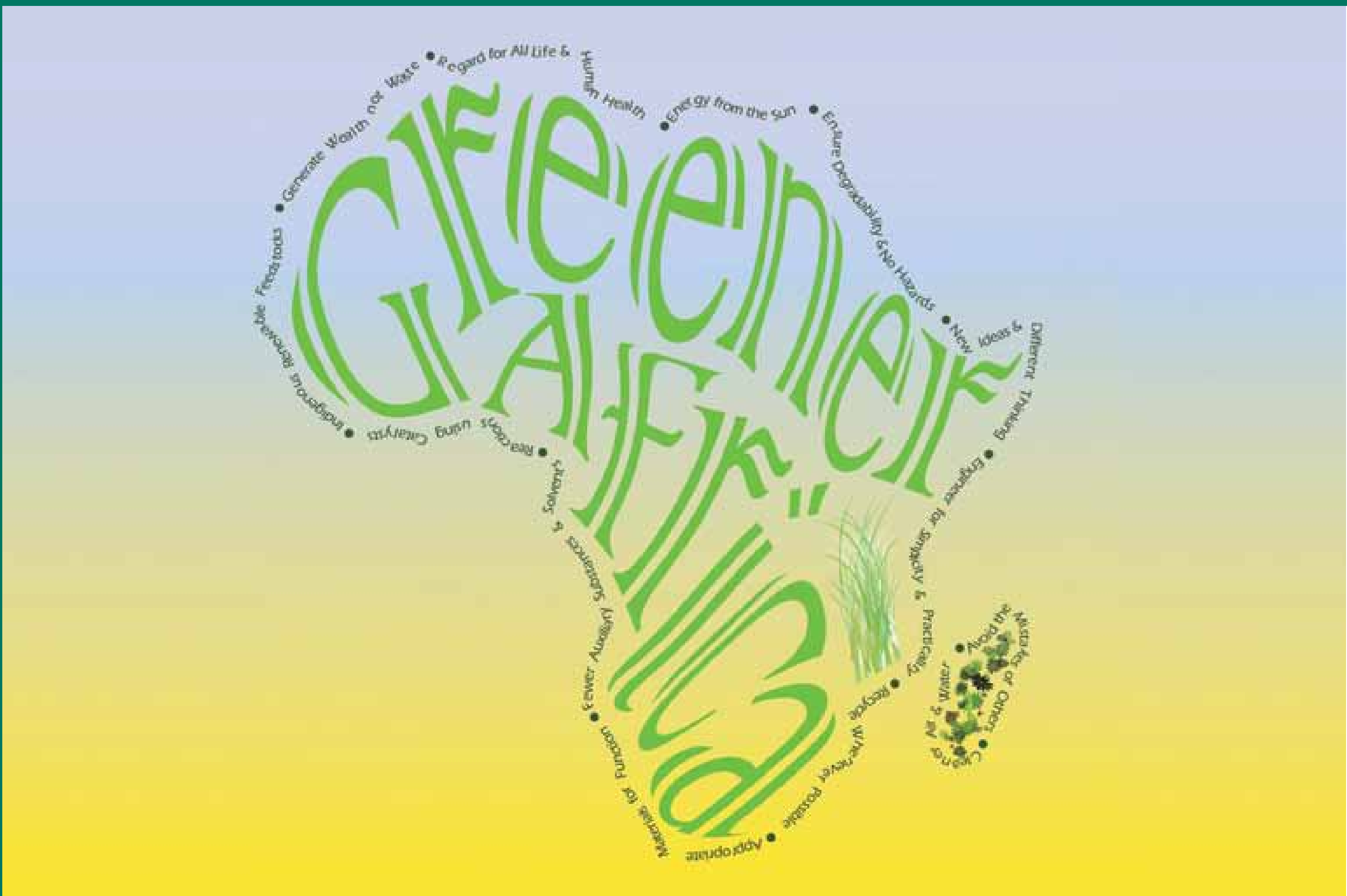
Wealth Not Waste

Green science and engineering for sustainable growth in Africa

A report by the **Pan Africa Chemistry Network** April 2011



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The Pan Africa Chemistry Network (PACN) was set up by the RSC in partnership with Syngenta, with a special focus on the Millennium Development Goals aimed at advancing the chemical sciences across Africa. It represents an innovative approach to working with universities, schools, scientists, teachers, and students. A coordinated approach is crucial to success and the PACN is engaging with chemical societies throughout Africa, together with the Federation of African Chemical Societies. The PACN has established regional hubs in Ethiopia and Kenya, and increased the existing collaboration with universities and other partners in South Africa.

The PACN seeks to create a self-sustaining science base in Africa, and it is encouraging the application of best practices to solving local challenges and enabling contributions to global scientific knowledge. It aims to:

- enhance collaboration between governments, universities, industry and communities;
- support the establishment of a sustainable science base across the continent, which attracts students to scientific careers and promotes public appreciation of the role of chemical science in Africa's future;
- disseminate information to researchers and entrepreneurs about available funding opportunities;
- coordinate support for education at all levels, from low-cost practical school teaching to training researchers in the use of modern research instruments;
- encourage the development of centres of excellence through the installation of modern analytical technologies and coordinated training.

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FOREWORD

The economies of African countries are growing. Economic activity in 2010 increased by almost 5% and, according to the World Bank, this looks likely to continue into 2011 and beyond. As the global economy recovers, powered in no small part by strong growth in China, demand for raw materials and agricultural products reaches new levels, pushing commodity prices to new highs and attracting a flood of foreign investment.

The question we must ask ourselves is how this economic growth and the efforts that will go to achieve it will touch the lives of ordinary people. Will it involve the full participation of Africans and improve the quality of life of ordinary people? Or will we allow this growth to be at the cost of increased environmental degradation, the depletion of non-renewable resources and a lower standard of living for our children?

As with any complex problem, there is no single solution, but I will highlight three vital measures that will enable us to grasp the growth opportunity and put ourselves on the path to a sustainable future.

