverty and hunger; they must be to be part of an integrated strategy aimed at improving overall human welfare.

A nation's ability to solve problems and to initiate and sustain economic growth depends in part on its capabilities in engineering, which in turn determines the ability to provide clean water, good health care, adequate infrastructure, and safe food. Development trends around the world need to be reviewed to evaluate the role of sustainable development in general and engineering in economic transformation in particular.

Information and communications technologies (ICTs), which now impact nearly all fields of endeavor, can also play a critical role in expanding primary, secondary, and tertiary education. For example, ICT can facilitate distance learning and offering remote access to educational resources. Many other technologies hold the promise of significantly upgrading human welfare, especially for women, in Africa by improving energy sources, agricultural technology, and access to water and sanitation.

Effective health care is also dependent on infrastructure. Critical health interventions—including the treatment and prevention of malaria, HIV/AIDS, drug-resistant tuberculosis, and vitamin and other micronutrient deficiencies—require new treatments, new vaccines, and other strategies appropriate to local circumstance. Building domestic competence in fields like chemical and process engineering is critical to expanding the technological basis for improving healthcare. In this area, the ability to produce generic medicines holds the promise of improving poor people's economic access to essential treatments. Engineering-based approaches such as redesigning houses and remodeling landscapes are examples of what can be done to help reduce mosquito breeding and malaria transmission, respectively. This would complement efforts to develop new antimalaria drugs and vaccines.[12]

Improved technological knowledge at the local level is indispensable for managing complex ecosystems, such as watersheds, forests, and seas, and for helping to predict (and thereby manage) the impact of climate change and the loss of biodiversity. Emerging fields such as industrial ecology offer new opportunities for addressing ecological challenges.[13] Access to clean water requires continuous improvement in low-cost technologies for water delivery and treatment.

Technological innovation is becoming equally critical in the management of freshwater resources. So far, much of the attention on freshwater has focused on market-related issues, such as privatization. Innovation-related responses are just starting to emerge. For example, concern over water scarcity in agriculture is generating interest in alternative approaches that can reduce the amount of water used to produce a unit of grain. Attention is also turning to the development of drought-tolerant crops using both conventional breeding methods and genetic engineering.

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11 Djibril Aw and Geert Diemer, *Making a Large Irrigation Scheme Work: A Case Study from Mali* (Washington, D.C.: World Bank, 2005). "The presence of supporting infrastructure is often fundamental to uptake of effective innovation and was a major factor in Asia's successful green revolution. Roads are critical to supporting input and output marketing, but the expansion of irrigation probably constituted the most important element of supportive investment." Gareth Thomas, "Innovation, Agricultural Growth and Poverty Reduction," in Juma, *Going for Growth*, p. 80.

12 Kai Matuschewski, "Vaccine Development Against Malaria," *Current Opinion in Immunology*, Vol. 18, No. 4 (June 2006), pp. 449–457.

13 Robert Frosch and Nicholas E. Gallopoulos, "Strategies for Manufacturing," *Scientific American*, Vol. 189, No. 3 (September 1989), p. 152. Industrial ecology involves efforts to "understand how the industrial system works, how it is regulated, and its interaction with the biosphere; then, on the basis of what we know about ecosystems, to determine how it could be restructured to make it compatible with the way natural ecosystems function." Suren Erkman, "Industrial Ecology: A Historical View," *Journal of Cleaner Production*, Vol. 5, Nos. 1–2 (1997), p. 1.

But technological innovation, however, can only have the desired impact if placed in the context of long-term sustainable development strategies, especially those associated with greater regional diversity and experimentation. In this regard, regional integration efforts across Africa represent a major opportunity to apply technological innovation in sustainable development, which in turn requires significant investment in creating engineering capacity.

Efforts should, therefore, be directed at providing support for institutions of higher technical learning (especially ones that focus on engineering), as well as for academies of engineering and technological sciences, professional engineering and technological associations, and industrial and trade associations. Engineering education is increasingly being recognized as a critical aspect of the sustainable development process. While primary education has been the focus of donor community attention for decades, secondary and higher education and research are only now beginning to gain policy attention in sustainable development circles.[14]

2. Frontiers Without Engineers: Poor Infrastructure

2.1. Infrastructure and sustainable development

Poor infrastructure and inadequate infrastructure services are among the major factors that hinder Africa's sustainable development.[15] Without adequate infrastructure, African countries will not be able to harness the power of science and innovation to meet sustainable development objectives and be competitive in international markets. Roads, for example, are critical to supporting rural development. Emerging evidence suggests that in some cases low-quality roads have a more significant impact on economic development than high-quality roads.[16] In addition, all significant scientific and technical efforts require reliable electric power and efficient logistical networks. In the manufacturing and retail sectors, efficient transportation and logistical networks allow firms to adopt process and organisational innovations, such as the just-in-time approach to supply chain management.

Infrastructure promotes agricultural trade and helps integrate economies into world markets. It is also fundamental to human development, including the delivery of health and education services. Infrastructure investments further represent untapped potential for the creation of productive employment. For example, it has been suggested that increasing the stock of infrastructure by 1 percent in a developing country context could add 1 percent to the level of GDP. But in some cases the impact has been far greater: the Mozal aluminium smelter investment in Mozambique not only doubled the country's exports and added 7 percent to its GDP, but it also created new jobs and skills in local firms.[17]

The advancement of information technology and its rapid diffusion in recent years could not have occurred without basic telecommunications infrastructure. In addition, electronic information systems, which rely on telecommunications infrastructure, account for a substantial proportion of production and distribution activities in the secondary and tertiary sectors of the economy. It should also be noted that the poor state of Africa's telecommunications infrastructure has hindered the capacity of the region to make use of advances in fields such as geographical information sciences in sustainable development.[18]

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14 Gobind Nankani, "Knowledge for Productivity-led Growth," in Calestous Juma, ed., *Going for Growth*, pp. 24–32.

15 Emerging evidence from South Africa shows the long-term implications of infrastructure investment for development: Johann Fedderke, P. Perkins and J. Luiz, "Infrastructural Investment in Long-Run Economic Growth: South Africa 1875–2001," *World Development*, Vol. 34, No. 6 (June 2006), pp. 1037–1059. Further historical evidence of the role of infrastructure in long-term economic development can be found in L. Cain, "Historical Perspective on Infrastructure and US Economic Development," *Regional Science and Urban Economics*, Vol. 27, No. 2 (April 1997), pp. 117–138.

16 A recent study of China shows "that low-quality (mostly rural) roads have benefit-cost ratios for national GDP that are about four times greater than the benefit-cost ratios for high-quality roads. Even in terms of urban GDP, the benefit-cost ratios for low-quality roads are much greater than those for high-quality roads. As far as agricultural GDP is concerned, high-quality roads do not have a statistically significant impact while low-quality roads are not only significant but also generate 1.57 yuan of agricultural GDP for every yuan invested. Investment in low-quality roads also generates high returns in rural non-farm GDP. Every yuan invested in low-quality roads yields more than 5 yuan of rural non-farm GDP." Shenggen Fan and Connic Chan-Kan, *Road Development, Economic Growth, and Poverty Reduction in China*, Research Report No. 138 (Washington, D.C.: International Food Policy Research Institute), pp. vii–viii.

17 Commission for Africa, *Our Common Interest*, p. 225.

18 See, for example, National Research Council, *Down to Earth: Geographic Information for Sustainable Development in Africa* (Washington, D.C.: National Academies Press).

Globalisation of trade and investment demands that countries upgrade their technological capabilities as a source of competitive advantage.[19] Infrastructure contributes to technological development in almost all sectors of the economy, serving as its foundation and representing, in effect, technological and institutional investment. The infrastructure development process also provides an opportunity for technological learning.[20]

Because infrastructure services act as intermediate inputs into production, their costs directly affect firms' profitability and competitiveness. Infrastructure services also affect the productivity of other production factors. Electric power allows firms to shift from manual to electrical machinery, extensive transport networks reduce workers' commuting time, and telecommunications networks facilitate flows of information. As an "unpaid factor of production," infrastructure increases the returns to labour and other capital. The availability of infrastructure may also attract firms to certain locations, which creates agglomeration economies and reduces production and transactions costs.[21] Infrastructure is a critical determinant of the destination of foreign direct investment (FDI).[22] It is one of the key factors that all types of investors consider in deciding on the location, scope, and scale of their investments.

Infrastructure and technology development reinforce each other. Expanded use of technology in sustainable development depends on the existence of infrastructure while the introduction of new technologies contributes to improvements in infrastructure services.

Given their strategic importance to creating and sustaining knowledge, research facilities need to be defined as part of Africa's critical infrastructure and managed as such. Many countries have well established sections of the military that deal with civilian matters on a routine basis. This function does not undermine the military role of the armed forces, but instead gives them new tasks that are consistent with a wider sense of national security. The time has come to rethink the role of the military in sustainable development and find constructive ways in which the armed forces can contribute to long-term sustainable development in general and technological innovation in particular.

All stages of an infrastructure project (including planning, design, construction, and operation) involve the use of a wide range of engineering inputs and institutional as well as management arrangements. Given their physical, organizational, and institutional complexity, infrastructure facilities and services require adequate technical capabilities on the part of engineers, managers, government officials, and others involved in these projects.

2.2. Status review

Investing in infrastructure is emerging as a critical item on Africa's sustainable development agenda. This interest has been inspired by the growing recognition of the role of infrastructure in sustainable development. It has also been reinforced by the demand for adequate infrastructure in the rapidly expanding urban areas. In 1980, for example, only 28 percent of the African population lived in cities. Today the figure stands at about 37 percent. Africa's annual urban growth rate is 4.87 percent, twice that of Asia and Latin America and Asia. This makes Africa the fastest urbanising continent in the world.[23]

African countries inherited a highly dispersed and unevenly distributed infrastructure from the colonial period.[24] Colonial development strategies focused solely on connecting natural and mineral resources to ports for export markets.[25] They failed to integrate the continent or stimulate local industrial development.[26] Africa's demand for

19 For a detailed discussion of this point, see Sajaya Lall and Carlo Pietrobelli, *Failing to Compete: Technology Development and Technology Systems in Africa* (Cheltenham, U.K.: Edward Elgar, 2002).

