Science, Technology and Innovation for Public Health in Africa

AFRICAN UNION

THE NEW PARTNERSHIP FOR AFRICA'S DEVELOPMENT

NEPAD

A Programme of the African Union

Editors: Fetson Kalua, Abolade Awotedu, Leonard Kamwanja & John Saka

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About NEPAD Science and Technology Programme

The New Partnership for Africa's Development (NEPAD) is a socio-economic development programme of the African Union (AU) whose express objective is to stimulate Africa's development by bridging existing gaps in Infrastructure (Energy, Water and Sanitation, Transport and ICT); Agriculture and Food Security; Human Resource Development, especially Health/Education, Youth and Training, Social Affairs; Science, Technology and Innovation; Trade, Industry/Market Access and Private Sector Development; Environment/Climate Change and Tourism; Governance/Public Administration, Peace and Security; Capacity Development, and Gender Development. The implementation of these programmes is based on the AU/NEPAD principles of African leadership and the ownership of the continent's development agenda and process, as well as a commitment to good political, economic and corporate governance.

African leaders have explicitly recognized that socio-economic transformation of the continent cannot be achieved without increased investments in science, technology, and innovation. To that end, the leaders have initiated a number of concrete actions geared towards promoting the continent's scientific and technological development. The actions include the creation of the African Ministerial Council on Science and Technology (AMCOST) and its subsidiary bodies -- the NEPAD Office of Science and Technology, and the AU Commission for Human Development, Science and Technology. These institutions have collectively developed a comprehensive strategy and action plan -- Africa's Science and Technology Consolidated Plan of Action -- adopted at the second African Ministerial Conference on Science and Technology in Dakar, Senegal, in September 2005.

The main goals of Africa's Science and Technology Consolidated Plan of Action (CPA) are to strengthen Africa's capacities to develop, harness and apply science, technology, and innovation to achieve millennium development goals (MDGs), as well as mobilizing the continent's expertise and institutions to contribute to the global pool of science and technological innovations. Key to these goals is the promotion of transnational Research and Development (R&D) programmes.

Preface and Acknowledgements

In 2006, the Bill and Melinda Gates Foundation provided NEPAD OST with a grant to undertake several studies with the objective of contributing to the building of health innovation systems in Africa. The findings of the research were ultimately discussed during an international workshop convened by NEPAD OST in Entebbe, Uganda, from 23-24th July 2007, focusing on harnessing Science, Technology and Innovation for the improvement of health in Africa. The reports were subjected to a review process by an independent team of reviewers and the accepted reports have been compiled in this monograph.

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CHAPTER 2

Technological Trends and Opportunities to Combat Diseases of the Poor in Africa

J. Chataway, K. Chaturvedi, R. Hanlin, J. Mugwagwa, J. Smith & D.Wield

Abstract

Scientific and technological breakthroughs do not necessarily lead to accessibility of a new product to the public. There is no automatic and smooth transfer from laboratory to product, and followed by delivery to the consumer. In order to have useful innovation and product development, issues such as funding, regulation, production and delivery need to be resolved not only by African governments but also the international community, industry and civil society.

In this chapter we address following questions on the issue of transfer (or translation): which technologies do health experts think have the greatest potential to address Africa's health challenges? what are the main barriers and challenges to developing or accessing those technologies; and, what can be learnt from the existing initiatives which are aimed at producing, supporting or promoting the procurement and application of science and technology (S&T)? It is important to note that the changes are complex and go beyond the concept of simple transfer and thus need to be systematic.

To that end, we have proceeded as follows: summarised the recent work of other groups on these questions; added the findings of our own Delphi survey; examined in detail three types of key technological trends and opportunities to see how they might be developed, and also to consider the constraints to be overcome. A key premise of this chapter is that there are three basic sets of challenges in developing technologies for diseases of the poor in Africa. First, that scientific and technological challenges are key to addressing specific diseases. Secondly, that it is essential to address market failures and construct policies to improve the supply of and demand for appropriate new health technologies and innovation. Thirdly, that greater attention be paid to the 'social technologies' - the organisational and institutional mix - involved in producing and distributing technologies.

Introduction

Scientific and technological advances have had numerous and profound impacts on public health in both advanced and developing countries. One recent example is the development of Highly Active Anti-Retroviral Therapy (HAART) which has transformed the chances of those people living with HIV/AIDS (Badri et al. 2004). While these therapies do not cure the disease, they certainly increase life expectancy and are seen as being partly responsible for the reduction in the international AIDS death rate (The Economist 2008). Again, advances in water purification also mean that it is now possible for more people to access safe drinking water (Strestha et al. 2006), while innovations in genomics mean advancement in the development of drugs, vaccines and diagnostics (WHO 2002). A 2002 report by the Joint Centre for Bioethics at the University of Toronto outlined the top ten biotechnologies for improving health in developing countries. At the top of the list were modified molecular technologies for affordable and simple diagnosis of infectious diseases (Daar et al. 2002).

In order that these and other technological advances have a greater impact on the health of the poor in Africa, a number of constraints need to be understood and overcome, and they include technical, economic, institutional and political. The development of HAART has not resulted in immediate access to this technology by those who needed it in many African countries (Montaner 2006). Access to such HIV/AIDS treatment in Africa has required resolution of funding, regulatory, production and delivery issues by not only African governments but also the international community, industry and civil society. At organisational and institutional level, frameworks for developing an HIV/AIDS vaccine are fast evolving with new challenges emerging all the time. Thus early in 2008, scientific challenges resulted in calls for, and movement towards a return to laboratory science and away from clinical trials in the AIDS vaccine field (Independent 2008). Major new investment in health research, including although not as significantly for neglected diseases[1], affords exciting opportunities and has built momentum (Hotez et al. 2008). What can be learnt from existing initiatives aimed at producing, supporting or promoting the procurement and application of these advances? And, how can African policy makers and the international community best move forward such initiatives and provide access to these technologies? Addressing these questions is the starting point to mapping the current status of current technological trends and opportunities to combat the diseases that afflict the poor in Africa.

1. The Current State of Science and Technology for Health in Africa

There is an increasing realisation of the importance to build infrastructure in science, technology and innovation for the development of nations in Africa. This is likely to translate into progress towards the United Nations' (UN) Millennium Development Goals (MDGs) aimed at reducing poverty, disease and hunger in the world. NEPAD has a whole programme devoted to Science and Technology, the Commission for Africa Report (2005) highlighted

the importance of science, technology and innovation for Africa's development and the UN Millennium Project set up a Task Force to investigate the role of science and technology for development. In order to overcome the competing policy demands and ensure an emphasis is placed on science and technology (S&T), the UN Millennium Task Force on Innovation (2005) emphasised a deliberate and systemic approach to the inclusion of, and application of, S&T highlighting the learning process of innovative activity. Chapter 1 of this volume articulates the arguments for Systems based approaches in more detail.

Some African countries have already adopted a systemic approach to S&T. South Africa, Kenya and Egypt have all introduced S&T policy initiatives that work to build a 'national system of innovation'. By this system, policy decisions enable the creation of a network of public and private institutions throughout all areas of the economy which work towards the creation and diffusion of S&T. For example, since 1996 when South Africa launched a White Paper on S&T, the country has placed an emphasis on networked multiple stakeholder involvement, competitiveness and collaborative research in areas of heath research. This means that there are focus areas for S&T innovation in biotechnology and nanotechnology as well as collaborative research projects around HIV and malaria vaccines. As a result it has been argued that South Africa is producing a 'health innovation program' within its national innovation system (Mahoney and Morel 2006).

There has been a massive increase in international support for work on neglected diseases. Bilateral and multi-lateral initiatives were spawned over the last decade and new global health partnerships have attracted billions of US dollars in financial support in recent years. Many of these initiatives are based to some degree on awareness of the importance of all three fundamentals of building new technologies and innovations to address diseases of the poor.

Despite this, Africa still has relatively low levels of research and development (R&D) and health innovation. Almost no African country reaches the investment target of 1% of GDP in R&D set in the Lagos Plan of Action (AU/NEPAD 2006). NEPAD and the African Union's Science and Technology Consolidated Plan of Action outlines other features of low levels of investment:

> *"Africa's low investment in science and technology is also manifested in declining quality of science and engineering education at all levels of educational systems. Student enrolment in science and engineering subjects at primary, secondary and tertiary levels is also falling. The continent is also loosing some of its best scientific and technical expertise to other regions of the world. In many countries infrastructure for R&D has been neglected and is decaying. Institutions of higher education, particularly universities and technical colleges, are in urgent need of renewal after many years of neglect and disorientation from local and national priorities."* (AU/NEPAD 2006)

The quote highlights the poor situation of African nations' S&T infrastructure. The lack of emphasis and attention placed on S&T in investment, economic and education policy is highlighted above. However, there has also been neglect of science and technology in health policy too (the emphasis being placed on the output of the health system – health*care* and its delivery) and vice versa (S&T policy did not include health components traditionally); a situation being compounded by small and competing budgets. For example, the World Health Organisation in its World Health Report (WHO 2001a) defines the health system in terms of 'healthcare' while the Commission for Macroeconomics and Health (2001) highlighted the lack of emphasis placed on health within science and technology policy. The emphasis has traditionally been on seeing each of these areas as separate to each other with only minimal inputs and linkages between them.

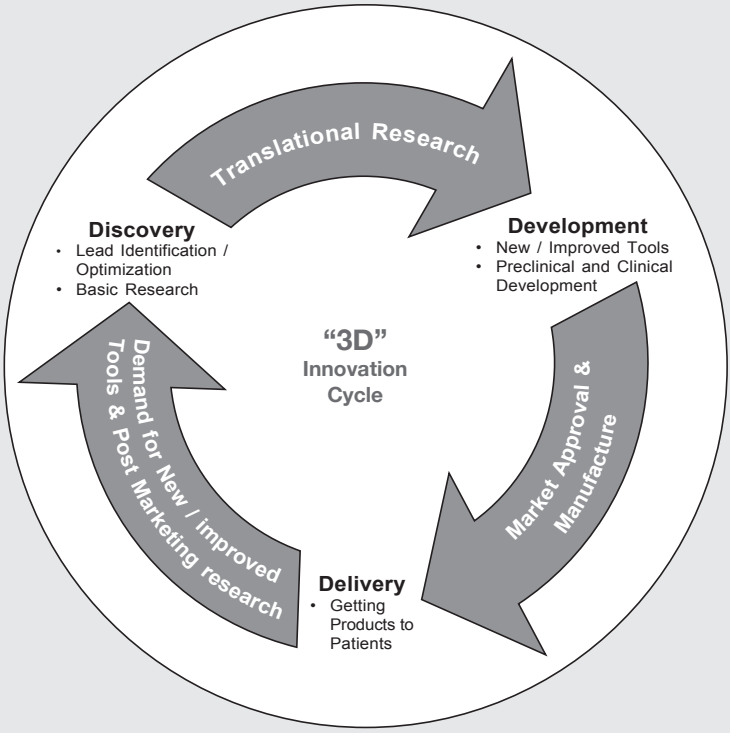
1.1 The Innovation Cycle – Building Sustainable S&T

A key lesson from the success of a number of countries in East and South East Asia is not just the need for investment in S&T, and in education, but the key role of problem-oriented innovation – the applied S&T that can solve problems and bottlenecks with new products and processes. One important lesson from South East Asia is that a problem-oriented focus – whether on new product development or on better or cheaper ways of delivering services -- seems to result in improved innovation. Scientific and technological capabilities are crucial and require resources. But these capabilities must be focused and honed on key innovation goals – improved or cheaper treatments, for example.