First, we need to apply science, or to be precise, green science and technology, to the challenges that affect us in Africa. We just have to look at the experiences of the industrialised nations over the last two centuries to see some of the mistakes that we must avoid. The investigation and implementation of environmentally sustainable practices will allow us to develop our industries in a way which enhances people's lives while increasing profits.

Next, it is vital that we have more talented scientists and engineers who can develop novel, locally applicable ways to reuse waste, optimise energy consumption and avoid pollution. In order to do this effectively, training the next generation of scientists should be a top priority. These scientists need to be able to share knowledge with colleagues across national boundaries, as many of the problems that they face are at least regional, if not global in nature. This means we can move on from applying knowledge which was developed elsewhere, to increasing our knowledge and making our own, significant contribution to the world of science.

Finally, we need to have enlightened governance which demands the best scientific advice and evidence. The failure to develop joined-up policies which address the challenge of sustainable development across all branches of government represents a failure to govern.

We can make a start by listening to our scientists. This timely report, which summarises the views of leading scientists from Africa and across the World, describes how green science and technology will be of benefit. It should be essential reading for anyone who wants to see Africa follow a sustainable path to growth.

Professor Ahmadou Lamine Ndiaye
Honorary Director l'EISMV
Honorary Founder Chancellor Gaston Berger University
President, Academy of Science and Technology, Senegal
President, African Academy of Sciences

Ahmadou Ndiaye is past vice president of the *Académie Nationale des Sciences et Techniques du Sénégal*. He graduated from the University of Lyon's School of Medicine as a veterinary surgeon in 1963 and became head of the production department at Dahra (Senegal) Zootechnic Research Center (CRZ) and later director of the Center. In 1967, he began teaching at Dakar's *École Inter-États des Sciences et Médecine Vétérinaires (l'EISMV)*. In 1988, he became personal adviser to the President of Senegal. Starting in 1990, he served as first chancellor of Gaston Berger University in Saint-Louis, Senegal. In 1999, he resigned from the university and was appointed special adviser to the President with the rank of cabinet minister. He is a member of several scientific organisations and academies and holds several national and international distinctions. On 28 February 2011, he has been elected President of the African Academy of Sciences.