20 Allan Macpherson, "Learning How to Grow: Resolving the Crisis of Knowing," *Technovation*, Vol. 25, No. 10 (October 2005), pp. 1129–1140.

21 See, for example, Garth Holloway et al., "Agroindustrialization through Institutional Innovation: Transaction Costs, Cooperatives and Milk-market Development in the East-African Highlands," *Agricultural Economics*, Vol. 23, No. 3 (September 2000), pp. 279–288.

22 Chantal Dupasquier and Patrick Osakwe, "Foreign Direct Investment in Africa: Performance, Challenges, and Responsibilities," *Journal of Asian Economics*, Vol. 17, No. 2 (April 2006), pp. 241–260.

23 Anna Tibaijuka, A*frica on the Move: An Urban Crisis in the Making*, submission to the Commission for Africa, London, 2004, p. 1.

24 Maximo Torero and Shayamal Chowdhury, "Infrastructure for Africa: Overcoming Barriers to Development," paper prepared for the 2020 Africa Conference, Kampala, Uganda, April 2004, sponsored by the International Food Policy Research Institute, p. 4.

25 Ambe Njoh, "Colonial Spatial Development Policies, Economic Instability, and Urban Public Transportation in Cameroon," *Cities*, Vol. 14, No. 3 (June 1997), pp. 133-143.

26 Commission for Africa, *Our Common Interest*, p. 109; and T. Ridley and Yee-Cheong Lee, "Infrastructure, Innovation, and Development," in Juma, *Going for Growth*, p. 62.

infrastructure across sectors is hardly being met for the majority of people, with its worst sectoral performance being in access to electricity.[27] Even where such access exists, supply is unreliable and the quality of services remains poor.[28] Generally, access to infrastructure services favours the rich and is more unequal in Africa than in any other part of the world.[29] In some cases infrastructure projects may perpetuate historical inequities.[30]

There are major disparities in access to clean water in urban settings. Of Africa's 280 million urban residents, over 150 million lack access to clean water and nearly 180 million do not have adequate sanitation. For example, some 48 percent of African urban households have a water connection, compared to only 19 percent of informal settlements. Similarly, 31 percent of urban households are connected to the sewerage system, but the figure for informal settlements is 7 percent.[31]

There is good news, however: the advent of ICTs is transforming the continent.[32] In 2001 Uganda became the first African country where mobile phones exceeded land fixed lines.[33] The market has expanded from under 20,000 users in 1993 to an estimated 18.2 million in 2003.[34] But despite such phenomenal growth rates, much of Africa still remains disconnected from the rest of the world because of poor communications infrastructure.[35] Access to high bandwidth services remains beyond the reach of most individuals and institutions. Similarly, prospects for enhancing private sector participation through improved telecommunications are being undermined by poor infrastructure.[36]

Transportation costs in Africa are the highest of any region in the world. With landlocked countries having to figure in transport costs of up to 75 percent of the value of their exports, the continent faces extreme challenges to compete in global markets.[37] In Uganda, for example, transport costs add the equivalent of an 80 percent tax on clothing exports. Freight charges for imports are 70 percent higher in West and East Africa than in Asia. Africa's landlocked countries pay more than double the rate of Asian countries for comparable transport services.[38] Most of Africa is isolated from major air and maritime routes, which allows access only to high-cost, peripheral routes.[39] More than 20 percent of African exports reach the United States[40] by air. It is estimated that air transport costs account for up to 50 percent of the value of exports to the United States. Internally, air transport costs across Africa are up to four times the cost of getting the same goods over the Atlantic.[41]

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27 Antonio Estache, *What Do We Know about Sub-Saharan Africa's Infrastructure and the Impact of its 1990s Reforms?* Draft Working Paper (Washington, D.C.: World Bank, June 2005), p. 35.

28 Adeola Adenikinju, "Electric Infrastructure Failures in Nigeria: A Survey-based Analysis of the Costs and Adjustment Responses," *Energy Policy*, Vol. 31, No. 14 (November 2003), pp. 1519–1530.

29 Alan Gelb et al., *Can Africa Claim the 21st Century?* (Washington, D.C.: World Bank), p. 137.

30 Ronnie Donaldson, "Mass Rapid Rail Development in South Africa's Metropolitan Core: Towards a New Urban Form?" *Land Use Policy*, Vol. 23, No. 3 (July 2006), pp. 344–352.

31 Anna Tibaijuka, *Africa on the Move: An Urban Crisis in the Making*, submission to the Commission for Africa, London, 2004, p. 8.

32 Banji Oyelaran-Oyeyinka and Kaushalesh Lal, "Internet Diffusion in sub-Saharan Africa: A Cross-country Analysis," *Telecommunications Policy*, Vol. 29, No. 7 (August 2005), pp. 507–527.

33 Jacqueline Hamilton, "Are Main Lines and Mobile Phones Substitutes or Complements? Evidence from Africa," *Telecommunications Policy*, Vol. 27, Nos. 1–2 (February/March 2003), pp. 109–133.

34 Pierre Guislain, Mavis Ampah, and Laurent Bescangon, *Connecting Sub-Saharan Africa: A World Bank Group Strategy for Information and Communication Technology Sector Development*, Working Paper No. 51 (Washington, D.C.: World Bank, 2005).

35 J. Britz, P. Lor, J., I. Coetzee, I. and B. Bester, "Africa as a Knowledge Society: A Reality Check," *International Information & Library Review*, Vol. 38, No. 1 (March 2006), pp. 25–40.

36 Ragnhild Overå, "Networks, Distance, and Trust: Telecommunications Development and Changing Trading Practices in Ghana," *World Development*, Vol. 34, No. 7 (July 2006), pp.1301–1315.

37 Commission for Africa, *Our Common Interest*, p. 53. "Our task now is to equip the poorest, through investment, with the capacity to compete, so companies can take advantage of trade in the rest of the world. But building capacity to trade is about more than investment in infrastructure; it must also be about investment in people and their education, skills and entrepreneurial potential." Gordon Brown, "Forward," in Calestous Juma, ed., *Going for Growth*, p. 5.

38 Gelb et al., *Can Africa Claim the 21st Century?* p. 136.

39 Commission for Africa, *Our Common Interest*, p. 53.

40 Azita Amjadi and Alexander Yeats, *Have Transport Costs Contributed to the Relative Decline of Sub-Saharan African Exports?* World Bank Policy Research Working Paper No. 1559 (Washington, D.C.: World Bank, 1995); and Commission for Africa, Our Common Interest, p. 269. . Gelb et al., *Can Africa Claim the 21st Century?* p. 136.

A loss of focus on the importance of economic growth in poverty reduction and a failure to appreciate the importance of infrastructure investment led to a drop in infrastructure spending in Africa. Development policy in the 1980s and 1990s asserted that infrastructure would now be financed by the private sector.[42] From 1990 to 2002 infrastructure investment in Africa stood at US$150 billion, of which only US$27.8 billion came from the private sector. Nearly two-thirds of this amount (US$18.5 billion) was for telecommunications.[43] Unfortunately, private sector participation in infrastructure investment has not taken off in Africa, contrary to policy opinion.[44] Over an almost twenty-year period, Africa has only managed to generate 230 projects in partnership with foreign operators, about half of which are located in South Africa. Irrespective of the South African bias of the data, the total number of projects is small and so is the average size of projects in Africa. The average project size is indeed less than half of that in other developing countries. Africa's share of total (mostly foreign) private investment attracted by infrastructure across all sectors in the developing world is roughly 1–2 percent (except in telecoms, 6 percent).[45]

Additional funding approaches now include private-public partnerships such as the Emerging Africa Infrastructure Fund set up by the Private Infrastructure Development Group (PIDG). The group was founded in 2002 by the Department for International Development (DFID), the Swedish International Development Cooperation Agency, the Netherlands Ministry for Development Cooperation, and the Swiss State Secretary for Economic Affairs.

The war-torn economies in Africa are perhaps the hardest hit by the inadequate provision of infrastructure services, where physical infrastructure stocks (e.g., telecommunications, airports, ports, roads, and bridges) are often key targets during war. Although only a fraction of a country may be directly affected by war, infrastructure investment and maintenance is neglected in favor of military expenditures.[46]

Africa is highly vulnerable to external shocks arising from natural disasters such as cyclones, floods, droughts, and earthquakes. The economic fragility arising from natural disasters often deepens precarious economic and social situations. Natural disasters tend to divert a large portion of government and donor resources from otherwise essential infrastructure investment to emergency relief operations.[47] But natural disasters can also serve as a stimulus for investing in engineering for disaster preparedness. Disaster management could therefore serve as a foundation for building expertise in ecological engineering.[48]

An equally important dimension in Africa's future is the possible impact of climate change on infrastructure development. Africa's high rate of urbanisation is partly reinforced by declines in rainfall in parts of Africa.[49] These trends suggest that African countries will need to invest in technologies needed for adapting climate change, most of which will involve the use of a wide range of engineering capabilities.[50]

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42 José Gómez-Ibáñez, Dominique Lorrain, and Meg Osius, *The Future of Private Infrastructure,* Working Paper (Cambridge, Mass.: Kennedy School of Government, Taubman Center for State and Local Government, April 2004).

43 Benno Ndulu, *The Challenges for Improving Access to Infrastructure Services in Africa*, background paper prepared for the Commission for Africa, London; and Commission for Africa, *Our Common Interest*, p. 234.

44 "Slashing the state indiscriminately will not build effective development. We learned this in the 1980s and 1990s when–to take one example–many development agencies and bilateral donors withdrew, or cut back sharply on, financial support for public infrastructure. The mantra then was that infrastructure financing should be a private sector activity, when in fact not much more than 25 percent of infrastructure in developing countries–and probably even less in Africa–is likely to be privately financed for the foreseeable future." Commission for Africa, *Our Common Interest*, p. 80

45 Estache, *What Do We Know about Sub-Saharan Africa's Infrastructure and the Impact of its 1990s Reforms?*, p. 17.

46 Gelb, *Can Africa Claim the 21st Century?* p. 135.

47 Banji Oyelaran-Oyeyinka, *Learning to Compete in African Industry: Institutions and Technology in Development* (Burlington, Vt.: Ashgate, 2006), p. 117.