As the concept of a systemic approach to S&T suggests, successful innovation of technology requires more than the creation of a technology. It is important to acknowledge the complex interplay of numerous contextual factors. Innovation does not occur within a linear framework through which inputs of skills and resources at the discovery phase will automatically lead to the production of a technology product, process or service. The innovation process is in fact highly complex involving actors and linkages between industrial, education and healthcare sectors.

In recognising the complex nature of innovation, it is therefore important to consider technological innovation at all stages of the innovation cycle (discovery, development and delivery; WHO 2006). This will ensure technologies move from bench to bedside. In order for successful technological advance to occur it is important to consider the inputs, influences and obstacles that occur when a technology is researched, produced and delivered. The three stages and their linkage in health are best illustrated in Figure 1.

Figure 1: The innovation cycle



Source: WHO (2006)

Discovery, development and delivery are all stages within a cycle of innovation; they do not occur in a linear fashion but include multiple feedback loops between the stages while once a technology has been delivered, end-user feedback provides inputs on which further discoveries and adjustments to a technology can be made. In many developing countries there exists a gap within the innovation cycle, however, due to the lack of market demand for the development of products, processes and services appropriate to the disease burden of a country. No one firm or other economic unit sees investment in research and technology as in their interest or domain. That means that needs are not automatically met with investment and product development. There is a lack of incentives to ensure the linkage is made in the cycle between the delivery stage and further discovery activities. One way to incentivise investment in these areas is through the use of public-private partnerships, institutional arrangements that link the public and private sector to share the risks and benefits of R&D activities. Where investment in science and technology does occur as a result of public sector investment, that investment is often modelled on traditional notions of scientific excellence which may result in good theoretical understanding, but not on

deliverables (Chapter 1, this volume). These are just one set of a number of barriers that exist in ensuring a continuous cycle of innovation occurs. Box 1 highlights the various barriers that exist through the case study of diagnostics for tuberculosis in resource poor settings.

Box 1: Tuberculosis diagnostics in resource poor settings

Two billion people or 30% of the world's population are infected with Tuberculosis (TB). The disease results in eight million new infections and 2 million deaths every year. South Africa has the highest incidence of TB of any country in the world. TB is an infectious disease which commonly affects the lungs. Accurate diagnosis of TB is difficult in resource poor settings. The microscopic examination of sputum (mucus from the lungs) is still the only widely available diagnostic tool for identifying TB in most developing countries. However, under field conditions sputum smear microscopy shows a sensitivity of only 40-60%, partly due to the difficulty of maintaining well-equipped laboratories to perform it and the need for specialized training but mainly due to the inherent low sensitivity of the test. Poor sensitivity is exacerbated in the presence of HIV co-infection (falling as low as 20%) because it becomes difficult to see the bacilli within the sputum.

New diagnostic tools for TB detection have been developed and introduced in developed countries. However, they have generally not been adopted in resource-limited, high-burden countries due to cost, complexity, lack of laboratory infrastructure or inadequate performance in endemic settings (e.g. failure to adequately discriminate between diseased patients and latently infected or vaccinated subjects). Novel technologies successfully introduced into developed countries require adaptation to match the needs of developing countries. The perception of companies involved in diagnostic tool development that this will not lead to an adequate return on investment has hampered subsequent introduction of such tools in high-burden regions.

Much of the basic research and discovery led activities into new diagnostics for TB is therefore conducted within the academic setting or by small start up companies who lack the funds to translate their discoveries into finalized products. Lack of sufficient market data has exacerbated this situation in the past in not providing sufficient incentive to larger pharmaceutical companies who have the money to conduct costly product development and move a new diagnostic tool to market. At the same time there is a perception that distribution of new diagnostic tools will be difficult, expensive and the costs hard to predict.

In order to move TB diagnostic tool development forward a number of partnerships have been set up that bring together public funds and private sector expertise (e.g. STOP TB Partnership and the Foundation for Innovative

New Diagnostics, FIND) to ensure new products are screened and that new product developments are initiated and introduced into the market. These initiatives ensure the provision of market data and advocacy and communications activities, the support of product specification process and co-funding of product development as well as facilitation of access including assisting and building up local regulatory processes. As such, these initiatives provide a means to complete the innovative cycle not only eliminating the gap at the translational research and market approval and manufacture level but also work to create demand for these products through their communication activities.

Source: Adapted from Stop TB (2006)

Innovation also occurs at multiple levels: macro, sectoral and micro (Chataway et al. 2007) and therefore it is important to develop policy relevant for innovation at all levels. Innovation requires an enabling macro level environment created through effective regulatory frameworks and national policies that strengthen the innovative environment. At the sectoral level a health system needs the capacity to take up and absorb any new technological products, processes or services that are produced and delivered through the micro level institutions and organisations working in health innovation activities. At each of these levels there is a dynamic and ever evolving interplay between actors from different sectors (health, education, industry etc.).

Considering innovation's procurement, development and application through such a systemic lens that acknowledges the cyclical and multiple layered nature of the innovation process will better enable sustainable and long-term successful implementation of chosen technologies. The process of innovation is not only cyclical and layered but further complicated by the interplay that occurs within it. Innovation usually occurs in a path dependent fashion (previous patterns of investment, resource deployment, technological trajectories and accumulated skills limit the scope for new technology to be discovered, developed and/or delivered). More targeted health innovative activity requires a specific catalyst or dedicated manipulation of policy and the wider environment.

The policy and infrastructural environment of a country's 'health innovation system' – the network of institutions, organisations, rules and norms that conduct innovative activities to find solutions to the country's health problems – described above will impact the ability of the country to innovate – to choose, discover, develop and introduce (new) technological advances. There is also no single tried and tested way of developing a health innovation system to ensure technology innovation can occur. Every country has different capabilities and capacities that each work in different ways and are influenced by different sets of economic, social and political contexts affecting innovation. Thus, creating new approaches, new technological platforms and introducing new innovations is far from straightforward. Excellent analysis of the challenges involved has to some extent already informed efforts

to create new technologies. Recent policy thinking about 'market failures' and incentives from governments and other actors is sophisticated and challenging. Public private partnerships (PPPs) such as the International AIDS vaccine Initiative (IAVI), Medicines for Malaria Venture (MMV) and others are fully aware that developing science and technology in ivory towers and expecting smooth and unproblematic translation to product development is extremely unproductive. Yet, the challenges in creating new technologies that really address the problems are huge. Those involved in analyzing these challenges and those trying to develop and deliver new treatments are aware that the 'social technology' needed to address the medical and health needs of the world's poor is lacking. Radical improvements in the understanding of how we create new paths through research, product development and delivery are needed. New approaches to encouraging new forms of communication and institutional/organisational mixes to bridge the various gulfs in thinking and action are required.

2. Mapping Recent Advances

There have been attempts at identifying technologies that appear to provide significant opportunity in combating diseases of the poor in Africa (cf. Daar et al. 2002; Grand Challenges in Global Health 2005; Jamison et al. 2006a; UN Millennium Project 2006). In particular, increased importance is being placed on biomedical and biotechnical advances in the life sciences, biotechnology and other technological advances over more systemic and social based technological advances to control diseases affecting developing countries. Of note are two reports which highlight these differences: the 2002 'Top Ten Biotechnologies' report (Top 10 report; Daar et al. 2002) from a group at the University of Toronto and the more recent Disease Control Priority Project's second report (DCP2; Jamison et al. 2006a).

Daar et al. (2002) outline the results of an in-depth survey of 28 eminent scientists and health policymakers to identify priority technologies to be used to improve the health of populations in developing countries. The report listed the following 10 biotechnologies as having the potential to improve health in developing countries: molecular diagnostic tools such as PCR (polymerase chain reaction); recombinant vaccines; vaccine and drug delivery systems; bioremediation (for environmental improvement); sequencing pathogen genomes to identify new anti-microbials; female controlled protection against sexually transmitted infection; bioinformatics; nutritionally enhanced genetically modified crops; recombinant therapeutic proteins and; combinatorial chemistry for drug discovery.

Jamison et al. (2006a) outline – amongst other things – the science and technology with the potential for future disease control in terms of biomedical research. The new technologies that it lists are: genomics, proteomics and cell biology; stem cell and organ therapy; information technology; diagnostics and hospital practices (surgery); human development and child and maternal health; neuropsychiatry; nutrition and genetically modified crops; social and behavioral science and; health systems and health economics.

What is important to note at this point is that the Top 10 report is exclusively dealing with technological advances relating to biotechnology[2] acknowledging the potential of genomic based solutions outlined in the 'Genomics and World Health' report (WHO 2002). It is principally an exercise in foresight that places the emphasis on scientific progress. The DCP2 report does place an emphasis on biotechnology based solutions but it does not focus exclusively on them. The focus of this report is on disease control more generally and how to reduce the incidence of disease within developing countries. In particular the emphasis is placed on where to allocate scarce resources within the health system. As such this report acknowledges that potentially useful technologies include process based technologies and social systems focused on human development and strengthening health systems.

Finding solutions to the chronic health problems that affect many African countries (as a result of diseases such as HIV/AIDS, TB and malaria) involves improved capacities to conduct scientific research to produce new drugs, vaccines and diagnostics. However, the argument put out in the DCP2 report suggest that equally important process based technological advances are required to ensure the technological products can be delivered appropriately and effectively. The DCP2 report highlights the importance of focusing not only on the development of purely scientific and technological product and processes as a means of combating disease but also on the need to have good organisational and institutional mixes; the importance of good 'social technology'.