BACKGROUND

Africa needs to ensure its long-term economic growth and to do this in a way which minimises damage to the environment. Science, technology and innovation will play pivotal roles in ensuring that our next generation of chemicals, energy and manufactured goods are made in a more sustainable way than is currently the case. The critical advantages which will enable Africa to capitalise on new and sustainable manufacturing technologies include:

- an abundance of sustainable natural resources which can be used as raw materials for new and growing industries;
- an abundance of sunlight as a valuable energy source;
- chemical and manufacturing industries which are in their infancy and therefore have no legacy of non-sustainable manufacturing practices;
- a wealth of local expertise in natural product chemistry;
- talented young scientists;
- a large and motivated workforce, which is enthusiastic about education.

Africa is well placed to capitalise on these advantages and to develop world-leading technologies based on the principles of green manufacturing. Making value-added products in Africa, where possible, rather than exporting the raw materials, will contribute to the economic growth of the continent.

The key areas which need to be considered if Africa is to benefit from economic growth based on sustainable chemicals and manufacturing technologies are:

- manufactured products;
- extracting natural products and developing useful products from them;
- greener waste disposal;
- educating African scientists and technologists;
- integrating African scientists into the international community;
- regulation and governance.

The basic requirements of society include water, food, shelter, medicines, energy, chemicals, transport and manufactured goods. This report discusses how science and engineering are fundamental to meeting these needs in a sustainable way. The principles of Green Chemistry and sustainable manufacturing are discussed and shown to be crucial if Africa is to enjoy economic growth by using, and at the same time preserving, its unique resources and biological diversity.

On 15-17 November 2010, the Pan Africa Chemistry Network (PACN), sponsored by the Royal Society of Chemistry (RSC) and Syngenta, held the 1st PACN Green Chemistry Congress at the Convention Centre of the United Nations Economic Commission for Africa, in Addis Ababa, Ethiopia. The findings and recommendations in this report represent the views of the 190 scientists and practitioners that attended this conference from 11 different countries in Africa, as well as from Europe, the USA and Brazil, and from the delegates who participated in the discussion forum at the post-conference workshop held at the RSC in London on 7 March 2011.

Report Contributors

Yonas Chebude, Addis Ababa University, Ethiopia

John Clough, Syngenta

Bob Crawford, Unilever

Temechegn Engida, UNESCO and Federation of African Societies of Chemistry, Ethiopia

Steve Lancaster, RSC (Editor)

Ray Marriot, Bangor University, UK

Jacob Midiwo, Nairobi University, Kenya

Romeela Mohee, Mauritius University, Mauritius

Vincent Nyamori, University of KwaZulu-Natal, South Africa

Alejandra Palermo, RSC

Martyn Poliakoff, University of Nottingham, UK

Sarah Ruthven, RSC

Tom Welton, Imperial College, UK

FINDINGS

1. Africa has enjoyed robust economic growth over the past decade driven by export-led industries. The future growth of Africa's industries will only be sustained through the application of green science and technology. Sustaining growth is essential if African people and investors are to benefit. For this to be achieved over the long term, the basic requirements of society: water, food, medicines, energy, manufactured goods and transport, must be made and delivered in ways which do not damage the environment, enabling the creation of wealth for future generations to enjoy.

2. Africa has an abundance of sustainable natural resources which can be used as raw materials in new and developing industries. Products based on the principles of green science and technology have a growing market worldwide, and the local manufacture of high-value products from sustainably produced raw materials will contribute to the growing economy of the continent. African scientists have valuable expertise in the chemistry of natural products, and innovation in these technologies presents a tremendous opportunity for Africa.