48 William Mitsch and Sven Jørgensen, "Ecological Engineering: A Field Whose Time Has Come," *Ecological Engineering*, Vol. 20, No. 5 (October 2003), pp. 363–377.

49 Salvador Barrios, Luisito Bertinelli and Eric Strobl, "Climatic Change and Rural–Urban Migration: The Case of Sub-Saharan Africa," *Journal of Urban Economics* (forthcoming). See also Andrew Simms, *Africa—Up in Smoke?* Second Report of the Working Group on Climate Change and Development (London: New Economics Foundation, June 2005).

50 The importance of technological innovation in mitigation strategies is illustrated in Harald Winkler et al., "What Factors Influence Mitigative Capacity?" *Energy Policy* (forthcoming).

3. Learning from Experience

Contemporary development history offers a wide range of lessons on the role of engineering in sustainable development in general and technological innovation in particular. These lessons range from the role of technical universities in economic reconstruction to business incubation. Africa and its international development partners can benefit considerably from these experiences. The rest of this section provides illustrative examples that demonstrate the linkages between engineering and sustainable development.

3.1. Economic reconstruction: the case of Rwanda

Rwanda experienced one of the worst human tragedies of the post–World War II period, which also destroyed much of the country's physical infrastructure and skill base. Its reconstruction efforts have been associated with high-level emphasis on the role of engineering in economic reconstruction. This is illustrated by Rwanda's decision in 1997 to convert the premises of a military academy into a base for a new technical university, the Kigali Institute of Science, Technology and Management (KIST). The evolution of KIST represents an interesting example of the role of international development cooperation in building engineering competence in Africa.

KIST was set up as a project of the United Nations Development Programme (UNDP), with the German Agency for Technical Cooperation (GTZ) as the implementing agency. The initial funding came from UNDP's core fund and a UNDP trust fund supported by Japan and the Netherlands. KIST started with major degree programmes in engineering and management. Compulsory courses included English or French language and remedial basic sciences. The institute was officially inaugurated in April 1998 and held its first graduation ceremony in 2002 when it awarded 403 diplomas and 62 degrees to its 465 pioneers in management and computer science disciplines.

KIST continues to strengthen its programmes and enjoys a growing number of international partners, including a key relationship with the Kaiserslautern University of Technology in Germany. It has introduced courses in computer and information technology; automotive, mechanical, and electronics technology; and electrical, civil, and environmental engineering. Additional courses have been established in applied chemistry, biology, and physics. Its undergraduate science and engineering population has now reached 2,000, and the total student population is projected to grow to 4,000 in five years, and to 9,000 by the year 2020.

Efforts are also being made through the Girls Empowerment Programme to improve the participation of girls in science and engineering subjects at KIST. The programme was launched in 2006 with over 200 girls taking a one-year foundational course to meet the requirements to study technology-related subjects.

In 2001, KIST received the Ashden Award for Sustainable Energy for developing an energy-efficient oven that uses 25 percent of the fuel required by traditional ovens. KIST subsequently established the Centre for Innovation and Technology Transfer (CITT) to develop solutions for rural areas, including renewable energy technologies which are being installed in prisons and schools. For example, at the Cyangugu prison in southwest Rwanda, the use of biogas has reduced fuel wood consumption from the surrounding forests by 75 percent. This effort gained international recognision when KIST was again honoured with the Ashden Award in 2005.

CITT is working on low-cost, environmentally friendly building techniques. Using a combination of prefabricated low-cost buildings and low-cost brick-making techniques, CITT is developing methods to construct classrooms and offices at half the cost of conventional buildings. In less than a decade, KIST has shown that a new generation of engineering-based universities can significantly contribute to economic reconstruction. Rwanda has already embarked on a process of reforming the National University of Rwanda to update its curriculum and teaching so that it can meet national development goals.

3.2. Technology diffusion and government policy: the case of Algeria

As foreign participation in infrastructure projects in Africa increases, the issue of technology transfer in infrastructure development becomes even more important. Empirical evidence on technology transfer suggests that government policies regarding the types of contracts stipulated for infrastructure construction can influence the degree of technology acquisition by a developing country.[51]

51 James Markusen and Anthony Venables, "Foreign Direct Investment as a Catalyst for Industrial Development," *European Economic Review*, Vol. 43, No. 2 (February 1999), 335–356.

The construction industry in Algeria is a good example. Since the 1970s, the construction industry has been considered in the Algerian Central Plan as one of the "industrializing industries," which is expected to generate a large part of employment and contribute to the GDP. The government initially encouraged the purchase of complex and advanced, though costly, systems of technology from foreign firms. Sophisticated and highly integrated contracts, such as turnkey and product-in-hand contracts, were used to assemble and coordinate all the project operations, from conception through implementation to installation, into one package. The aim was to transfer the entire responsibility to the foreign technology supplier.

These types of contracts did not lead to as much technology transfer as the government hoped. Although the turnkey contracts required that the foreign supplier take full responsibility of the project, they did not include the sourcing or training of local skills. There was continuous reliance on external assistance for management and skilled operations, while operations by local management remained inefficient due to a lack of understanding and skill. The use of turnkey contracts (which emphasized hardware acquisition) required an appropriate level of knowledge, skill, and experience that was not adequately available when Algeria started using the integrated contracts.

The problem existed even with the product-in-hand contracts, which were supposedly an improved version of the turnkey contracts, as they included the procurement and training of a local labour force required by the projects.[52] Because foreign suppliers took responsibility of the technology transfer process, however, there were limited opportunities for local managers and construction organizations to gain hands-on experience in project design, implementation, and installation. The lack of involvement of end users and local managers often resulted in unsuccessful technology transfer.

Having learned from past failures, the Algerian government later supported "decomposed" or "design and installation supervised" contracts, under which infrastructure projects were more fragmented and involved more local firms than under the integrated contracts. Local firms could take charge of the phases prior to installation, such as exploration and planning, which were originally completed by foreign technology suppliers under integrated contracts. Local managers executed the project with the technical assistance and supervision of foreign suppliers. This approach reduced uncertainty in implementation and facilitated the accumulation of technological capabilities in local firms through learning-by-doing. The approach also contributed to the development of investment and managerial capability of local managers.

3.3. Engineering and business incubation: the case of Zambia[53]

In many African countries, reorienting universities to play a greater role in the development of their countries has to take centre stage. They can accomplish this by strengthening their entrepreneurial activities, as well as by supporting national projects, industry, and other centres of excellence.

In 1990, the director of the computer centre at the University of Zambia (UNZA) connected a few personal computers to exchange emails within the institution, with Rhodes University in South Africa, and then with the rest of the world. The university network grew to serve national health institutions, nongovernmental organisations (NGOs) and other development agencies. In 1994, Zambia became the first sub-Saharan country outside South Africa to connect to the internet.

Zambia benefited from several programmes which included the Eastern and Southern African Network (ESANET) that focused on promoting connectivity among universities in the region. The lack of human capital forced the University of Zambia to pool all the resources of related projects at the computer centre. This created a culture of mutual understanding, trust, and interest. Similarly, in-house training of users by experts served to popularize the email system and provide necessary technical knowledge to those at the university.

The connectivity project at the UNZA was successful and highly supported in principle by the government and donors. Despite high-level interest, however, it failed to attract any direct support from donors. Early in 1994, the university decided to establish a campus-based company called Zamnet Communication Systems to link the institution to the internet and provide service to commercial customers. At this point the World Bank expressed an interest in covering 80 percent of the operating cost of the first year. It lent Zamnet the start-up capital, on the condition that the university would offer some shareholding in the unit to the public.

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52 For a discussion of the role of procurement in technology development and employment generation in the South Africa's housing industry, see R. Watermeyer, "Poverty Reduction Responses to the Millennium Development Goals," *Structural Engineer*, Vol. 84, No. 9 (February 2006), pp. 27–34.

53 For more details please see Victor Konde, "Internet Development in Zambia: A Triple Helix of Government-University-Partners," *International Journal of Technology Management*, Vol. 27, No. 5 (2004), pp. 440–451.

The administration worked with customers and other interest groups and intensified marketing. The university provided most of the manpower and the operational space for four years. The number of commercial accounts grew from 5 to 165 between January and June 1995, and seven months before the lapse of the World Bank loan, Zamnet was generating enough income to buy new equipment.

The commercialization of Zamnet demonstrated that provision of internet services could be good business even in poor countries. The demand for email and internet services was high. Soon after Zamnet's launch, the link to South Africa became saturated. Zamnet installed a VSAT by late 1996, which was upgraded to 265 kbps by January 1998. Other institutions soon followed suit. Using the experience gained from Zamnet, the national regulator, Zambia Telecommunication Corporation, developed a new unit that specialized in internet service provision.

The economic impact of Zamnet has yet to be fully assessed. Zamnet's market share, however, is estimated at between 70 percent and 80 percent of Zambia's internet users. Therefore many of the country's businesses, government departments, learning institutions, and most of the internet cafés and telecentres are connecting through Zamnet. The impact of Zamnet in encouraging enterprise development, and thereby creating employment opportunities and livelihood, is immense.

This case demonstrates how countries could utilize and channel international resources through universities to achieve national objectives. It also shows the importance of local management of projects through an accessible and transparent implementing mechanism under which different players feel comfortable, as well as the importance of a supportive government and policy environment.

3.4. Building new universities: the case of Korea

The role of the private sector in supporting training in engineering is a subject of extensive policy debate. Much of the attention has focused on the extent to which the private sector provides market signals for higher education. Little attention, however, has been devoted to the role of the private sector as an incubator of universities. South Korea's Pohang University of Science and Technology (POSTECH), founded in 1986, offers important policy lessons for the engineering community. It is a product of two innovators: Professor Hogil Kim, the founding president of POSTECH, and Tae-Joon Park, the chair of the Pohang Iron and Steel Company (POSCO). These two had the goal of setting up a leading research university in South Korea.[54]

The university started off with a small number of outstanding students who were fully funded and drawn from the top 2 percent of high school graduates. In 1987 POSTECH admitted 249 students into nine science and engineering departments. It admitted its first graduate students the following year.