Decisions about a choice of technology can be made based on a wide range of factors. Decisions about how a technology is sustainably developed and delivered can involve complex trade offs such as between short term gain (immediate results e.g. reduced disease burden) and longer term health returns (building sustainable health systems and processes). Trade-offs are also required between specific health related S&T e.g. development of drugs and vaccines for HIV/AIDS and other less 'technical' options that are also important e.g. clean water and improved sanitation.

The trade-offs (and their implications for the degree of focus on biotechnology based technological advances alone) require consideration if useful and relevant scientific and technological opportunities are to be advanced that have the potential to combat diseases of the poor in Africa. Thus in 2006 we conducted a mapping exercise that used these two reports as a base and aimed also to consider the opportunities relating to social innovation as well as science and technology. The mapping exercise consisted of an extensive literature review and a Delphi-type survey of prominent scientists and health policy makers the details of which are given below.

2.1 Survey Process

Using principally survey techniques – particularly an adapted Delphi technique – we aimed to gain an insight into what the major experts in public and international health, science

and medicine believe are the scientific and technological advances with the greatest potential to address Africa's major health challenges as well as the barriers to their advancement. The survey data was added to material gained from a literature survey and analysis in order to develop an overview – particularly working using case studies – of initiatives and areas of attention that offer hope or need scrutiny by African policy makers and the international community in order for the identified scientific and technological advances to be maximised.

Over 100 key experts from around the world were emailed twice using a similar format to a 'Delphi' survey. The experts included those particularly from Africa who are key medical and biological scientists as well as those involved more generally in the field of public and international health and specifically the diseases of poverty. We also contacted key actors from global health initiatives and those working in interesting new initiatives such as drug trial centres, multi-disciplinary clinical ventures, vaccine initiatives, etc. The response rate was not as high as expected with a 15% response rate to the first email and a 10% response rate to the second. A restricted time scale was the principal reasoning for the low response rate. The respondents were not always the same people on both occasions. Respondents came from a range of specialisms both from within the traditional and social sciences.

The first round of the survey consisted of an email requesting the respondent to rank in order of importance what they saw as being the five recent advances in the life sciences and related technological innovations that offer greatest potential to address Africa's major health challenge. We also asked respondents to list the key barriers to advancing these technologies in, and for, Africa in the next few years. A number of the responses were followed up with telephone calls to discuss the responses in more depth.

The replies were analysed and a list produced outlining the most frequently and highest ranked responses received by those that responded to our survey. These were then tabularised (see Table 1) alongside the technological advances identified in both the Top 10 and DCP2 reports.

Table 1 was then sent out by email to all 100+ experts who were asked to review the table and pick out five of the technologies listed that they saw as having the greatest potential to address Africa's health challenges, and to list their reasoning for the choices they had made.

Table 1: Recent health technologies with potential to address Africa's health challenges

Top 10 Biotechnology	DCP2	Our Survey
Molecular diagnostic tools such as PCR (polymerase chain reaction)	Genomics, proteomics and cell biology	HIV/AIDS treatment in the form of anti-retroviral drugs
Recombinant vaccines	Stem cell and organ therapy	Insecticide treated bed-nets for malaria
Vaccine and drug delivery systems	Information technology	Artemisinin based malaria drugs
Bioremediation and environmental improvement technologies	Diagnostics and hospital practices (surgery)	Information technologies
Sequencing pathogen genomes to identify anti-microbals	Human development and child and maternal health	Vaccines
Female controlled protection against sexually transmitted infection	Neuropsychiatry	Diagnostics
Bioinformatics	Nutrition and genetically modified crops	
Enriched genetically modified crops	Social and behavioral science	
Recombinant technology for therapeutic products (e.g. insulin)	Health systems and health economics	
Combinatorial chemistry for drug discovery		

The results gained are outlined below. The exercise aimed to feed back those advances most mentioned by experts first to obtain a sense of whether there is consensus. However, and as importantly, the exercise also attempted to move beyond lists, by looking at reasoning for choice, in order to gain more in-depth insight into the implementation and access issues that require attention.

2.2 Survey Results

The survey is not intended to be representative or statistically significant but to get a snap-shot view of current thinking and trends. The survey was also not intended to supersede the work conducted by University of Toronto or the Disease Control Project. Instead the survey was designed to complement these studies and see if attitudes and perspectives had moved beyond biotechnology related advances in the way that the DCP2 report suggests. Thus the results of our survey and the discussion that follows are presented here in conjunction with the results of the Top 10 and DCP2 reports.

Table 2 outlines the results of the survey. Two of the advances highlighted in our survey are more disease specific than those mentioned in other reports: HIV/AIDS treatment and malaria treatment/prevention. Rather than emphasising general life science based technological advances the respondents in our survey highlighted the importance of combating HIV/AIDS and malaria due to the high disease burden inflicted by these diseases on Africa's populations with one respondent saying the starting question that needed to be asked was, *"what is the evidence of the effect of having the technologies in place".*

As such respondents felt:

> *"I believe vaccines would be directly pertinent to the three leading infectious disease burdens of HIV, TB and malaria (as well as a few other cause infections) and an affordable, effective, and practical vaccine would directly avert a large amount of morbidity and mortality."*

> *"HIV/AIDS treatment via ARVs – most immediately beneficially effect for those infected with HIV."*

In particular the main disease specific technologies put forward included antiretroviral (ARV) treatment for HIV/AIDS, vaccines for HIV/AIDS and malaria together with malaria drugs based on artemisinin. In the first round of the survey we also received a large number of inclusions of microbicides against HIV/AIDS and long-lasting insecticide treated bednets for malaria. Other less frequently cited technologies which are also less traditionally 'scientific' in make up were cell phones, the internet, residual spraying for malaria control, clean water and sanitation.

Other respondents chose to focus on generic life science based technological advances. The decision to focus on generic technological solutions was highlighted by one respondent who in the second round picked the category of 'genomics, proteomics and cell biology' as the main technological advance with most potential arguing *"these cut across all subjects, and carry potential for use by local scientists to address their own national problems."*

Table 2: Health technologies ranked in order of potential to address Africa's health challenges

Top 10 Biotechnology	DCP2	Our Survey
Molecular diagnostic tools such as PCR (polymerase chain reaction)	Genomics, proteomics and cell biology	Vaccines (including delivery systems
Recombinant vaccines	Stem cell and organ therapy	Diagnostic tools
Vaccine and drug delivery systems	Information technology	HIV/AIDS treatment in the form of anti-retroviral drugs
Bioremediation and environmental improvement technologies	Diagnostics and hospital practices (surgery)	Nutrition and genetically modified crops
Sequencing pathogen genomes to identify anti-microbials	Human development and child and maternal health	Health systems and health economics
Female controlled protection against sexually transmitted infection	Neuropsychiatry	Sequencing pathogen genomes to identify anti-microbials
Bioinformatics	Nutrition and genetically modified crops	Malaria treatment (with Artemisinin) & prevention (with bed-nets)
Enriched genetically modified crops	Social and behavioral science	
Recombinant technology for therapeutic products (e.g. insulin)	Health systems and health economics	
Combinatorial chemistry for drug discovery		

Four main generic life science advances were mentioned most frequently in our survey. Recombinant vaccines and their delivery systems were seen to be important because they *"[w]on't be the answer to everything, but there are still huge gaps in infectious disease control, resulting in great disease burdens"* and are *"[l]ikely to provide protection for a variety of diseases in a safe manner."* It was felt that *"[t]here will be no effective treatment at individual and community level if we do not have the respective diagnostic tools and strategies at the point of care (i.e. not in any specialized centre, possibly even in the North)."* GM crops and *"better nutrition and crop yields would not only yield better food security and reduce hunger (another MDG) but also help improve performance at school and generate at the family/village level excess marketable produce which can start to create wealth to reduce poverty."* The fourth generic advance that was identified was sequencing of pathogen genomes to identify microbials.

In fact the reasoning for a technology's inclusion by respondents differed slightly in each

of the two Delphi rounds. Predominately in the first round of the Delphi many of the respondents to our survey highlighted how burden of disease was one of the main factors influencing their ranking decisions. Ranking decisions in the first round were also based on the degree to which technologies were also readily available for introduction. In the second round, the reasoning given was much more placed on optimism and the need to improve difficult current situations as quickly and as efficiently as possible.

Such reasoning echoes that found by the researchers of the Top 10 report who reported the following factors as being important in assisting biotechnological advance:

- Impact
- Appropriateness
- Burden
- Feasibility
- Knowledge gap
- Indirect benefits

The need to consider multiple reasoning in choosing technology is illustrated by this quote taken from an interview of one respondent:

> *"ARV trials are getting quite exciting and showing promising results. Certainly potential is there but treatment and care needed includes HIV/AIDS prevention, counselling and testing, nutritional management, and, of course, access to ARV drugs. Money needs to be invested in education, training and healthcare resources as well as in developing new drugs. Besides, national and local policy leadership is a big issue."*

The difficult choices required in deciding which technologies to focus on were also highlighted by another respondent:

> *"I'm having real trouble with the lists. I think it's very tough to compare, for example, "health systems and health economics" with, for example, "recombinant technology for therapeutic products" and tougher still to compare "human development and child and maternal health" with "sequencing pathogen genomes to identify anti-microbials". Of course, none of the rest of it makes much difference unless you have a health system (of some kind -- maybe more private sector than public but still a system) or a commitment to human development so I suppose those things have to go to the top of any list."*

An emphasis throughout the survey – and as illustrated by the above quote – was also placed by respondents on the need for integrated approaches – the need to focus on more than one of these technological advances at any one time:

> *"It is the combination of ACT [Artemisinin-based Combination therapy] with the*

use of bednets that will make a huge difference. I deliberately put them together as only the integrated approach of combining the curative and the preventive approaches will lead to success"

"I believe the shortage in many countries of capable health workforce and weak health systems, if they were addressed successfully, would enable the delivery of a range of cost-effective interventions such as bednets. The effective use of health systems/ health economics would lead to the use of other valuable technologies. Without the systems and economic tools, the justification for prioritizing these technologies may not be so clear and the resources to deliver them may not be developed."

The inclusion of health systems and health economics was therefore identified as both a barrier and an advance in dual measure. Weak health systems and poor economic tools were seen as hindering the ability to introduce and use other potential technological advances. Stronger and more effective health systems were seen to provide an enabling environment necessary to ensure that technologies were developed and their opportunities realised. Functioning health systems were seen as an overarching requirement for all the other activities and technological advances to take place. An emphasis was not so much placed in this respect on science and technology but more on the need for innovation in the area of health systems and their analysis. More specifically these answers relate to the importance of 'social technologies' or the importance of the right organisational and institutional mix throughout the research-development-access continuum.