3. The use of solvents with a relatively low environmental impact, such as water, ethanol and carbon dioxide, is essential in the sustainable manufacture of plant-based products. There is growing demand for food, health and personal care products derived from natural products, and much interest in plant-based pharmaceuticals. African industries have a competitive advantage in these areas because of the wealth of available plant resources and local expertise. The manufacture of natural products requires solvents to extract the active ingredients from plant material. Conventional processes use solvents that contribute to the production of toxic waste and the cost of their disposal is a significant proportion of the manufacturing cost.

4. A focus on recycling will benefit all Africans. There is no single best method of waste management. This will be different for each country and set of circumstances. The type and amount of waste produced depends on the consumer habits, the wealth and the size of the population of each country. There needs to be a focus on recycling to preserve resources, for instance, by increasing the use of compost from agricultural waste to improve soil fertility.

5. For Africa to meet these challenges it must tap into local expertise, expand the skills base through education and develop effective networks. It is vital that there is a trained cadre of scientists ready to develop and apply green science and technology across Africa. Schools and universities must be able to increase the supply of talented individuals going into science and engineering. The scientists they train need to participate in international networks to allow optimal utilisation of equipment and to enable people with different skills and capabilities to work together. Collaboration between academia and business is the key to driving innovation and unlocking the potential of green manufacturing.

6. African leaders must have the vision to capitalise on innovation in green science and technology and to learn from the past mistakes of the economically developed world. Policies should be developed and implemented across government to ensure the adoption of the principles of green science and technology. Strong, enlightened governance is vital if the people of Africa are to benefit from export-led growth while dealing with the challenges of a growing population and the need to improve living standards.

RECOMMENDATIONS

- Recognise at the political level that the practice of green science and technology will result in economic growth for Africa. This report should be sent to appropriate African Ministers.
- Encourage African scientists and recognise excellence in the practice of Green Chemistry in Africa. PACN, in collaboration with other organisations such as UNECA, national, regional, continental and global academies, should establish a Green Chemistry Award for Africa. This will lead to international recognition for work which has advanced economic development through the innovative application of Green Chemistry.
- Focus on recycling waste to preserve resources. This should employ innovative composting and anaerobic digestion technologies to give products which are useful for agriculture. PACN should facilitate capacity-building workshops which should include technologists from developed countries to enable knowledge sharing.
- Increase awareness of the dangers of waste proliferation, encourage safe practices and incentivise people and communities to recycle their waste by holding workshops for communities, schools and local authorities, farmers and waste operators.
- Standardise the quality of compost. This could be facilitated by the implementation of defined standards for compost-based materials.
- Build networks to enable progress in science and technology. PACN should facilitate the creation of links between African scientists practicing Green Chemistry and experts worldwide. It should promote publication by African scientists in leading scientific journals and participation at international scientific meetings, and foster industry-academic collaboration. These networks should be multidisciplinary, and include social scientists.
- Utilise indigenous natural raw materials to manufacture high-value products which will be key to securing economic growth in Africa. Facilitation of collaborative networks between Africa, South America and other countries which have commercial and technical expertise in this area should be a goal of PACN.
- Train and support programmes for educators to ensure that the teaching of green technology is of the best quality. PACN, the RSC and other like-minded organisations are well placed to facilitate this through continuing professional development programmes for teachers, researchers and those working in industry and community services.
- PACN to bring together African scientists and experts in the field to write and develop curricula materials on Green Chemistry that are suitable for Africa.

1. INTRODUCTION

Science and engineering are fundamental to the delivery of the basic requirements of society, including water, food, medicines, shelter, energy, transport and manufactured goods. Historically, the provision of these requirements has relied on rather unsophisticated processes which produced large amounts of harmful by-products and waste requiring disposal into the air, land and water. These processes are often highly energy-intensive and rely on the use of diminishing reserves of mineral oil-based feedstocks, solvents and raw materials. The human and environmental cost of their use is now recognised as being too high.