POSCO's research facilities were transformed into an independent Research Institute of Industrial Science and Technology (RIST) and served as a joint arm of the university and the company, making it a model university-industry partnership. POSTECH places heavy emphasis on research and is emerging as a leader in science and engineering education in Asia. In 1998 AsiaWeek magazine selected POSTECH as the top university in science and technology. In addition, the Ministry of Education has consistently recognized POSTECH for its outstanding leadership in educational reform in the country.

The one major lesson that Africa can take from this case is the role that POSCO, a private company, played in developing POSTECH. POSCO's initial goal was to train world-class engineers for its operations. It shows that private companies in Africa might successfully support higher education not only for their benefit but also for national economic development. Africa already has several well-established industries that rely heavily on innovations in science and technology that could emulate this model.

Although the costs involved in the creation of POSTECH are currently well beyond the means of most African countries, the model still has the potential to be applied to a variety of fields. Telecommunications firms, for example, that have benefited from the cell phone revolution could explore the possibility of creating leading information and communications schools using POSTECH experiences. Similarly, mining, oil and gas, tourism, and agriculture firms can serve as sources of new innovations in their respective fields.

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54 "While R&D activities begun in the late 1970s provided adequate in-house technical capabilities, POSCO was unable to carry out central research work required for a forward-looking modern corporation. The company was seeking business diversification, anticipating the inevitable decline in steel-making activities of Korea in the early years of the coming century." Y.-G. Kim, "Innovation and the Role of Korea's Universities," in Lewis Branscomb, and Young-Hwan Choi, eds., *Korea at the Turning Point: Innovation-based Strategies for Development* (Westport, Conn.: Praeger, 1997), p. 134.

4. Redesigning African Economies

The cases provided in the previous section underscore the important role that investment in engineering can play in society. They also represent a wide range of practical models available both to African countries and their development partners for broadening and building engineering capacity for sustainable development. But such efforts need to be placed in the appropriate national and regional policy contexts.[55]

4.1. Regional integration

While it is prudent for Africa to emphasise international trade, doing so requires greater investment in developing capabilities to trade, including technological innovation, development of business and human resources, and institutional strengthening. The impact of larger markets on technological innovation, the economies of scale, and the diffusion of technical skills arising from infrastructure development are among the most important gains Africa could obtain from regional integration.[56]

A common feature of African regional integration agreements is their recognition of the importance of engineering in sustainable development. The integration of engineering is based on the recognition that individual African economies are small and poorly endowed with the human, physical, and financial resources necessary to develop and harness engineering capabilities. The cost of building science and technology infrastructure often appears to be an overwhelming task for national economies, especially in smaller and poorer states.

There is momentum in African regionalism that is characterized by deliberate efforts to design and implement plans for the application of engineering to sustainable development. Cooperation in engineering can take various forms, including joint projects, information sharing, conferences, building and sharing joint laboratories, setting common standards for research and development, and exchange of expertise. Furthermore, the sheer magnitude of the necessary infrastructure development actually requires regional cooperation in project design and implementation to not only reduce costs but also facilitate greater learning.

Some African countries are already endowed with robust science and technology infrastructure, which could easily be utilized by less well-equipped countries. New regional initiatives will need to emphasize the use of science and innovation in their sustainable development strategies.[57]

4.2. Improving governance

Governance has emerged as one of the central themes in international development cooperation.[58] Promoting a growth-oriented agenda will entail adjustments in the functions and structure of government so that it can play a key role in promoting investment.[59] More fundamentally, issues related to science and innovation will need to be addressed in an integrated manner at the highest level possible in government.[60] Effective economic management is associated

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55 Industrialized countries have been called on to launch the equivalent of the Marshall Plan for Africa. This metaphor, however desirable, may be misplaced. The New Deal launched by U.S. President Franklin D. Roosevelt in the 1930s provides a more appropriate inspiration model for relief, recovery, and reform for the kinds of economic crises that Africa faces. For a pertinent and provocative study of rural electrification under the New Deal, see Ronald Tobey, *Technology as Freedom: The New Deal and the Electrical Modernization of the American Home* (Berkeley: University of California Press, 1996).

56 Romain Murenzi, "Africa in the Global Economy," in Juma, *Going for Growth*, pp. 48-59.

57 There are eight major regional economic communities in Africa: Community of Sahel-Saharan States (CEN-SAD), Common Market for Eastern and Southern Africa (COMESA), Economic Community of Central African States (ECCAS) Economic Community of West African States (ECOWAS), Intergovernmental Authority for Development (IGAD), Southern African Development Community (SADC), Union du Maghreb Arabe (UMA) and the East African Community (EAC).

58 See, for example, Department for International Development, *Eliminating World Poverty: Making Governance Work for the Poor* (London: Department for International Development), pp. 18–41.

59 "At the heart of the proper function of government is establishing an economic environment that encourages investment. That means basic functions such as providing security, setting sound economic policies under the law, collecting taxes and delivering adequate public services like health and education. It means seeing that physical infrastructure is in place—roads, railways, water, electricity and telecommunications. But there are also more abstract forms of infrastructure, such as legal systems to protect basic property rights, human rights, and respect for contracts, to uphold order and to act as a check on governments." Commission for Africa, *Our Common Interest*, p. 24.

60 David King, "Governing Technology and Growth," in Juma, *Going for Growth*, pp. 112–124.

with the development of the appropriate institutional infrastructure, which includes legal systems and arrangements such as those needed to protect property rights, safeguard human rights, enforce contracts, uphold order, and shield the people from government abuse.

Bringing engineering to the centre of Africa's economic renewal will require more than just political commitment: it will need positive executive leadership. This challenge requires "concept champions" who in this case will be heads of state spearheading the task of shaping their economic policies around science and innovation.

Quality executive leadership in these areas will depend on how well political leaders are informed about the role of engineering in sustainable development. Advice on science and innovation needs to be part of the routines of policymaking. An appropriate institutional framework needs to be created for this to happen. Many of the African cabinet structures are a continuation of the colonial model that was structured to facilitate the control of local populations rather than to promote economic transformation.

So far, most African countries have not developed national policies that demonstrate a sense of focus to help channel available technologies into solving developmental problems. They still rely on generic strategies dealing with poverty alleviation, without serious consideration of the sources of economic growth.

Advisory structures differ across countries. In many countries, science advisers report to the president or prime minister, and national scientific and engineering academies provide political leaders with advice. Whatever structure is adopted, the advisory functions should be supported by some statutory, legislative, or jurisdictional mandate to advise the highest levels of government. They should have their own operating budget, including funding for policy research. The adviser should have access to good and credible scientific or technical information from the government, national academies, and international networks. The advisory processes should be both accountable to the public and able to gauge public opinion about science and innovation.

Successful implementation of science and innovation policy requires civil servants to have policy analysis capacity (which most civil servants currently lack). Providing civil servants with training in technology management, science policy, and modeling and foresight techniques can help integrate science and innovation advice into decisionmaking. Training diplomats and negotiators in policy aspects of engineering can also increase their capacity to handle technological issues in international forums.[61]

The growing recognition of the role of engineering in sustainable development has inspired interest in a new generation of policy studies on the subject. There is increasing demand for expertise on the interactions between science, innovation, and society. For example, strengthening the competence of civil servants with negotiating roles to engage technological issues is an essential aspect of international relations. The importance of this field has grown in recent years, in tandem with advances on issues ranging from infectious diseases and biotechnology to sustainability and information technology. In all of these areas, international public servants and diplomats increasingly depend on expertise to make their policy decisions, although many currently do not receive systematic advice.

Most issues of science and innovation now cross lines of national sovereignty. Science and engineering have already become a truly global activity, characterized by collaboration among various nations. International networks created by science and engineering diplomacy offer excellent opportunities for exchanging lessons from past experiences, opening up countries to international funding sources, and sharing organizational competence in science and innovation. Participation in international networks can also help build the domestic political and scientific credibility of academies and science advisory institutions, especially in Africa. Building competence in science and innovation policy will require investment in specialized courses of study and degree programmes on the subject. This could be accomplished by

61 "Scientists and engineers with firsthand experience of the scientific, technical, and health issues that are fast becoming the main items of the diplomatic agenda will become the diplomats of the twenty-first century. Technology has become a kind of new international currency, and intellectual property rights and technological competitiveness are items on the global trade agenda and the subject of international negotiations. Engineers can make unique contributions to discussions in all these areas," Norman Neureiter, "Engineering and American Diplomacy," *The Bridge*, Vol. 32, No. 2 (Summer 2004), p. 7. For a review of the role of science and technology in multilateral diplomacy, see National Research Council, *Knowledge and Diplomacy: Science Advice in the United Nations System* (Washington, D.C.: National Academy Press, 2002).Universities are starting to respond to this need by offering specialized courses for policy makers. The Science, Technology and Innovation Policy executive training programme that runs annually at Harvard University's John F. Kennedy School of Government provides high-level leaders from government, academia, industry, and civil society with a unique opportunity to integrate science and technology into a national sustainable development policy.

graduate schools of science and innovation policy that can then cooperate with similar programmes in other countries through a variety of training programmes (including mechanisms such as summer schools).

Discussing governance in Africa would be incomplete without addressing the continent's pandemic of corruption.[62] Fighting corruption has become an important standard against which public leadership is judged in Africa. But victory will remain elusive unless the efforts are accompanied by deeper institutional reforms that involve aligning public expectations with the makeup of the legislature and the proper use of executive authority by presidents. The reinvention of public service should involve leadership training at all levels in the governance of public affairs in general, and innovation and ethics in particular. Every new crop of leaders should attend specially designed leadership training courses before taking office. Dedicated "schools of governance" or their equivalent are needed on a large scale to focus on this important task. By extension, civil education institutions should begin to focus on providing the ethical foundations needed to educate "good citizens." The media and civil society organizations could play a key role in such educational campaigns. They will, however, need to start with their own housekeeping.