Thus our mapping exercise has highlighted three types of technological advance with the potential to combat diseases of the poor in Africa. We have identified a number of generic life science and biotechnology based advances in the form of vaccines, diagnostics, genome sequencing and GM crops. Secondly we have identified a number of disease specific interventions for malaria and HIV/AIDS. And thirdly, we have identified the importance of 'social technologies' or the organisational and institutional mix that is necessary to ensure successful development and/or uptake of the generic scientific and disease specific technological advances.

This final set of technological advances relates particularly to the reference by respondents to the importance of health systems and health economics. This reference is a worrying reminder that problem-oriented R&D has to include analysis of the problem of how to deliver new health innovations. Just as products must now be designed for use as well as for cheap manufacture and recycling, health technologies must be designed in function of their use in difference types of location.

As such, this initial assessment of new technologies highlights the need to think hard about policies and practices that pull together new science and technology, like 'sequencing of pathogen genomes' with choice factors such as 'the burden of disease'. This requires radical

new ideas that link science, technology and innovation communities with health practitioner communities, locally, nationally, regionally, and internationally.

3. Mapping Technologies and their Application

As highlighted above, in reviewing our survey results and the Top 10 and DCP2 reports, we can identify six life science based technological advances and one 'social technology' advance (health systems and health economics) that have the potential to address Africa's health challenges from diseases such as HIV/AIDS, tuberculosis, malaria, cholera etc. These can be grouped into the following categories:

1. Generic life science based technological advances:
    - recombinant vaccines;
    - diagnostic tools;
    - sequencing of pathogen genomes to identify anti-microbials; and
    - genetically modified crops.

2. Disease specific technological advances for HIV/AIDS and malaria:
    - Vaccines for HIV/AIDS and malaria;
    - Malaria drugs;
    - HIV/AIDS drugs; and
    - Microbicides.

3. 'Social' technology innovations particularly in the form of functioning health systems and their analysis. These relate to the need for the correct combination of funding, infrastructure and skilled personnel who are linked into supporting networks.

Each of these will now be introduced before more in-depth analysis in Section 3.4 of their potential and impact, status and constraints impacting their advance. The discussion of these technologies in this section uses the work of the Toronto group's Top 10 report as a base and updates this information where appropriate. The decision to include in this discussion the concept of a 'social technology'[3] is due to the importance of advances in the (social) interactions between and within innovation communities and those working within the health system as much as the importance of having a new drug, vaccine or diagnostic available.

3.1 Generic Life Science Based Technological Advances

The Top 10 report highlights the importance of biotechnology based technological advances and the potential of a number of these to combat diseases of the poor in developing countries (see Table 3). Our mapping exercise highlighted three of those listed in this table which are deemed to provide an opportunity to address the main health related MDGs of combating poverty, reducing child mortality and improving maternal health. These, together with GM

crops which the Top 10 report also highlighted and which is seen as necessary to contribute to the MDG on improving children's nutrition, will now be discussed. We will consider the current status and (the extent to which they are available and being used in Africa).

Table 3: Priority biotechnologies identified in the Top 10 report

Technology	Advantages	Examples
Recombinant Vaccines	Reduced risk compared with attenuated vaccines & rational vaccine design	Malaria subunit vaccine RTS,S (with AS02 adjuvant) in phase 3 clinical trials in children in Mozambique
Improved vaccine and drug delivery methods	Needle-free technologies reduce need for trained personnel, risk of HIV infection controlled, release systems help overcome non-compliance heat-stability & eliminates need for refrigeration	Temperature-stable, controlled-release formulations of synthetic peptide analog of hepatitis B antigen and trehalose ester derivatives
Sequencing of the genomes of pathogens and their vectors	Boosts search for novel drugs and vaccines & improves understanding of disease mechanism	Ten strains of West Nile disease vector *Culex pipiens*, one strain of malaria-carrying *Anopheles gambiae* have same point mutation in acetylcholinesterase for insecticide resistance
Molecular diagnostics	Early detection, timely intervention, helps prevent spread of infection & avoids waste of resources on inappropriate treatments	Dipstick assay for the detection of *Salmonella typhi*-specific IgM antibodies, same-day results, small volume of serum needed, stability of reagents and simplicity of assay allow use in absence of laboratory facilities
Recombinant proteins	Synthesis by transgenic plants and animals & potentially cheaper than mammalian cell culture	Cheaper biosynthesis of antimalarial artemisinin by *Escherichia coli* engineered to express yeast mevalonate isopreniod pathway proteins
Combinatorial Chemistry	Rapid generation of many varieties of chemical compounds; Increased efficiency, potentially lower costs, fewer by products	Two new classes of drugs inhibit *Leishmania mexicana* cysteine protease, found from combinatorial library of 150,000 compounds

Source: Lambo (2005) and based on Top 10 report findings

3.1.1 Recombinant vaccines

Biotechnology has helped in the development of recombinant vaccines with many advantages over conventional technology, and has been applied to develop new and improved diagnostic assays which are cheap, rapid, sensitive and strain specific. The classic types of vaccines are all limited in their dependence on biological products, which often must be kept cold, may have a limited life, and can be difficult and expensive to produce. The development of recombinant vaccines – those using chromosomal parts (or DNA) from a different organism

inserted into a foreign cell[4] - has generated hope for a new generation of man-made vaccines.

Vaccines stimulate an immune response in the body and can therefore reduce the chances a person has of an infection contracting a serious level of infection. Vaccines are the ultimate prevention tool being responsible for the total eradication of smallpox and the virtual eradication of polio in the world. However, vaccine science is complex and not every infection and disease has a vaccine against it. This is particularly true of the big killers, HIV and malaria while the tuberculosis (BCG) vaccine was developed nearly 100 years ago and its effectiveness is questioned (Novelli 2006).

Traditionally vaccines were either killed or weakened (attenuated) forms of whole pathogens. With modern recombinant technology it is possible to be much more precise in controlling vaccine characteristics. It is therefore possible to work with only specific parts of an infectious organism (in the case of subunit vaccines) through the antigens. One such vaccine is the hepatitis B vaccine. One of the first recombinant vaccines to be approved for human use is made using recombinant yeast cells genetically engineered to include the gene coding for the hepatitis B antigen. Because the vaccine contains the antigen, it is capable of stimulating antibody production against hepatitis B without the risk that live hepatitis B vaccine carries by introducing the virus into the blood stream.

Other molecular biology tools have made it possible to identify which proteins are conserved among different strains of a virus or bacteria, or which are responsible for virulence of pathogens or oncogenesis in tumours. These proteins may be good candidates for vaccines. There are also novel approaches being taken to produce what are known as naked DNA vaccines which use a plasmid (a circular piece of DNA that self-replicates) as a vehicle to carry a pathogen into the body against which the body produces antigens to stimulate immunity. These are novel because they would not require a cold chain mechanism which currently hampers much immunisation effort in Africa. Plant vaccines also offer hope. The most promising option here is not necessarily vaccines being developed in plants which are then eaten but where antigens are expressed from plants such as tomatoes or potatoes and then processed into a dose regulated form such as a capsule which again requires no cold chain and can easily be taken involving no needle pain. As medical knowledge has increased researchers worldwide are working towards developing new vaccines and therapeutics for cancer, tuberculosis, melanoma, AIDS, influenza, and malaria based on r-DNA.

3.1.2 Diagnostic tools

The use of accurate diagnostic tools to detect pathogens through associated molecules such as DNA and proteins in cells and blood is vital in controlling disease. As such the group of experts surveyed in the Top 10 report voted accurate diagnostic tools as “the most prominent biotechnology for improving health in developing countries in the next 5-

10 years." In particular the report mentioned advances in PCR, monoclonal antibody and recombinant antigen technologies as having the potential to revolutionise the diagnostic tools that are available for disease control in developing countries.

Several enzymatic amplification processes, generally categorised as nucleic acid amplification techniques, have been developed and introduced as commercial products in developed countries. The most widely used are PCR, TMA (transcription modified amplifications) and SDA (strand displacement amplification). PCR allows for the production of multiple copies of a specific DNA sequence quickly, safely and accurately. This technique can be conducted within hours rather than days and can be used to identify more dangerous pathogens to work with very safely (e.g. HIV). The technique can also identify pathogens that are difficult to produce in laboratory conditions in the case of malaria and tuberculosis. The rapid and accurate diagnosis of tuberculosis remains a major challenge for all developing countries and particularly for Africa with TB in HIV positive individuals, in children and in patients with extrapulmonary form of TB. PCR is increasingly being used to test for drug resistance at the same time as identifying the disease pathogen. However, the level of sophistication, complexity (requiring trained laboratory personnel) and cost associated with the technique restricts its general application in resource-poor settings.

Anti-body coated dipstick tests (see Box 2) that diagnose disease are increasingly used both within the clinical healthcare setting particularly in developing countries where electricity and water are in difficult supply (they are single-use test kits) and where more advanced medical centres are located at long distances from a community. Developments in the areas of monoclonal antibodies (a number of identical mass produced cells from a single parent cell) and recombinant antigens (mass produced antigens that are created by genetically engineered organisms e.g. bacteria or yeast) are also used as the base for dipstick tests (such as PATH's HIV1 dipstick test) as well as ELISA (enzyme-linked immunosorbant assay) screening where basic laboratory equipment is available to detect antigens and antibodies.

Although PCR and the other technologies have provided opportunities for the creation of simple to use, rapid test kits, the cost of these kits and PCR can be expensive. The cost of PCR testing is being reduced through the development of methods to test for more than one disease at a time (multiplexing) and by modifying the storage and processing techniques it requires, however the cost of these technologies may make these diagnostic tools beyond the reach of many governments with limited budgets and competing demands on funds. There has been successful transfer of PCR technology to developing countries through the work of the Sustainable Science Institute in San Francisco and the Swiss Tropical Institute in Tanzania with the local modification of equipment and the recycling of reagents (Harris and Tanner 2000).

The DCP2 report highlights how other non-biotechnology related advances are also occurring in the diagnostic tools area which include advances in imaging techniques such as magnetic resonance imagine (MRI) scans, computer tomography and ultrasound. These have the

opportunity to revolutionise healthcare in the developing world although the cost of these technologies make them out of reach for many healthcare providers in the developing world.

Box 2: New dipstick test

The development of a pioneering new diagnostic tool for trachoma could help to eradicate the most common cause of blindness due to infection.

Dr. Helen Lee and Claude-Edouard Michel of the Diagnostic Development Unit at the University of Cambridge, and collaborators, have developed and trialled a rapid dipstick test that can diagnose the presence of infection within half an hour. The new 'point-of-care (POC) test' was developed specifically for use in developing countries, as it is cheap, quick and simple to perform, and requires no expensive equipment or skilled labour.