As these resources dwindle and demand increases, the ways in which these basic commodities are produced must be changed to ensure sustainable economic growth for the future. In addition to these fears over the future availability of scarce natural resources, a growing human population, climate change, and an urgent need to preserve biodiversity are other drivers for change. In the future, the face of manufacturing will be completely different to that which we have today, with 3-D printing technology being one example of a game-changing advance in technology.[1] In the near future, commodities will be manufactured in much more environmentally friendly ways. It is being increasingly recognised that good environmental practices in manufacturing are inextricably linked to profitability and economic growth in a sustainable way.[2,3]

The chemical sciences should play a pivotal role in ensuring that food, water, shelter, medicines, energy and our next generation of manufactured goods are more sustainable than those of the current generation. Worldwide demand for environmentally friendly chemical processes and products requires the development of novel and cost-effective approaches. One of the most attractive concepts for sustainability is Green Chemistry, where the use and production of hazardous substances is minimised or eliminated. The focus is on minimising the hazard and maximising the efficiency of any chemical process.

The philosophy of Green Chemistry is underpinned by a set of 12 principles that reduce or eliminate the use or generation of hazardous substances in the design, manufacture, and applications of chemical products.[4] Although some of the principles seem to be common sense, their combined use frequently requires the redesign of chemical products or processes. It should be noted that the rapid development of Green Chemistry is due to the recognition that environmentally friendly products and processes will be economically beneficial in the long term.

The principles of Green Chemistry were originally focused on the chemical industries in economically developed countries. In Africa these industries are in early stages of development. At the 1st PACN Green Chemistry Congress in Ethiopia, the original 12 principles were extended to 13 to enshrine the philosophy of chemists and chemical engineers in Africa and elsewhere.[5]

Thirteen Principles for a Greener Africa

G - Generate Wealth not Waste
R - Regard for All Life & Human Health
E - Energy from the Sun
E - Ensure Degradability & No Hazards
N - New Ideas & Different Thinking
E - Engineer for Simplicity & Practicality
R - Recycle Whenever Possible
A - Appropriate Materials for Function
F - Fewer Auxiliary Substances & Solvents
R - Reactions using Catalysts
I - Indigenous Renewable Feedstocks
C - Cleaner Air & Water
A - Avoid the Mistakes of Others

The goal should be to create a substantial chemical, agricultural and manufacturing infrastructure for the African continent with significant socio-economic benefit to the African people. In agriculture, there are numerous opportunities to improve productivity using combined genetic and Green Chemistry approaches. This will involve maintaining soil fertility through sustainable fertilisation, soil chemistry and land husbandry, leading to an increase in productivity and a reduction in the need for potentially damaging change to agricultural land use.

Much current research in the area of Green Chemistry focuses on the search for renewable feedstocks and more environmentally acceptable solvents to replace petroleum-based products. Additionally, new reactions, processes and catalysts which minimise waste production and energy usage will play an increasingly important role.

Africa is a continent of extraordinary biodiversity. Thus, Green Chemistry is particularly relevant to the needs of Africa, which faces rapidly expanding populations and an increasing demand for chemicals.

Ten years after the Millennium Development Goals were first formulated, African progress relies upon several criteria. Good governance and education for all are the foundations upon which development must be built, but the most important factor in the solution of Africa's development challenges of poverty, hunger, disease and resource scarcity is science, technology and innovation.

The application of Green Chemistry to science and technology is likely to have a dramatic impact on the continent's development by helping to solve many of its challenges. Among these will be a green revolution in agriculture that significantly increases crop yields, and ultimately the prosperity of the 80 per cent of Africans who depend on agriculture to support themselves and their families without damaging the environment.