4.3. Identifying strategic opportunities

A key strategy in building up engineering capabilities in Africa is to link training programmes to infrastructure projects in growing fields. For example, the expansion of ICT infrastructure provides unique opportunities for setting up training programmes in electronic engineering.[63] Similarly, expansion of power supply facilities could be used as a platform for creating linkages with training facilities in electrical engineering and related fields.

For example, expanding geothermal energy production in Eastern Africa (covering Djibouti, Eritrea, Ethiopia, Kenya, Tanzania, Uganda, and Zambia) could be linked to engineering and environmental programmes at various universities. Using existing technologies, the region has the potential to generate over 2,500 MW of electricity from geothermal energy (out of the current global output of 8,100 MW). The installed capacity of Kenya and Ethiopia is about 65 MW. Expanding production in the region could be directly linked to the development of related engineering and other sciences.

Transportation projects also provide similar opportunities. For example, the Maputo Corridor is a joint initiative of South Africa and Mozambique, aimed at addressing the poor state of transport infrastructure between the Indian Ocean port of Maputo in Mozambique and the industrial interior of South Africa. The initiative represents a new opportunity to create linkages with other sectors. The corridor plan's focus has included upgrading and constructing road links from Witbank to Maputo; improving rail facilities from Maputo to Johannesburg, together with lines connecting Maputo to Zimbabwe and Swaziland; updating Maputo's port and harbour operations; and setting up a new, integrated border post to facilitate movement between Mozambique and South Africa. It also included improving telecommunications facilities, as well as related nontransportation investment such as the Maputo iron and steel plant, which will use natural gas from Mozambique's Pande fields. The diversity of the technology-based activities within the parameters of the Maputo Corridor project illustrates the range of opportunities for linking engineering education to infrastructure projects.

African countries also need to enhance their own ability to develop, operate, and maintain infrastructure services. Foreign construction and engineering firms will continue to be the main sources of technological, organizational, and institutional knowledge for infrastructure development. But governments in African countries should devise policies both to encourage technology transfer and build local capabilities in infrastructure projects.

Research and development (R&D) activities for the development, operation, and maintenance of infrastructure should also be created and linkages should be established with both domestic and overseas research networks. Given their strategic importance, research facilities need to be defined as part of Africa's critical infrastructure and managed as such. Existing research facilities can be networked as part of regional research cooperation. Not only will this reduce duplication in the availability of such facilities, but it will also enhance mobility and cooperation among researchers.

Infrastructure services may be provided through a combination of public and private enterprises, while taking into account the needs of the poor. Governments may reduce their role as producers of infrastructure but retain their roles

62 Robert Guest, *The Shackled Continent: Power, Corruption, and African Lives* (Washington, D.C.: Smithsonian Books, 2004).

63 Manorama Tripathi, "Transforming India into a Knowledge Economy through Information Communication Technologies—Current Developments," *International Information & Library Review*, Vol. 38, No. 3 (September 2006), pp. 139–146; Gillian Marcelle, "How do Telecom Firms Build Capabilities? Lessons from Africa," *Telecommunications Policy*, Vol. 29, No. 7 (August 2005), pp. 549–572; and N.H. Rao, "A Framework for Implementing Information and Communication Technologies in Agricultural Development in India," *Technological Forecasting and Social Change* (forthcoming).

as regulators, financiers, suppliers, and even competitors to private providers. Whatever roles they play, governments need to recognise that different types of infrastructure require different policies and approaches.

Different types of infrastructure have different technologies and organisational arrangements. Governments may need to assume a direct role in certain infrastructure projects if they see strategic importance in fostering the transfer and buildup of local capability in the required technologies. In planning and implementing infrastructure projects, efforts should be made to harness the enthusiasm and drive of young professionals, many of whom are looking for an opportunity to serve Africa.

4.4. Reinventing engineering education

African countries need to create indigenous capacity by training scientists, technologists, and engineers in relevant fields. The most damaging legacy of the African system of higher education is the separation between research, training and practical activities.[64] Engineering-related research is generally carried out in government institutes that do not enroll students.[65] Universities, on the other hand, do little research of direct relevance to society. Most of their engineering departments lack the necessary capacity and resources to be of practical value. Conventional responses to this challenge include seeking more funding for universities, strengthening collaboration between universities and the industrial sector, and increasing student access to research institutes and the private sector.

Such proposals, however commendable, fall short of the radical steps needed to bring research, training and operational activities under the same institutions. Training must suit current conditions and fulfill practical needs.[66] It must also anticipate future trends and prepare the next generation of engineers accordingly.[67] Such a strategy would help address local concerns in agriculture, industry, and services. Universities can play a vital role in sustainable development by supporting national and regional innovation systems. It is therefore imperative for universities in African countries to focus on engineering as well as on other advanced technological fields. It is also necessary to focus on certain key national priority areas and design action plans accordingly.

The growing presence of multinationals and foreign firms in African countries provides an additional impetus for these countries to focus on engineering, because these organizations require increasingly skilled and educated workers. Participation in the global economy requires that African countries hire and train more educated workers in local firms as well, so that new technology can be adopted and adapted accordingly.

Current government policies tend to portray technological innovation as a luxury that is irrelevant to immediate human needs. Another misconception is that technology destroys jobs. Technology has merely changed employment patterns, reducing the number of jobs in the production of goods relative to services while increasing the relative importance of highly skilled occupations within sectors, and by broadening skills within occupations.

Broadening Africa's technical skill base will involve increasing the number of women who train in engineering. Though women should play a major role in the development and application of bioengineering in Africa's socio-economic transformation, they currently constitute only a relatively small number of the total population of scientists and engineers.[68] Providing incentives that encourage the participation of women in higher education would place Africa in a strategic position to become an important locus for research and technology development. Human resource development strategies will need to give deliberate attention to increasing women's enrollment in engineering courses at higher education institutions. Emphasis could be placed on improving and making R&D infrastructure meet the needs of women (for example, part-time work, flexible hours, infant care support, extended maternity and child care leave, and research programmes to address issues important to women). In addition, funding schemes that provide

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64 For additional information on this theme, see, Calestous Juma, *Reinventing African Economies: Technological Innovation and the Sustainability Transition*, The John Pesek Colloquium on Sustainable Agriculture (Ames, Iowa: Iowa State University University, April 2006) and Calestous Juma, "Reinventing African Universities," *Falmer*, No. 44 (Summer 2006), pp. 8-10.

65 See, for example, United Nations, *Africa's Technology Gap: Case Studies on Kenya, Ghana, Tanzania and Uganda* (New York and Geneva: United Nations, 2006).

66 James Wei, "Engineering Education for a Post-industrial World," *Technology in Society*, Vol. 27, No. 2 (April 2005), pp. 123–132.

67 National Academy of Engineering, Engineer of 2020: *Visions of Engineering in the New Century* (Washington, D.C.: National Academies Press, 2004).

68 For a review of advances in bioengineering, see Paul Citron and Robert Nerem, "Bioengineering: 25 years of Progress—But Still only a Beginning," *Technology in Society*, Vol. 26, Nos. 2–3 (April–August 2004), pp. 415-431.

incentives for girls to enroll in science and engineering courses need to be explored. There are other measures that can be used to strengthen the participation of women in engineering in Africa. A quota system can be used to ensure women receive at least a proportion of opportunities offered by biosciences networks (which include training scholarships, fellowships and research grants). Mentoring arrangements, web-based outreach programmes, regular meetings for young female scientists, and indicators of the involvement of women in the sciences could play a key role in strengthening the role of women in the life sciences in Africa.

Addressing the sustainability challenge requires greater investment in the generation and utilization of scientific and technical knowledge. This goal can be achieved by aligning the missions of universities and other institutions of higher learning with their government's development goals, including those related to business incubation. Universities, as shown in the case of Zambia, can play a key role in serving as business incubators. They can also create and run their own enterprises.[69]

In addition to providing degree training, a new view is emerging that places universities and research institutions at the center of community development.[70] The application of this concept also extends to other levels of learning, such as colleges, research and technical institutes, polytechnics as well as high schools. Higher education and research institutions therefore have become a valuable resource for agribusiness, industry and society. In facilitating the development of business and industrial firms, universities can contribute to economic revival and growth in their regions.

Higher education and research institutions integrate into the production sector and into society in many ways. They conduct R&D for industry; create their own spin-off firms; are involved in capital formation projects, such as technology parks and business incubator facilities; introduce entrepreneurial training; and encourage students to transform research into enterprises.[71] This approach is based on the strong interactions between academia, industry, government and relevant sections of civil society.

Universities should also work more closely with the private sector in sustainable development activities and serve as agents of community development. Promoting enterprise development, especially in the urban areas, is one of the most effective ways to improve human welfare. Doing so will require the establishment of programmes designed to promote enterprise creation and development, especially among the urban poor. Similar efforts need to be adopted in rural areas. More specifically, institutions of higher learning as well as other mechanisms could serve as business incubators and sources of ideas and support for upgrading urban and rural economic activities.

Although most universities in Africa are located in urban areas, they have little connection with municipal authorities. Much can be gained by adjusting the curricula, pedagogy, and management of urban universities to address challenges such as sanitation and the improvement of the conditions of slum dwellers. Government funding, for example, could be provided to universities that adopt research and support engineering-based programmes formulated jointly with urban authorities. Similarly, universities and research institutions located in rural areas could serve as the locus for research, training, and outreach on the management of natural resources. Furthermore, universities could help strengthen science and math education in high schools. In turn, high schools could serve as critical nodes in local "learning communities" across Africa. [72]

Government and other support is necessary to rehabilitate and develop university infrastructure—especially with regard to information and communications facilities—to help them be part of the global knowledge community and network with others around the world. Such links will also help strengthen their research connections with the rest of the world.[73]

69 See, for example, Jong-Hak Eun, Keun Lee and Guisheng Wu, "Explaining the "University-Run Enterprises" in China: A Theoretical Framework for University–Industry Relationship in Developing Countries and its Application to China," *Research Policy* (forthcoming).