Dr Lee and team then compared the accuracy of this new dipstick test with the gold standard polymerase chain reaction (PCR) test in a trial in remote trachoma-endemic villages in Tanzania. The trial [in 2004 and 2005], involving 664 children aged 1-9, showed that the dipstick test was more accurate in identifying the presence of infection, correctly predicting over 97 per cent of cases, against 43.6 per cent for the current method.

The findings could profoundly influence the future diagnosis and treatment strategies for trachoma worldwide.

Source: www.wellcome.ac.uk

3.1.3 Sequencing of pathogen genomes

PCR technology enables the efficient sequencing of pathogen genomes. The opportunities afforded by this form of genome sequencing and that of parasite genome sequencing provides the base for much modern health research. As such the Top 10 report highlighted it as a ‘priority area’ while WHO devoted a whole report to the potential impact of genomic research on world health in 2001 (WHO 2002). Genes regulate the organisms within the biochemistry pathway and it is from this base that most diseases can be defined. As such the sequencing of genomes provides a means of understanding how a disease is caused or the makeup of a parasite and how it may be controlled. Sequencing – via a process called the Sanger or Dideoxy method – is the discovery and recording of the nucleotide sequence within an organism’s DNA. Knowing the sequence of a genome is the first step to understanding its biology and finding ways of controlling it.

Genome sequencing is not only used in diagnostic tools such as PCR. Genome sequencing is also providing an input into the production of vaccines and drugs by providing information as to the gene sequence characteristics of important proteins. It is also possible to compare

genomes of disease carrying strains and non-disease carrying strains of organisms to find the differences that can be used as a way forward in drug and vaccine production.

Genome sequencing provides the opportunity to map the genetic layout of disease pathogens, parasites, humans and animals (see Box 3). This provides a means of determining genetic variability around the world between different species, countries and population groups. Sharing genetic information between researchers through free websites such as HapMap (www.hapmap.org) provides a means for all scientists throughout the world to be able to access this information. Similarly, creating gene banks where large pools of generic data are created is another source of data sharing which can be used as a base for research. This is particularly important in the emerging field of bioinformatics whereby data is assembled using computer based models and tools to search genetic data for clues about genetic makeup and how to control and identify disease.

Unfortunately there are numerous scientific obstacles and a lack of understanding still around how genes are expressed (Bentley 2004). Along side this are institutional roadblocks that limit the access and knowledge around genomic sequencing. Currently the big genome projects are based in the UK and the USA and the lack of genomic based research in the developing world has created the phrase ‘the genomic divide’. The global genome mapping project, HapMap, includes developing countries such as Nigeria while South Africa has invested in setting up a bioinformatics institute and encourages private health biotechnology firms to set up around innovation centres. On the whole however, the amount of basic research, such as around genome sequencing, within biotechnology that is conducted in Africa is small.

Box 3: Pathogen genomes

"The parasite genome is very plastic," explained Dr Manolis Dermitzakis, co-leader of the project from the Wellcome Trust Sanger Institute, "and carries the scars of its battle against its three main challenges - our rapidly evolving human immune system, the defensive responses of the mosquito and the insecticides and drugs we use to challenge it."

"Our variation studies bring biology to the parasite genome, uncovering the secrets of Plasmodium without - but as a prelude to - work in the lab. Our overview of evolution points to those gene variants that are responsible for disease effects - some were expected, but some are surprises."

Humans infected with malaria often carry several variant strains. A consequence is that vaccines to combat malaria are very difficult to develop and may become ineffective if the parasite switches its coat. Moreover, the range of parasite diversity means that resistance to new drugs can become rapidly established from small numbers of existing resistant organisms. Widespread resistance to chloroquine has developed in only 50 years.

The Plasmodium map of variation can be used alongside maps of human variation, such as the HapMap or that of copy number variation published in Nature recently by a team from the Sanger Institute, to understand how the genome of each has been moulded by the activities of the other.

"The human genome carries imprints of our history of infection by malaria", commented Dr Mark Walport, Director of the Wellcome Trust. "Similarly the genome of the malaria parasite shows how it interacts with the human immune system. Understanding these interactions is key to the development of effective vaccines against malaria."

The new map was developed with biological expertise from researchers at St George's, University of London and the Weatherall Institute of Molecular Medicine, University of Oxford, John Radcliffe Hospital, Oxford. It is a snapshot of Plasmodium evolution, and provides a wealth of information for the malaria community, for example, by identifying genes that evolve too rapidly to be good drug targets. It shows researchers where to search for new treatments and where to avoid.

Source: www.sanger.ac.uk

3.1.4 Genetically modified crops

Improved nutrition can significantly improve the life chances of infants in the developing world where malnutrition affects one in five people. One way of doing this is to genetically modify staple foods such as cassava, maize, potatoes and rice. Traditionally to improve a species of plant, farmers have cross breed two species to mix the genes and introduce new genes into a plant. Genetic modification is a modern, biotechnological equivalent by which a plant's composition is modified by artificial means. This enables genes from one species to be inserted into an unrelated species. Gene technologies can produce new varieties more quickly than conventional breeding (Nuffield Council on Bioethics 2003). The usual method is to insert a gene into an organism so that as that organism grows the genes are taken up by the cell in which its placed. One example of this is Golden Rice, a variety of rice that was modified to contain added vitamin A and iron.

Up to now, most GM crops have been grown with just two characteristics – herbicide tolerance and insect resistance. Herbicide tolerance allows, in principle, farmers to kill weeds but not crops, sometimes using less herbicide over the whole growing cycle. Similarly, insect resistance allows, in principle, farmers to kill insects without damaging crops, sometimes allowing fewer applications in total, lowering labour and insecticide. However, other characteristics are possible with genetic modification, such as drought resistance, ripening control, fat content, and nutrition.

There are arguments against the use of GM crops. These focus on issues of risk to humans,

animals and the overall ecosystem balance in the production and consumption of GM crops. At times these become part of a wider discussion around the way new technologies should be regulated (Tait and Chataway 2007). This has led to resistance on the part of many people to the introduction of GM crops including the refusal of some countries to receive food aid from GM sources (Scott 2004). Proponents of GM crops however argue that they could have significant potential on farming production and food production similar to the impact of the 'green revolution'.

One example is that of Vitamin A enhanced (Golden) rice has been produced with the primary aim to help prevent vitamin A deficiency (VAD), which affects 14 million children under five and is a prime cause of blindness. About 250 million children had sub-clinical deficiency, one-third of whom live in rice eating areas of Asia. There are arguments about whether golden rice is just a technofix, but public-private partnerships between companies and researchers are ongoing, linked to building regulatory systems so that clinical trials can ascertain whether the vitamin A in the rice will be taken in by the body. Research is also taking place on vitamin A sorghum, including via a large consortium, the African Biofortified Sorghum Project, funded by the Grand Challenges in Global Health Initiative of African, American and Japanese institutions to enhance sorghum with iron, zinc and vitamin C (AU/NEPAD 2006). Others are working on nutritionally enhanced cassava and protein enriched potato.

3.2 Disease Specific Technological Advances for HIV/AIDS and Malaria

During our mapping exercise HIV/AIDS and malaria were two diseases that featured prominently as those contributing to the significant burden of disease affecting many countries in Africa. WHO (2005) estimates that 3.2 billion people a year are affected by a bout of malaria and 1.2 million are killed. The highest mortality is amongst children and those living in Africa where 90% of all malaria related deaths occur. About 39.5 million people are infected with HIV/AIDS in the world. Of the 4.3 million new infections estimated to have occurred in 2006, 65% were in Africa. The region now has 24.7 million HIV/AIDS infected people (WHO/UNAIDS 2006).

Research into finding treatments and preventive technologies for these two diseases has traditionally been hampered by low levels of funding and investment, particularly by the private sector in the industrialised world – where much of the expertise and funding lies. The increase in funding sources through philanthropic organisations e.g. the Bill and Melinda Gates Foundation, and the development of new financing mechanisms e.g. International Financing Facility for Immunisation are providing ways forward. There are also increasing calls for African governments to take increasing responsibility and build their capacity to do so (Dickson 2008; Hanlin, 2008).

Very significant amounts of money are being spent on HIV/AIDS research. In the period 2002 -2006, the EU spent 74.3 million Euros, however the US is by far the biggest country

donor contributing 86% of all public funds raised for HIV vaccine research and 74% of all microbicide investment. Overall, the US National Institute of Health spends approx US$2 billion annually on HIV/AIDS research although of course not all of this will be relevant to developing countries. The science of antimalarial drug research has moved rapidly in the past decade through a large networked approach with funding increasing considerably. The European Union committed approximately 43.1 million over the period 2002-2006 (IAVI 2006). Total expenditure on malaria R&D in 2004 was estimated at US$323 million predominately due to contributions from the US National Institute on Allergic and Infectious Diseases and the Bill and Melinda Gates Foundation. The combined investment of these two groups constituted 49% of malaria R&D investment. Three quarters of this money was given to entities conducting research and research managers (particularly the partnership groups of Medicines for Malaria Venture [MMV], Program for Appropriate Technologies in Health (PATH's) Malaria Vaccine Initiative and WHO's Tropical Disease Research group).

Funding shortfalls for both HIV/AIDS and malaria R&D exist and few African countries contribute significant national funds to promote such R&D investment with the exception of South Africa which has heavily funded HIV vaccine development activities and to a lesser extent microbicide research (de Francisco and Matlin 2006). Even once these products are developed there is still however a major constraint to be overcome that is more than simply financial. All drug, vaccines and diagnostics require strong access pathways and this requires good distribution networks and demand for affordable, effective, easy to use products. These access issues also need to be considered during discussions around developing specific disease related technological innovations.

Technologically and scientifically there have also been barriers to advancing treatment and prevention options. These will be discussed in more depth in Section 3.4 however it is important to note here that, although great strides have been made in the areas of drug treatments for HIV/AIDS and malaria, hope is provided by advances in other directions as well. These come in the form of anti-AIDS drugs being used as a preventative (pre-exposure) prophylaxis, improved condoms (both male and female), cervical barriers (such as microbicides) and male circumcision (Padian et al. 2008; The Economist 2008). Advancement in vaccine science for both malaria and HIV/AIDS has been much slower. It is expected that a malaria vaccine will be produced in the coming years with a number of malaria vaccine candidates having undergone and in the process of Phase III testing. An HIV vaccine is however still much further off. The lack of success in preventative biomedical advances such as vaccines and microbicides has led to a call for 'combination prevention' whereby known preventative methods (such as condoms and circumcision) are combined with treatment of HIV/AIDS (Cohen 2008). Again however, the emphasis here is on treatment and prevention of two of the 'big three' (HIV/AIDS, malaria and TB) at the expense of other neglected diseases.

3.2.1 Malaria drugs

The malaria burden on Africa demonstrated above is made worse by high levels of drug resistance hampering treatment efforts. In recent years many countries in Africa have had

to change their first line malaria drugs due to growing resistance particularly of *Plasmodium falciparum* malaria to traditionally used treatments using chloroquine and even more recent Sulfadoxine/Pyrimethamine treatment introduced in the wake of chloroquine resistance. The WHO now recommends the use of artemisinin based treatments. Artemisinin drugs first introduced in South-East Asia a little over a decade ago have proven to be well tolerated and the most potent of antimalarials. However, artemisinin drugs have a very short half-life and thus a multiple dose regimen of seven days is required to achieve an acceptable cure rate. When artemisinins are used as monotherapy, recrudescence of malaria is common. Combining an artemisinin drug with a partner drug that has a longer half-life improves the efficacy of the artemisinin. It also reduces treatment duration with the artemisinin and the likelihood of development of resistance to the partner drug.

The R&D required to produce these new combination therapies and the uncertain return on investment has reduced the degree international pharmaceutical companies are willing to invest in producing malaria drugs. To incentivise investment new innovative partnerships are being used. One example is the work of MMV, a not-for-profit organisation which aims to "bring public, private and philanthropic sector partners together to fund and manage the discovery, development and registration of new medicines for the treatment and prevention of malaria in disease-endemic countries." (www.mmv.org). MMV currently has over 20 projects in its portfolio, representing what is widely viewed as the largest antimalarial drug research portfolio ever. Following a fifth call for proposals which closed in February 2006, MMV's Expert Scientific Advisory Committee recommended seven new projects be added to the portfolio, subject to contract and availability of funding. These projects include one development project, four discovery projects and two natural products projects. MMV has included two fixed combinations of artesunate, a semi-synthetic derivative of artemisinin, with other known antimalarials to create chlorproguanil-dapsone-artesunate and pyronaridine artesunate in its portfolio which show promise as new affordable ACT drugs for malaria treatment (see Box 4).

Box 4: Malaria drugs

Chlorproguanil-dapsone-artesunate (CDA) in sub-Saharan Africa
GlaxoSmithKline (GSK), the World Health Organisation's Special Programme for Research and Training in Tropical Diseases (WHO-TDR) and MMV are collaborating in the development of the drug – a new-fixed dose artemisinin combination therapy, combining chlorproguanil, dapsone and artesunate, known as Chlorproguanil-dapsone-artesunate (CDA). CDA, which could be a major weapon against malaria, is a fixed-ratio three-drug combination of Lapdap™ with an artemisinin derivative, being developed to treat uncomplicated Plasmodium falciparum malaria. A Phase II dose-ranging study in adults and children with acute uncomplicated malaria has been completed using sites in the Gambia and in Malawi, and the choice of artesunate dose for the fixed

combination is now finalised. A Phase III clinical development programme prepared according to International Conference on Harmonization (ICH) guidelines and the UK Medicines and Healthcare products Regulatory Agency (MHRA) is underway in several African countries. In addition, a longitudinal 'Phase IIIb' trial is being designed at present, and discussions around the design of a possible Phase IV programme are underway.

University scientists have already collaborated with GSK and other partners to develop the anti-malarial, Lapdap™. This drug has a short half-life, which creates a short 'resistance selection window' or exposure period, to the parasite, helping to preserve its anti-malarial efficacy. CDA has been created by adding artesunate to Lapdap to create a fixed-dose therapy and should bring greater therapeutic benefits including more rapid parasite clearance from the blood and reduced risk of drug resistance.

Pyronaridine and Artesunate (PANDA) fixed dose combination
Pyronaridine-Artesunate is a new fixed-dosed combination based on artemisinin combination therapy, currently the most effective type of antimalarial treatment. The novel formulation technology applied to both drugs by Shin Poong of Seoul, Republic of Korea, MMV's partner in this development programme, has resulted in Good Manufacturing Practice quality tablets. Single, repeated doses escalation, interaction and food effect components demonstrated that the combination was well tolerated, with pharmacokinetics showing improved bioavailability and supporting once-daily dosing. PANDA has completed its large Phase II studies with 470 patients in Asia and Africa. While data are being processed for final analysis and reporting, planning has started for a multi-centre large Phase III trial in Africa and in South-East Asia in both children and adult patients. These studies will be followed by another study in younger children which will assess efficacy of a new paediatric formulation. If the Phase III trials confirm the phase II results, regulatory filing to the European Medicines Agency (EMEA) and the Korean Food and Drug Agency was expected by the end of 2007 with the new antimalarial ready to market in 2008.

3.2.2 HIV/AIDS drugs

HIV antiretroviral drugs or ARVs disrupt the action of the virus. There are various combinations of these drugs which act at various different stages of the lifecycle of HIV (see Box 5). The virus mutates very quickly and as such it is often necessary to change the drug regimen being used to ensure it is most effective and resistance does not occur. Usually a cocktail of drugs is used such as HAART which involves treatment with at least three active antiretroviral medications. Treatment is highly effective but only if continued for life as it is not a cure.

Unfortunately there are a number of factors that hamper ARV access in Africa related both to distribution but also production. Médecins Sans Frontières (MSF) (2006) lists the following factors as hampering delivery of ARVs in developing countries:

- Shortage of health workers and the high costs charged to patients for the drugs and clinic visit;
- Too few children receiving ARVs because of the lack of diagnosis and treatment tools as well as the lack of availability of strategies to prevent mother-to-child transmission;
- Failure to coordinate TB and HIV control programmes and a lack of tools to diagnose and treat TB in HIV patients and;
- Newer formulations and combinations of drugs are often not available or registered in developing countries resulting in a lack of access to the best drugs that are available.

A related issue to the availability and cost of drugs relates to the form ARV drugs take i.e. whether they are patented and so registered to the company that made them who have sole rights to produce and market them (such as those listed in Box 5) and generic (non-patented) variations which are significantly less in cost. Generic drugs have reduced the cost of first line drug regimens (as opposed to second line regimens which are given commonly when first line drugs do not work as a result of resistance or TB) by 99% to an average cost of US$132 a year per patient. 50% of those taking generic drugs are taking drugs produced in India. Since 2005 India has started enforcing Trade Related Intellectual Property Rights (TRIPS) legislation which subject new drugs to up to 20 years patent protection. Groups such as MSF argue that this has the potential to drastically effect drug supplies to HIV patients around the world, including in Africa, through increased prices (www.msf.org). Efforts such as WHO and UNAIDS' '3x5' initiative and William J Clinton Foundation's collaboration with drug manufacturers are however improving drug access in Africa.

Box 5: HIV drugs

Each type, or "class", of ARV drug attacks HIV in a different way. There are four main types of drug currently available:

1. The first class of anti-HIV drug was the nucleoside reverse transcriptase inhibitors, also called "nukes". These drugs work by stopping the HIV genetic material being converted from RNA into DNA. Examples of such drugs are AZT (ZDV, zidovudine, Retrovir®) and Tenofovir (Viread®).
2. Another class of drug blocks the same step of the life cycle, but in a different way. This class is the non-nucleoside reverse transcriptase inhibitors, or NNRTIs. Three NNRTIs have been approved: Nevirapine (NVP, Viramune®), Delavirdine (DLV, Rescriptor®) and Efavirenz (EFV, Sustiva®).

3. The third class of antiviral drug works at the time when the new virus within the body matures and blocks the raw material for new HIV virus from being cut by the protease enzyme that enables it to be assembled into a functioning virus. Ten protease inhibitors have been approved.
4. The newest class of ARV drug includes fusion inhibitors. They prevent HIV from attaching to a cell during one of the first stages of the HIV life cycle. Only one fusion inhibitor has been approved: Enfuvirtide (T-20, Fuzeon®)

Source: Adapted from www.aids.org/Factsheets/403-What-is-Antiviral-Therapy.html

3.2.3 Microbicides

In the absence of a vaccine, novel biomedical methods for the prevention of HIV transmission such as microbicides are being seen as an important potential weapon against HIV infection. “Microbicides have the potential to give many women in developing countries the power, for the first time, to control their risk of contracting HIV and other sexually transmitted diseases” said Hilary Benn, the UK's international development secretary. Jonathan Weber, professor in genito-urinary medicine and communicable diseases at Imperial College London, backed that view: “We desperately need new methods to prevent HIV transmission in the face of rising prevalence of infection globally. “As we have still not been able to develop an effective HIV vaccine, vaginal microbicides are now the most promising bio-medical intervention for the prevention of HIV infection on the horizon.” (BBC news Tuesday, 23 March 2004).

Microbicides are chemical agents with the potential to be used topically by women within the vagina to prevent HIV and other sexual transmitted diseases. Candidate agents that block the HIV virus binding to cells currently being investigates include several high molecular weight anionically charged sulphated polymers such as PRO 2000 (a naphthalene sulphonate polymer). PRO 2000 has been extensively studied in vivo and is now in phase III trials in women at risk of HIV infection in Africa. In addition, research attention is being directed at the possibility of using oral antiretroviral therapy, specifically tenofovir, for pre-exposure prophylaxis (PrEP) to prevent HIV infection (Weber et al. 2005). As of June 2008, there were 11 candidates in clinical development, three of which were being evaluated in ongoing phase II/IIB or phase III trials (see Table 4).

Table 4: On-going microbicide clinical trial projects

Phase	Candidate	Partners	Countries
3	PRO 2000/5 gel	Indevus, MRC, DFID (Funder)	South Africa, Tanzania, Uganda, Zambia
2B	Tenofovir gel	CAPRISA, USAID, LIFElab, Gilead, FHI, CONRAD	South Africa
2/2B	PRO 2000/5 gel (P) and BufferGel®	NIAID, Indevus, ReProtect	Malawi, South Africa, United States, Zambia, Zimbabwe
1	Dapivirine (TMC120) gel	IPM	Belgium
	Ethanol in Emollient Gel	NIAID	Kenya
	HEC/CS/N-9†	CONRAD/USAID	USA
	Tenofovir/PMPA gel	CONRAD, IPM/USAID	Dominican Republic, United States
	Tenofovir gel	NIAID	United States
	UC-781 gel	NIAID, CONRAD	United States
	UC-781 gel	UCLA, NIAID, CONRAD	United States
	UC-781 gel	CDC, Thailand Ministry of Health, CONRAD	Thailand
	UC-781	CONRAD	United States
	UC-781	CONRAD, CDC, Emory University	United States
	VivaGel™ (SPL7013 gel)‡	DAIDS/NIAID, NICHD, Starpharma	Puerto Rico, United States
N/A	Placebo ring±	IPM	Kenya, South Africa, Tanzania

Source: http://www.global-campaign.org/candidates.htm. Accessed 15 August 2008

Global Partnerships and networks of collaborators enabled such a rapid development of the field. The Alliance for Microbicide Development, an alliance of scientists, product developers and advocates, began in 1998 to coordinate and promote investment in, and development of, microbicides. Four years later saw the formation of a public-private partnership, the International Partnership for Microbicides (IPM), to assist with financial and regulatory issues.