70 Jens Hansen and Martin Lehmann, "Agents of Change: Universities as Development Hubs," *Journal of Cleaner Production*, Vol. 14, Nos. 9–11 (2006), pp. 820–829.

71 Gideon Markman et al., "Innovation Speed: Transferring University Technology to Market," *Research Policy*, Vol. 34, No. 7 (September 2005), pp. 1058-1075.

72 It has been noted that "elite private universities of science and technology—such as Pohang University of Science and Technology, which could get top marks in every aspect of university evaluation—were founded in provincial cities, and they are achieving a level comparable to that of the traditional private universities of high social prestige in Seoul [in South Korea]." Toru Umakoshi, "Private Higher Education in Asia," in Philip Altbach and Toru Umakoshi, eds., *Asian Universities: Historical Perspectives and Contemporary Challenges* (Baltimore, Md.: Johns Hopkins University Press, 2004), p. 47.

73 Banji Oyelaran-Oyeyinka and Catherine Adeya, "Dynamics of Adoption and Usage of ICTs in African Universities: A Study of Kenya and Nigeria," *Technovation*, Vol. 24, No. 10 (October 2004), pp. 841–851.

There is an urgent need to bring research, teaching, and community outreach together in new institutional designs. For example, medical schools should be more integrated into hospitals just as agricultural research stations should have a larger teaching role. Similarly, strong links should be forged between universities and the agribusiness community. This process may involve reforming universities, creating new ones, or upgrading other existing institutions.

There is an urgent to need to take stock of the full scope of research and training facilities in East Africa, especially those that fall outside the formal rubric of "universities," and explore how they could supplement the contributions of existing universities. All government ministries are involved in some aspect of research and training, and thereby hold the seed for populating the economic space with new species of higher learning institutions that can be adapted to specific needs.

Collective efforts will be needed to reform curricula by replacing outmoded sections with new approaches that encourage creativity, enquiry, and entrepreneurship. These reforms should also include close cooperation with the private sector and the local communities in which universities are located. In turn, government at all levels (central, urban, and regional) should be at the forefront of creating opportunities for universities to contribute to sustainable development.

But reform in curricula will not be sufficient unless it is accompanied by adjustments in pedagogy to emphasise experiential learning.[74] The need to provide students with access to practical experience and learning from direct engagement is particularly critical in rapidly changing technological fields. Experiential learning can be more readily promoted in universities that have direct links with economic sectors. This makes local community connections even more crucial to the effective functioning of universities.

Universities should enjoy greater autonomy in management so that they can adapt in a timely manner to a rapidly changing world. But this autonomy should be guided by the need to deliver community development and not seen simply as an artifact of good governance. But if African universities do not make these changes—if they do not make themselves relevant to local needs—they will become increasingly marginal and their status in society will decline.

Financing higher education in Africa is probably one of the most contentious issues in the history of higher education in this field.[75] The perceived high costs of running institutions of higher learning have contributed to the dominant focus on primary education in African countries. But this policy focus has also blinded leaders from exploring avenues for supporting technical higher education. Indeed, African countries such as Uganda and Nigeria are experimenting with measures that include providing government scholarships and lowering tuition fees for those going into the sciences.

There are other long-term measures to support technical higher education, which include providing tax incentives to private individuals and firms that create and run technical institutes on the basis of agreed government policy. This is an area that Africa has hardly utilized as a way to extend higher technical education to a wider section of society. Mining companies, for example, could support training in the geosciences. Similarly, agricultural enterprises could help to create capacity in business. Institutions created by private enterprises can also benefit from resident expertise.

Governments too need to formulate policies that allow experienced government, industry and civil society staff and other professionals to serve as faculty and instructors in these institutions. This can be implemented as part of a national service system or as an effort to expose students to practitioners. Such programmes would also provide opportunities for students to interact with practitioners in addition to the regular faculty. Much of the corporate social responsibility investments by private enterprises in Africa could be better used to strengthen the continent's technical skill base.[76] Additional sources of support could include the conversion of the philanthropic arms of various private enterprises into technical colleges located in Africa.

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74 See, for example, José Zaglul and Daniel Sherrard, "Higher Education in Economic Transformation," in Juma, *Going for Growth*, pp. 34-46.

75 Nancy Birdsall, "Public Spending on Higher Education in Developing Countries: Too Much or Too Little?" *Economics of Education Review*, Vol. 15, No. 4 (October 1996), pp. 407–419.

76 For a survey of corporate social responsibilities approaches, see Joselyn Mackie, Andrew Taylor, Abdullah Daar and Peter Singer, "Corporate Social Responsibility Strategies Aimed at the Developing World: Perspectives from Bioscience Companies in the Industrialised World," *International Journal of Biotechnology*, Vol. 8, Nos. 1/2 (2006), pp.103–118.

4.5. Spurring business and social entrepreneurship

Economic change is largely a process whereby knowledge is transformed into goods and services through business enterprises.[77] In this respect, creating links between the generation of knowledge and business development is the most important challenge facing Africa.[78] For Africa to promote the development of local technology, it needs to review the incentive structures already in place.[79] There is a range of structures suitable for creating and sustaining enterprises, from taxation regimes and market-based instruments to consumption policies and sources of change in the national system of innovation.[80]

Small and medium-sized enterprises (SMEs) should play leading roles in the development of new opportunities and the use of technology. Governments need to develop, apply, and emphasise the important role of engineering in SMEs in sustainable development. They need to support business and technology incubators, export processing zones, and production networks as well as help sharpen the associated skills through business education.[81] Banks and financial institutions also need to play key roles in fostering technological innovation in SMEs.

Civil society has played an important role in promoting a wide range of sustainable development activities in Africa.[82] Indeed, civil society organisations are key sources of social innovation through their diversity and creativity. In the political arena, for example, civil society organisations have been at the forefront of promoting democratic change. Similarly, these organisations have been vital in other fields such as environmental conservation, where their contributions have ranged from raising awareness to carrying out field-based practical activities. Civil society organisations are often adapted to local needs and guided by narrowly defined objectives. This gives them the capacity to respond quickly to immediate challenges that might arise. As a result, however, their operations tend to focus on short-term measures. The growing interest in competence building will require expanded sources of support for sustainable development activities. Indeed, civil society organisations could be an important platform for social entrepreneurship that will complement the work of the private sector. In this regard, their participation would help facilitate the adoption of new technologies.[83]

These entities can support innovation in a variety of ways. First, they can help to bring social justice to the application of engineering in sustainable development, and redress some of the inequities associated with the use of new technology. Second, they can serve as an important mechanism for bringing civic engagement in technological innovation. This is an important aspect of democratic decisionmaking and practice. Finally, they can help define demand-oriented strategies for technological development.

Protecting intellectual property rights (IPRs) is a critical aspect of business development and international partnerships. But overly protective systems could have a negative impact on creativity. It is therefore important to design intellectual property protection systems that take the special needs of African countries into account.

To encourage innovation and unlock local capital, individuals and corporations need to feel that their research is protected; where IPRs have been violated, compensation must be provided. Most countries, however, developed

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77 Rosa Grimaldi and Alessandro Grandi, "Business Incubators and New Venture Creation: An Assessment of Incubation Models," *Technovation*, Vol. 25, No. 2 (February 2005), pp.111–121.

78 See, for example, House of Commons International Development Committee, *Private Sector Development* (London: Stationery Office Limited, 2006).

79 Calestous Juma, *Entrepreneurship and Development: Opportunities for Private Sector Participation*, submission to the International Development Select Committee, United Kingdom Parliament, London.

80 "The evolution of the modern state mirrors the emergence of a distinct sphere of self-interested economic activity in the private sector. While the state is concerned with the provision of common goods, its economic impact needs to be assessed with regard to the social interests that mark its relationship with the private sector. This holds for the evolution of fiscal systems as well as for other domains of government activity, involving the temporary carrying out of the entrepreneurial function." Alexander Ebner, "Institutions, Entrepreneurship, and the Rationale of Government: An Outline of the Schumpeterian Theory of the State," *Journal of Economic Behavior & Organization*, Vol. 59, No. 4 (April 2006), p. 497.

81 Rustam Lalkaka, "Business Incubators in Developing Countries: Characteristics and Performance," *International Journal of Entrepreneurship and Innovation Management*, Vol. 3, Nos. 1/2 (2003), pp. 31–55.

82 Robert Tripp and Dirk Willem te Velde, "Civil Society and Growth," in Juma, *Going for Growth*, pp. 102–110.

83 This view would run counter to the "slow race" hypothesis that involves greater civil society participation as put forward in Melissa Leach and Ian Scoones, *The Slow Race: Making Technology Work for the Poor* (London: Demos, 2006).

without these protections being structured across the economy in any clear way. Indeed, institutional development of patent regimes usually occurred after a country's firms achieved a significant level of innovation capability and then desired to protect their investments. This line of thinking would lead to a global intellectual property regime that acknowledges the co-evolutionary nature of technological innovation and enforcement of intellectual property rights.

The need to strike a balance between enforcing intellectual property rights and meeting the technological needs of developing countries became a key aspect of the global intellectual property system. Article 8 of Agreement on Aspects of Intellectual Property Rights (TRIPS) of the World Trade Organization (WTO) states that countries "may, in formulating or amending their laws and regulations, adopt measures necessary to protect public health and nutrition, and to promote the public interest in sectors of vital importance to their socioeconomic and technological development, provided that such measures are consistent with the provisions of this Agreement."

This flexibility suggests that African countries need to formulate their interests through national policy and legislation. The successful use of the flexibility granted in the TRIPS agreement will depend on the relationship between a country and its major trading partners in the industrial world, because most of the inventions that are likely to be affected by national laws belong to rights holders in the industrial world.

The TRIPS agreement (Article 66.2) also states that "developed country Members shall provide incentives to enterprises and institutions in their territories for the purpose of promoting and encouraging technology transfer to least-developed country Members in order to enable them to create a sound and viable technological base." This provision has received little attention, despite a 2003 decision of the TRIPS Council that called for annual reports on its implementation. The provision is particularly relevant to Africa where most least-developed countries are found.