Partnering with academia and industry is helping to move science along much more rapidly

than any single group could accomplish alone. Advocacy has increased and financial support, prompted by the Bill and Melinda Gates Foundation, has increased from national governments, WHO, European Union for finding a vaccine. A structured technology platform like MMV or IPM that combines different disciplines and expertise to facilitate understanding the biology of difficult diseases, has accelerated the discovery of promising new mechanisms and compounds.

3.3 'Social' Technology Innovations

Ensuring successful innovation of generic and disease specific technologies as outlined in Section 1 is not straightforward. The organisational and institutional mix within which technologies are produced and distributed also requires attention. Our mapping exercise and review of the literature highlighted the importance of what we term 'social technologies'. It argued for the importance of a systemic approach to technological innovation. It is important to consider integrated approaches that take into account the whole innovation cycle and not only discrete aspects of it at any one time. The first step towards this, and as pointed out by many of the survey respondents is, the need for better health systems.

3.3.1 Health systems

David Weatherall and his colleagues in the DCP2 report write *"As well as the mainstream biomedical sciences, research into providing health care for the future will require a major input from the social and behavioural sciences and health economics."* Although not a technological advance as per the biomedical advances discussed above, the importance of functioning health systems can be seen as a 'social technology' that has the potential to address Africa's health challenges in a way biomedical technological advances cannot. This is because, as one respondent to our survey put it, *"the strengthened health system is the "magic gun" for all the "magic bullets" that will be developed."* A strong health system (the institutions and mechanisms within which healthcare is produced, financed, governed and provided) is required for all the biomedical technological advances to succeed.

Many developing countries, particularly in Africa, suffer from health systems that lack resources (funding, infrastructure, personnel) and knowledge (skilled personnel). This has implications on how medical research is conducted, what health technologies are produced as well as when and in what manner these technologies are made available and accessible to those that need them. Take the example of HAART used at the beginning of this study. HIV/AIDS as a disease is evolving all the time, constant research is required to ensure that drugs that are available to treat the disease are effective. Research that considers the effectiveness and efficacy of AIDS drugs is being carried out in research institutes in a number of African countries but a few such as the Kenya Medical Research Institute (KEMRI) have sufficient trained staff and access to technology to measure CD4 counts, viral loads and drug resistance. And even here there are issues around ensuring a pool of well-trained researchers are available from the countries educational establishments.

KEMRI benefits from international partnerships with groups such as the Wellcome Trust and Swiss Tropical Institute which assists in capacity building activities but not all countries have these links. And although the research is being conducted not everyone in Kenya has access to AIDS drugs when they need them. This is due to issues on the demand and supply side. At times there is not the supply of drugs that are required and where supplies are available they are not able to guarantee the same drug regimen is available. This makes it difficult to ensure compliance with drug taking as it becomes confusing for AIDS sufferers as to which drugs to take, when. More specifically, however, on the demand side are issues of cost. Very rarely are anti-retroviral drugs given for free and when they are the cost of purchasing the drugs to the provider can mean that only the cheaper older lines of the drugs are affordable.

Strengthening health systems requires an in-depth analysis of all aspects of their performance (financing, production, governance and provision). In order to 'fix' health systems it has been suggested that an integrated and systemic approach is required:

> *"institutions and agencies concerned with improving the currently grim health outlook in Africa must take a more systemic approach -- turning at least some of their attention to apparently mundane matters within the health system, such as infrastructure, training, capacity building, human resources, and health planning, that form the foundation for future advances in the well-being of Africa's citizens."* (De Savigny et al. 2004)

A well known example is the work of TEHIP in Tanzania which worked to strengthen district health care planning activities through linking data collection techniques regarding burden of disease with budget calculations along with capacity building of staff in the techniques. This project took an integrated approach to strengthening the health system in order to address the district's health challenges.

Another example of strengthening the health system through integrated approaches is provided by Ethiopian malaria control activities. Supported by several development organisations, the Ethiopian government is undertaking an integrated malaria control approach. The emphasis is not simply on provision of anti-malarial drugs to treat malaria but on prevention through the distribution of insecticide treated mosquito bednets and its working to strengthen treatment activities through the use of rapid diagnostic test kit provision for health posts as well as recommending and improving access to an artemisinin based drug for which the malaria parasite has not developed resistance yet.

Strengthening and building effective health systems is only one part of the answer. It is important – as stressed in Section 1 – to build up the whole process to ensure technologies move from bench to bedside. This requires a holistic approach taking the idea of an innovation cycle as the starting point for more problem-orientated innovation that stresses the linkages and disconnects between the different actors and institutions involved in the whole innovation

process. Most important for health innovation is to strengthen the links – to work out how to build better links via innovation practices – that is, to work out how integrated approaches can solve health problems. Strengthening one element in isolation from the others is a means to an end, but not the end itself.

In stressing the importance of social technologies it is not possible to put together a list of what is required; there is a lack of evidence as to 'what works' unlike for many of the diseases currently affecting the poorest populations in Africa while 'what works' in one place may not meet the requirements in another. Attempts have been made to outline what is required to ensure a functioning health system (WHO 2001; Jamison et al. 2006b) in terms of the determinants or 'pillars' that make up the 'system': information and infrastructural inputs, management, human resources and financing. Thus some countries may require an emphasis being placed on data collection in order to match health system and health research responses to disease burden or a better medicines supply chain. Other countries may require stronger leadership and policy support or ways to retain and train medical staff. Then there are countries that need to balance the needs and financing of public sector health care provision with the often used but unregulated private sector suppliers. Many countries require a combination of these activities. This also requires – particularly when a holistic innovation systems lens is used – interaction with those placed outside of the realm of 'health' or even 'research' and 'science and technology'. A functioning health system requires interactions with systems of education, finance, regulation and law, politics etc.

3.4 Potential and Impact of New Technologies on Health Systems

In the previous section we listed three broad types of technological advance with potential to address Africa's health challenges. These all have the chance to reduce the burden created from diseases such as HIV/AIDS, TB, malaria and cholera etc. To be successful in the introduction, adoption and development of any of these technologies it is however necessary to consider various technological constraints affecting their implementation and development. At the same time, and as highlighted by the implications of 'social technologies', there is a need to consider the importance of building robust health innovation systems that provide a way to create enabling environments that will empower the integration of new science and technology with the potential to address Africa's health challenges.

The successful introduction and uptake of technologies relies on a complex relationship with social, economic and political forces. There are numerous examples of technologies that have not successfully been introduced or produced due to inabilities to understand or contend with forces external to the technology itself. AIDS vaccine research has been constrained by scientific uncertainty while the female condom has been plagued by a combination of its design and subsequent attitudes towards it. Even where a product is available and efficacious, for example in the case of polio vaccination efforts, traditional beliefs and attitudes amongst communities, reiterated at times by community leaders, has

also hampered progress. Thus, it is important to consider both:

1. Constraints affecting each technology in its advance;
2. The wider enabling environment constraints.

These will now be discussed in turn.

3.4.1 Constraints affecting a technology's progress

Sequencing of genomes as a technology has great potential in providing the first step towards addressing the health challenges faced by Africa. As highlighted above, the opportunities afforded by being able to isolate and understand individual genes has provided the catalyst for breakthroughs in diagnostic PCR technology as well as malaria drug development. Unfortunately issues exist regarding the capacity of African science bases to become involved in this technology. However a number of African countries are using and developing the technologies, such as PCR, that result as a consequence of information gained from sequencing genomes. As was highlighted above, the Top 10 report placed diagnostic tools as having the greatest potential to address health challenges. This is because many diagnostic tools currently exist and are in use throughout the world. PCR technologies and new developments in diagnostic testing are transforming the speed at which disease diagnosis and detection occur. However the cost of these technologies sometimes makes them less available to developing countries. A variety of new recombinant drugs and vaccines are available and some cost less to produce than older varieties, however, recombinant vaccines are still not available for HIV, malaria and TB (although progress is being made) and issues of resistance hamper some development efforts. One of the biggest issues affecting drug and vaccine development however is their delivery systems. This issue is linked to the need for stronger health systems, the 'social technology' listed above. Allied to the need for stronger health systems is an increasing awareness of the social determinants of health[5] of which hunger and poverty is one. The potential offered by GM crops as a means of increasing (more nutritious) food production is seen as a means of working to reduce hunger and poverty in developing countries.

Thus each of these different technological advances are at different stages of existence and have differing potential impact in terms of reducing burden of disease. This is not only in terms of their impact in controlling disease through providing treatments but also in terms of prevention activities. The TEHIP example given above provides a case where decisions regarding what areas of disease control should be focused on where weighed against budgetary constraints and current burden of disease within the local health districts. These kinds of priority setting issues are important when considering which of the above technologies has the potential greatest impact on Africa's health challenges but made more difficult by the lack of predictability in science (see below). The Council on Health Research for Development (COHRED) has worked extensively with the Alliance for Health Policy and Systems Research to consider successful priority setting of health research agendas following

the work of the Ad hoc Committee on Health Research[6]. If choices have to be made as to which of these technologies a country should focus its attention undertaking priority setting activities are the first step to take as exemplified by the South African government who set up a foresight process following the identification of research priorities using the Essential National Health Research approach.

3.4.2 Enabling environment constraints

The potential these technologies have to address Africa's health challenges is dependent on a number of constraints that they face at the various stages of their development. A number of these have already been made mention to above and have also been covered in Chataway et al. (2007). These and other constraints that affect the impact these technologies will have on addressing Africa's health challenges will now be discussed in a little more depth.

The unpredictability of science

A very important constraint can be the strict process of priority setting. This can limit the areas where major advances are discovered. Science is not always predicable but can occur very much the result of chance. This was the case for Jenner in discovering that smallpox could be vaccinated against using cowpox and how, more recently, penicillin was discovered. Science requires a degree of freedom to explore but also a degree of connectivity as science also requires interaction and dialogue between scientists and researchers. A further science related constraint is the more practical constraint faced by rising drug resistance by pathogens. There is a need for flexible policies to work with these to ensure for example that new drugs and vaccines can be introduced as and when required before resistance comes to dominate. Secondly, science is not always the responsibility of, or possible at, national level. Leading edge science (like a new vaccine for HIV/AIDS) relates at times to a global risk, not a national one. However, getting local capacity to test for vaccines and drugs is a national level activity. There needs to be the flexibility, integration and understanding to provide for this.