African countries are steadily enhancing their capacity to use scientific and technical knowledge to solve local problems. They are investing in communication infrastructure and improving technology policies. For such measures to be effective, African countries also need greater access to the world's pool of knowledge. Emerging efforts to promote "open access" systems will make it easier for Africa to have access to technical information available in the public domain.[84]

4.6. Harnessing expertise in the diaspora

Africa has a large pool of engineers working in the diaspora whose expertise could be leveraged to support local sustainable development efforts. A number of countries have adopted policy measures aimed at attracting expatriates to participate in the economies of their countries of origin. They are relying on the forces of globalization such as connectivity, mobility, and interdependence among nations to promote the use of the diaspora as sources of input into national technological and business programmes. These measures include hosting investment conferences, creating rosters of experts, and promoting business networks.

Efforts to encourage expatriates to return home often occur after countries emerge from periods of civil unrest or economic decline. Like other professionals, expatriates respond to incentives and a sense of purpose. The most important starting point, therefore, is to establish a clear mission around which the diaspora can rally. The onus is on the governments to design programmes and offer incentives that enable expatriates to contribute to national efforts.[85] They also need to promote a culture of respect for professionalism and create flexibility in existing institutions to encourage the participation of the diaspora in local educational activities. Countries that do not make full use of local expertise are unlikely to make effective use of the diaspora.

Significant experiments are underway around the world to allow countries to make effective use of their diaspora. The Swiss government has converted part of its consulate in Cambridge, Massachusetts, into a focal point for interactions between Swiss experts in the United States and their counterparts at home. The Swiss House was created in recognition of the importance of the area as the world's leading knowledge centre, especially in the life sciences. In addition to Harvard University and the Massachusetts Institute of Technology, the Boston area is home to more than fifty colleges and universities as well as a cluster of science and engineering activities.

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84 Calestous Juma and Gavin Yamey, "Improving Human Welfare: The Crucial Role of Open Access," *Science Editor* (forthcoming).

85 Beatrice Séguin, Leah State, Peter Singer, and Abdullah Daar, "Scientific Diasporas as an Option for Brain Drain: Re-circulating Knowledge for Development," *International Journal of Biotechnology*, Vol. 8, Nos. 1/2 (2006), pp.78–90.

In another innovative example, the National University of Singapore has established a college at the University of Pennsylvania to focus on biotechnology and entrepreneurship. The complementary Singapore-Philadelphia Innovators' Network (SPIN) serves as a channel and link for entrepreneurs, investors, and advisors in both the Greater Philadelphia region and Singapore. SPIN seeks to create opportunities for collaboration and partnerships between the two countries.

India is introducing a number of policy measures—including granting dual citizenship to Indians in countries of strategic interest—aimed at strengthening the role of diaspora in national development. This is a major change of policy, based on the study of how countries such as Taiwan have benefited from their diaspora. These approaches can be adopted by other African countries, where the need to forge international technology partnerships may be even higher.

These examples illustrate that need to complement concern over the "brain drain" with new approaches that make effective use of the opportunities provided by the existence of large pools of expertise among the diaspora.[86] Such efforts will require countries to look at globalization in a new light and identify the opportunities that it offers. The old-fashioned metaphor of "brain drain" needs to be replaced by a new view of "global knowledge flows."[87]

4.7. Managing technological risks

Technological risks to society and the environment have become an integral part of global public policy.[88] Managing these risks and responding to public perceptions of them are necessary if engineering is to be effectively deployed to meet sustainable development needs. New technologies have been credited with creating new industrial opportunities but also with destroying the status quo. In fact, maintaining the status quo comes with its risks as well. In some cases the risk of doing nothing may outweigh the challenges associated with investing in new responses to social challenges.

In the past, technological risks were confined to countries in which new technologies emerged or even to the sectors in which they were applied. Concerns two decades ago over the use of microprocessors in industry were restricted to their possible impact on employment displacement in the manufacturing sector. Workers and labor organizations around the world protested the use of this emerging technology. Today echoes of these debates are still heard in discussions of the replacement of skilled workers with automated industrial functions.

Although interest in the impact of microelectronics on employment was expressed in many parts of the world, it did not become a mass movement involving a wide range of social groups for at least two reasons: first, the possibility of job displacement was weighed against the benefits of raising industrial productivity; and second, the global economy was not as integrated as it is today, and as a result, many debates were localized. Globalization gives technological risk a wider meaning and turns local debates over certain products into mass movements. This is, in itself, a source of new risks.

Risk perceptions vary considerably across technologies, and this defines the scale of social mobilization. Attempts in the 1980s to promote the adoption of renewable energy technologies were undermined by social opposition.[89] Sporadic opposition was recorded in many parts of the world, but it did not translate into mass movements. Risk perceptions of pharmaceutical products, for example, are not a major challenge to the use of new medicines, partly because of the limited range of options available to consumers in life-threatening situations. Fear of genetic engineering, however, stems from scientific, technical, economic, cultural, and ethical concerns. Opposition is differentiated along product lines

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86 "A global knowledge economy built on policies that foster mutual gain would be both richer and fairer than one premised on a war for talent. The more that imaginative people from different places are able to share and build on one another's ideas, the more knowledge will be discovered and the more diverse uses of it will be invented." David Hart, "From Brain Drain to Mutual Gain: Sharing the Benefits of High-Skill Migration," *Issues in Science and Technology* (forthcoming).

87 Francisco Sagasti, *Knowledge and Innovation for Development: The Sisyphus Challenge of the 21st Century* (Chiltenham, U.K.: Edward Elgar, 2004).

88 "Since the beginning of civilization, the twin innate human quests to understand nature in its physical, biological and social aspect—what has come to be called science—and to modify nature and build artifacts—the vast activity encompassing endeavors such as engineering, medicine and agriculture, that we can call technology—have had a fundamental impact on the evolution of human societies. They have also been indissolubly interconnected, because to modify nature, we must understand it and to understand it, often we must manipulate it and build artifacts," George Bugliarello, *Science, Technology and Society—The Tightening Circle*, InterAcademy Workshop on Science & Technology and the Future Development of Societies, June 26–July 1, 2006, Treilles, France. See also Bernard Amadei, "Engineering for the Developing World," *The Bridge*, Vol. 32, No. 2 (Summer 2004), pp. 24-31.

89 A. Sebitosi and P. Pillay, "Energy Services in Sub-Saharan Africa: How Conducive is the Environment?" *Energy Policy*, Vol. 33, No. 16 (November 2005), pp. 2044–2051.

(such as transgenic crops, fish, trees, and cattle). Many people oppose genetic engineering because of corporate control of the industry, which they perceive as a social risk.

A focus on technological risks can overshadow the possible benefits of an emerging technology, which are often difficult to predict. At the time of their invention, computers were envisioned as being able to perform nothing more than rapid calculation in scientific research and data processing. The rise of the internet as a global phenomenon could not have been predicted based on the early uses of information technology.

Technological risks have to be weighed against both the risks of existing technologies and the risks of not having access to new technologies. The risks of not having access to the internet may outweigh the risks of employment displacement that shaped many of the attitudes toward information technology in its earlier years. The concerns over employment displacement were genuine, but the risks were often projected to whole industries or sectors. The debate was then dominated by concerns over job displacement rather than the potential contributions of the new technologies to economic productivity.

On the other hand, there are also numerous cases in which society has underestimated the risks posed by new technologies or adopted them without possessing adequate knowledge of their dangers. Managing technological uncertainty will require greater investment in innovative activities at the scientific and institutional levels. Technological diversity is essential to ensuring that society is able to respond to emerging challenges with the appropriate knowledge at its disposal. Technological diversity demands greater investment in scientific enterprises as well as the creation of measures to facilitate access to available technical options. It also requires flexibility in institutional arrangements to enable society to respond swiftly to technological failure. Such flexibility can be built into the design of technological systems themselves. Diversification of energy sources, for example, is an institutional response to the risks posed by dependence on centralized fossil fuel power plants. Similar diversification principles apply to information storage, especially as the world community moves into the information age.

Trends in industry suggest that a combination of incentives and regulations can shift technological change to meet environmental goals. Already enterprises are responding to the growing environmental consciousness among consumers and starting to adopt new environmental standards in fields such as emissions and energy use. This work is being promoted through the International Organization of Standards (ISO), whose ISO 14000 series is being used to set voluntary environmental standards.

5. Forging Ahead

Solving Africa's pressing challenges will require concerted effort and close collaboration among governments, industry, academia, and civil society. It will also involve experimentation and the willingness to risk failure. And there will be failure. But success will depend on a willingness to learn on the part of all development partners: It is only through experimentation and learning that we can reduce the costs of errors and enhance the benefits of innovation.[90] The set of options for action provided below can be implemented in any order. Overall, the most urgent ones involve engaging the engineering community, recognizing and utilizing their contributions, and inspiring the next generation.

5.1 Challenging the engineering community

A first step in moving ahead will involve challenging the worldwide engineering community to come up with solutions relevant to Africa. This can be done in a variety of ways. One approach is to launch a series of challenge mechanisms that could help to focus the attention of the engineering community on international development issues.

An example of this approach is provided by the Grainger Foundation through the United States National Academy of Engineering (NAE). The focus of the challenge is finding a solution to arsenic poisoning, which affects a quarter of the population of Bangladesh. To help solve the problem, NAE is offering Grainger Challenge prizes of US$ 1,000,000, US$ 200,000, and US$ 100,000 for first, second, and third place, respectively, for designing and creating an economical and

90 For a survey of options for action open to the engineering community, see UN Millennium Project, *Innovation: Applying Knowledge in Development*, Task Force on Science, Technology and Innovation (London: Earthscan, 2005); and Juma, *Going for Growth*.

functional point-of-use water treatment system for arsenic-contaminated groundwater in Bangladesh, India, Nepal, and other countries that suffer from arsenic poisoning. The premier Grainger Challenge prizes will be awarded in February 2007 and will be worth watching as the winning technologies come into the marketplace. Other "grand challenges" under this programme will follow.[91]

But this "grand challenge" strategy can be replicated at more modest scale, and engineering academies—with the help of governments, industry, academia, and private individuals—might well launch similar challenge programmes emphasizing the role of engineering in international development.