Skills availability

The continent suffers from an overarching constraint in respect of the skills sets available in the areas of health and science and technology. In R&D activities there is a lack of trained staff to work in laboratories and little opportunity for such experience in the educational setting. In the healthcare setting there is an increasing lack of staff who are willing to work when more money can be made working in other occupations or other countries. This reduces the capacity, particularly in the public sector, for healthcare providers to distribute and use these technologies. There are also gaps in capacity at the policy level which impacts the quality of the decision making and governance process within which these technologies are advanced. The heavy burden HIV/AIDS is having on the continent is also

playing a part in affecting the numbers of the health and science and technology workforce. The issue of skills is not simply one of individual level human capital, in many instances there is a need to build team-orientated and project management approaches; there are times when groups of experts with various specialisms are required to ensure problems are overcome in a clinical, R&D, project management and policy level.

Make or buy decisions

In the case of diagnostics and some vaccines and drugs the technologies are available and decisions have to be made about whether it makes sense to buy technologies or develop domestic manufacturing capabilities. South Africa, Kenya, Nigeria and Egypt have built strong diagnostic, drug and vaccine manufacturing capabilities at present. However, ensuring manufacturing capability requires serious financial investment and the prospects of markets. There are also issues regarding economies of scale of production that make it difficult to ensure the sustainability of manufacturing capability for some drugs in Africa. This is one reason the World Bank has argued that production will remain in the hands of a small number of large manufacturers and as such most countries should buy in pharmaceutical products such as ARVs produced from elsewhere (Rovira 2004). However, a number of firms are starting to produce generic ARVs particularly through joint ventures. One example is Quality Chemicals in Uganda produce ARVs in a joint venture with Cipla Pharmaceuticals of India from June 2007 (Anderson 2006).

The same decisions come into play when decisions are made regarding the development of a country's own basic research and development facilities. In trying to encourage the development of R&D South Africa has set up innovation hubs, centres around which incentives and subsidies are given to companies wishing to invest to start up an R&D company, particularly in the area of biotechnology. In other places public-private partnerships are emerging that are providing a means to build scientific capacity on the ground (Chataway and Smith 2006) suggesting solutions can be found to this constraint around a decision to get involved in production of R&D.

Purchasing power

Constraints relating to purchasing power can be found in both the supply and demand. On the supply side there are constraints in terms of ensuring that the infrastructure and equipment are able to be purchased to do good quality basic research and to have first class manufacturing capability. Recently Zambia announced that it was unable to afford new diagnostic tools and was having to rely on older methods to conduct medical tests (Ngandwe and Tallaksen 2006). As has been highlighted above public private partnerships have been suggested as a means of moving forward in this area. However the impact of the private sector on health care has been, and continues to be hotly debated (Soderlund 2003). Similarly there are constraints created from purchasing power issues on the demand side. In many countries there is a lack of purchasing power within the general public who

have to access healthcare services. These exacerbate issues of equity of, and access to, healthcare.

Regulation and quality control

Whether a decision is made to conduct basic research or manufacture in-country or import ready produced technologies from outside, products are required to be of high quality and well regulated. Unfortunately, regulatory and quality assurance networks tend to be weak in many countries and regionally. The situation is improving in areas such as clinical trials of new drugs and vaccines where a demand is being placed on all those involved having been trained in Good Laboratory Practice or Good Clinical Practice and some laboratories have been given international accreditation to conduct clinical trial work e.g. the Kenyan AIDS Vaccine Initiative in Kenya. However, the quality of many manufactured drugs both those imported and manufactured locally can be poor. The efforts of Dora Akunyili, Nigeria's Head of the National Food and Drug Administration and Control, show that improvements can be made but it has been argued that there is a need for more emphasis on cooperation and training to build regional regulation and to use WHO's pre-qualification process to ensure quality, safety and efficacy of medicines (Gray 2004).

Policy environment

Having policy makers who understand the value of a functioning health system goes a long way towards ensuring that goal. Similarly, it is important that policy makers understand and value the potential of these technologies in order for them to push the requirements needed to ensure these technologies are produced and delivered. Secondly, there is a need for them to work together to realise that it is not just an issue of science or of healthcare delivery but of gaps within a wider system of health innovation (see Chataway et al. 2007).

Access issues

One aspect of the access issue relating to the last element of the innovation cycle is how to ensure compliance with treatment doses and regimens by both medical staff and patients themselves. One mechanism to overcome this has been the development of pre-packaged drugs to aid correct treatment action. This relates to a wider issue of general awareness and understanding regarding technology. A number of studies have found that communities and policy makers alike may not understand the mechanisms of technological advance, say for example the process of clinical trials (cf. Leach and Fairhead 2005). There can also be little understanding regarding the need for, or value of, new technologies. Gaining understanding is not the only issue that hinders good delivery. Ensuring any of the technologies listed above are delivered requires a combination of constant and reliable delivery mechanisms, safe and regulated supplies as well as trained staff to deliver and use the technologies. These require a functioning and effective health system i.e. a system that is able to effectively finance, produce, govern and deliver healthcare and its related activities. This also makes

clear that access issues are multiple and are not just limited to the last stage of the innovation cycle. Access is required to all information, skills and personnel throughout the innovation cycle. Without these it will not be possible to build functioning and effective health innovation systems.

Thus although these technologies have much potential to address Africa's health challenges and many are available for use and delivery having been successfully developed there are a number of constraints that hold up their ability to address these health challenges. The next section will consider these issues and come up with a number of policy recommendations.

4. Conclusion and Policy Recommendations

A very significant momentum has built up in relation to the problem of neglected diseases in Africa and particularly in using scientific and technological tools to further capacity to treat disease and ill health. In the last decade there has been an explosion of new initiatives in this area. The challenge now is to make sure that this momentum is continued and leads to the construction of the kind of capacities that will enable Africans to benefit from good health on a more sustained basis.

Below we have put together some of the main policy recommendations of ways African countries can move forward. There is no universal 'one size fits all' formula. Nothing that has been outlined in this study may be suitable to be taken up by all countries in Africa.

Successful development of health related technologies or technology based health products requires productive organisations and institutions, it requires the right 'social technology'. It requires a consideration of all issues and activities that relate to innovative technology in a systemic way. It is necessary to consider not only the constraints affecting a particular technology's progress but also the wider enabling environment constraints listed in Section 3.4.

There is no one framework or model of activities that each country can undertake nor is there a single checklist of areas that each must consider. Each country, each initiative and each new technology has, and will, evolve in individual and quite separate ways with different types and strengths of linkages and interactions being made that both stimulate and detract from innovation.

One set of key and current policy issues for African countries is where future improvements might be made quickest and to best advantage. Deciding which scientific and technological advances to choose and how best to provide the 'social technology' to aid their development requires strong strategic planning and priority setting activities.

Undertake strategic planning and priority setting that starts with foresight activities to identify

the best mix of scientific and social technologies.

In thinking about health innovation systems a move is made from thinking in terms of discrete areas of activity and towards the wider architecture of actors and linkages required to ensure a technology is developed and/or introduced. This creates a means of ensuring not only that technology is developed or delivered but that it is also taken up and used – something that currently is not often considered. Currently, an emphasis is often placed on getting treatments out using top-down approaches that tend to ignore the complexity on the ground when attempting to introduce a technology.

Create Health Innovation and Development Platforms

Health Innovation and Development Platforms would most likely be problem-oriented platforms rather than science-led or health system pulled. They would build on, but also go way beyond the idea of cross-functional teams in product development. In the same way that the new global initiatives for technologies – e.g. for vaccines or new drug regimes for TB, have emerged, these new platforms would be ambitious and would need to include science, technology and innovation capabilities as well as health systems capabilities. They would be dedicated to improving coordination and understanding of different product development and treatment efforts and would be a way for the African Union and NEPAD to play a direct role in policy making in the development of health innovation and coordinated capacity building in health systems. These platforms will need to be very ambitious but are very necessary if the 'problem-orientation' is not to stop with new innovative products that cannot be delivered. Designing new health delivery systems would then be a part of the innovation process reducing the disconnect between innovation of technology and development of healthy populations.

Platforms should allow for regional and international level activities

In order to access all the resources and capabilities a platform might require there would need to be mechanisms through which linkages could be made to regional and international actors. In many instances there are likely to be large overlaps and similarities between different country's platform mechanisms and objectives. There would need to be explicit approaches to build more universal principles and to learn from one location to another so as not to have to 'reinvent the wheel'. One way of achieving this would be to regionally organise the platforms to make the most of regionally available expertise. The NEPAD and African Union frameworks provide one mechanism through which to organise such platforms. Similarly the ability to make linkages with international organisations and countries outside of the region will need to be encouraged.

Notes

1. These are defined as those diseases that predominately affect the poorest populations who lack the purchasing power to buy the medicines needed. The diseases also receive less attention from international pharmaceutical companies and donor funding. There are increasing calls that this definition be used in a narrower sense to refer only to a list of diseases (excluding the 'big three' of HIV/AIDS, malaria and tuberculosis) such as schistosomiasis, lymphatic filariasis, onchocerciasis, and trachoma (Hotez et al. 2005).

2. The definition of 'biotechnology' used throughout the reports and our survey relates to a wide definition of biotechnology as any technological application of biological or living organisms.
3. This is usually defined to refer to technologies that facilitate, or are facilitated by, communication and social processes. Our use of this term differs slightly in that we denote an organisational and institutional mix that is one part of the process of ensuring successful innovation.
4. Recombinant DNA (rDNA) technology is a field of molecular biology. The practice of cutting, pasting, and copying DNA dates back to Arthur Kornberg's successful replication of viral DNA in a breakthrough that served as a proof-of-concept for cloning. This was followed by the Swiss biochemist Werner Arber's discovery of restriction enzymes in bacteria that degrade foreign viral DNA molecules while sparing their own DNA. Arber effectively showed geneticists how to "cut" DNA molecules. This was followed by the understanding that ligase could be used to "glue" them together. These two achievements launched rDNA technology research.
5. As evidenced by the setting up of the WHO Commission on Social Determinants of Health.
6. See www.cohred.org and www.alliance-hspr.org & the work of WHO's Ad hoc committee on health research concerning future intervention options e.g. 1996 report, "Investing in health research and development" Geneva: WHO.

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