5.2. Recognizing excellence and inspiring future generations

Engineering academies can also recognize and honour engineers and practitioners who have played important roles in providing innovative solutions to sustainable development challenges. This could be accomplished by dedicating honours, awards, or prizes. In addition, new programmes could be created to encourage young engineers to engage in international development. There are a growing number of initiatives such as Engineers without Borders (EwB) that provide opportunities for young people to participate in international development, which could be strengthened by the support of engineering academies. Organizations such as Practical Action (formerly known as the International Technology Development Group) and the U.S.-based Appropriate Infrastructure Group (AIG) have played leading roles in highlighting the critical role that ingenuity plays in development. They also are important sources of inspiration for young engineers, many of whom are students at leading research universities.

An example of such activities is the Mondialogo Engineering Award, which encourages engineering students in developing and developed countries to establish international teams to work on projects that seek to implement the MDGs. The award recognizes practical, high-quality engineering projects that benefit local communities in developing countries. Ten Mondialogo engineering awards of €20,000 are awarded to teams with outstanding project proposals and 20 teams receive honorable mentions worth €5,000 each. Mondialogo is a joint initiative of DaimlerChrysler and the United Nations Scientific, Educational and Cultural Organisation (UNESCO).

5.3. Providing intellectual leadership and offering advice

Africa's development cooperation strategies have hardly been modeled after successes in other parts of the world. Many of the development policies advocated for African countries in the past two decades have generally failed to draw from experiences elsewhere. As a result, critical lessons regarding the role of engineering in sustainable development were either ignored or their application discouraged.[92]

An obvious step forward would be for the engineering community, especially through their academies working in close cooperate with other academies and like-minded institutions, to launch a global review of the lessons learned from international development efforts over the last 50 years.[93] The focus of such a study should be to identify good practices and inspirational models, not simply to measure the impact of engineering on sustainable development.[94] Such a review would focus on identifying critical lessons that could then be used by academies of engineering to guide a new phase

91 For a review of the value of prizes in social advancement, see James English, *The Economy of Prestige: Prizes, Awards, and the Circulation of Cultural Value* (Cambridge, Mass.: Harvard University Press, 2005).

92 "Several science academies, learned societies and professional institutions are taking action and a number of non-governmental organisations in the UK are engineering-based and committed to work for the alleviation of poverty in the developing world. However it has been suggested that the work is fragmented and lacks leadership." Royal Academy of Engineering, *Pilot Study Investigating Engineering Capacity Building in Sub-Saharan Africa* (London: Royal Society of Engineering, 2006).

93 Such an effort could take a variety of forms and could include some of the elements outlined in Paul Rowitt and Kate Beckmann, *Engineering without Frontiers* (London: Institution of Civil Engineers, 2006).

94 The work of measuring the impact of the science and technology on development is critical and continues to attract research attention. For a discussion of some of the methodological issues involved in such research, see Nikos Varsakelis, "Education, Political Institutions and Innovative Activity: A Cross-country Empirical investigation," *Research Policy*, Vol. 35, No. 7 (September 2006), pp. 1083–1090.

of international development cooperation. It would build on the growing recognition of the role of science and engineering in sustainable development.[95] These studies (and the associated good practices) could also provide a basis upon which to conduct dialogues on critical issues related to engineering and international development. In other words, providing international leadership on these issues will strengthen the convening ability of engineering academies.

Based on knowledge obtained from reviews of the kind mentioned above and from other studies, engineering academies could play key roles in providing advice to governments and other institutions involved in international cooperation. More specifically, agencies responsible for international development in various sectors of government, industry, and civil society could benefit from independent studies carried out by engineering academies.

The United States National Academy of Sciences, for example, is helping to strengthen the capacity of African academies to provide evidence-based advice to governments. At the international level, the InterAcademy Council (IAC) has produced a set of advisory studies. The Council of Academies of Engineering and Technological Sciences (CAETS) could play a key role in complementing the work carried out by the IAC.

5.4. Building capacity

Engineering academies in industrialized countries are currently involved in a variety of activities related to building competence in engineering. They achieve this by promoting interactions between government, industry, academia, and civil society. These interactions lead to a greater understanding of the role of engineering in society, all of which could be extended to include African countries. Care will need to be taken to limit such activities to inspirational cases, especially those involving foreign firms operating in Africa. Such interactions are becoming an important aspect of the design of sustainable development projects. This is partly because they help to provide the additional knowledge needed for reducing the risks of project failure. They therefore serve as critical elements in overall social learning.

One of the key challenges facing Africa lies in finding ways to strengthen engineering education. This involves creating and strengthening training programmes, as well as creating new engineering-based training institutions. Current efforts in Africa to rethink the future of higher education may provide important opportunities for engineering academies to mobilize their members to contribute to such efforts.

As suggested above, such efforts could be linked to specific infrastructure development initiatives in these countries. In addition, there are cases (for example, in Malawi) where African leaders have expressed explicit interest in creating new institutions of technical higher learning that are relevant to local needs. In other cases (such as that of Rwanda) African governments are working to reform existing national universities to bring them in line with national sustainable development priorities. Other countries (such as Kenya) are currently working to upgrade technical colleges to become full universities. These efforts offer opportunities for helping to bring engineering to the service of sustainable development.

On the whole, reforming engineering education to bring it in line with contemporary social needs is emerging as a common theme among industrialized and developing countries. This provides a unique opportunity for Africa and the industrialized countries to work together in designing curricula and teaching approaches that are suited to modern challenges. More specifically, providing "practice-oriented" engineering education is one of the most urgent challenges facing the field of engineering.[96] Such reorientation will need to be reflected in all levels of the educational system, starting with elementary schools.[97]

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95 See, for example, House of Commons Science and Technology Committee, *The Use of Science in UK International Development Policy*, Vol. 1 (London: Stationery Office Limited, 2004); National Research Council, *The Fundamental Role of Science and Technology in International Development: An Imperative for the US Agency for International Development* (Washington, D.C.: National Academies Press, 2006); and Netherlands Development Assistance Council, *Mobilizing Knowledge to Achieve the Millennium Development Goals: Advisory Report to the Dutch Knowledge Infrastructure on the Field of International Development*, Publication No. 27 (The Hague: Netherlands Development Assistance Council, 2005).

96 See, for example, Karl A. Smith, Sheri D. Sheppard, David W. Johnson, and Roger T. Johnson, "Pedagogies of Engagement: Classroom-Based Practices," *Journal of Engineering Education*, Vol. 94, No. 1 (January 2005), pp. 87-101.

97 "Exposure to engineering may be most profound in grades 3 through 8. In these formative years, hands-on engineering experiences, conveyed through inquiry-based, design-oriented instructional methodologies, can support the learning of standards-based science and mathematics while stimulating student learning and making engineering come alive." Jacquelyn Sullivan, "A Call for K-16 Engineering Education," *The Bridge,* Vol. 36, No. 2 (Summer 2005), p. 23.

5.5. Serving as a role model

Africa is in the early stages of developing its scientific academies and seeking to bring their expertise to bear on sustainable development policy. Africa has twelve national academies (in Cameroon, Egypt, Ghana, Kenya, Madagascar, Nigeria, Senegal, South Africa, Sudan, Tanzania, Zambia, and Zimbabwe) and one continental academy (the African Academy of Sciences). Historically, these academies—which have tended to focus their activities on basic research—are now starting to extend to other fields. The growing focus on infrastructure development in Africa will generate demand for advice on engineering-related issues. There may be a role for engineering academies to help African countries strengthen the engineering components of existing academies or to help strengthen separate engineering academies, when created.

Already the academies (operating through the Network of African Scientific Academies) have been addressing issues such as energy with explicit reference to the role of engineering. Modest efforts—such as joint studies on major infrastructure initiatives—could serve as a starting point for long-term collaboration between African and other academies. Some of the funding that is used to support conferences and workshops would be aligned to contribute to such joint studies and help advance the use of evidence-based decisionmaking in African countries.

Conclusion

Africa's ability to meet its human welfare needs, participate in the global economy, and protect the environment will require considerable investment in science and innovation in general, and engineering in particular. Weak infrastructure, for example, imposes critical limitations on Africa's capacity to utilize its abundant natural resources. This situation is also closely associated with limited opportunities for engineering education in African universities. A number of international organizations are responding to this challenge by offering a variety of "capacity building" projects in engineering.

Most of these efforts focus on training individuals and are not directly related to regional sustainable development efforts in Africa. This lecture argues that viable strategies for building competence in engineering should seek to link engineering training directly to infrastructure projects. Africa's focus on regional integration provides a policy context in which such efforts should be embedded. Considerable innovation will be needed both in the design of infrastructure projects and the functioning of training institutions. Engineering academies need to play a central role in helping to redesign the role of engineering in international development in the new millennium. Support from governments and other sources of funding for such activities represent an important step in advancing efforts to implement the MDGs.

The political basis for pursuing the ideas presented in this paper already exists. For example, the G8 nations have "agreed to invest more in better education, extra teaching and new schools, and to help develop skilled professionals for Africa's private and public sectors by supporting networks of excellence between Africa's and other countries' institutions of higher education and centres of excellence in science and technology."[98] But this will not happen unless there is complementary leadership in Africa to put science, technology and innovation at the centre of the sustainable development process. In a timely move, the African Union will devote its January 2007 presidential summit on "scientific research and technology for socio-economic development". The outcomes of the summit and follow-up activities will be decisive in creating a strong basis for forging international partnerships on engineering for sustainable development.

98 David King, "Governing Technology and Growth," in Juma, *Going for Growth*, p. 120.

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The Royal Academy of Engineering
29 Great Peter Street, London, SW1P 3LW
Tel: 020 7227 0500 Fax: 020 7233 0054
www.raeng.org.uk