Teaching the philosophy of sustainability to a younger generation of scientists is just as important as research in the field. Thus, incorporating Green Chemistry courses in the curriculum and increasing the awareness of students and researchers by conducting workshops and conferences are crucial. There are promising signs that African scientists are increasingly aligned behind the full array of Africa's development challenges. There is also evidence that more and more governments are increasingly recognising that science, in particular the chemical sciences, offer a huge potential for the continent. The 1st PACN Green Chemistry Congress was a milestone in the efforts to advance sustainable development on the continent. But more has to be done.

Green Chemistry provides a unique opportunity for African scientists because it combines the search for new science with the development of sustainable chemical technologies appropriate to the needs of the community. Therefore, the resources of Africa – such as a plentiful supply of intense sunlight, a wealth of unique plant species, and numerous enthusiastic young people – provide its researchers with numerous opportunities. With the encouragement of international scientists, African scientists can take this development-led science to the next level.

Green science and technology emphasise the need to reduce the input of materials and energy, to prevent hazards from the outset and to minimise negative environmental impact. Africa should make every effort to safeguard its unique biodiversity by using technology to meet the challenges it faces. Here is a real opportunity for African countries to learn from the mistakes of the more developed nations.

In summary, Green Chemistry is sustainable development, sustainable business and sustainable living practices, which are all essential elements in ensuring our long-term survival.

Case Study 1 – The Power of Solar Water Heating in Low-Income Communities

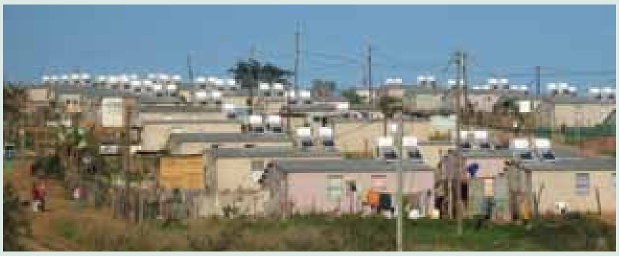
Jaco du Toit
School of Public Planning and Management
University of Stellenbosch, South Africa

KwaNokuthula SWH project

Installing solar water heaters (SWH) in low-income households can contribute to sustainable developments as shown by studies in South Africa's Western Cape Province. Advantages include:

- providing sufficient running hot water in homes where it is not currently available;
- reducing household electricity cost for water heating by US$86/household/annum;
- creating around 12 jobs per 1,000 SWH systems installed, on the assumption that locally-manufactured systems are used;
- saving 1.2 tonnes CO_2/household/annum.

The key barrier to market uptake of SWH is the high initial cost of the system, resulting in pay-back periods of up to eight years. The cost driver in the value chain is identified as the high cost of materials due to the relatively small scale of the South African SWH industry. Government support of the industry can help eliminate this barrier, leading to the robust development of a solar industry. Through the sustained demand for low-cost solar systems, the sale of authorised emission reduction certificates and small monthly contributions from households, the initial investment required for government-subsidised installations can be recouped over several years.



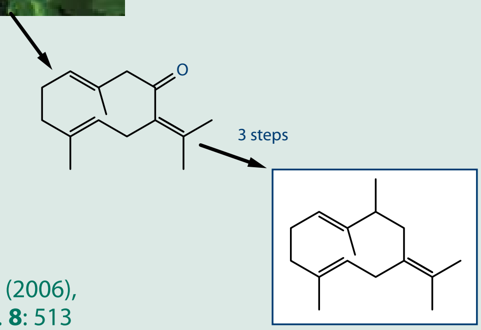
Case Study 2 – Green Approaches to Crop Protection

John A. Pickett
Department of Biological Chemistry
Rothamsted Research, United Kingdom

Companion planting may provide a sustainable approach to crop protection. This process is already being trialled amongst African farmers. It involves planting different crops in close proximity so they can help each other to increase nutrient uptake, pollination and pest control. By exploiting secondary plant metabolism, farmers can choose local crops identified from African plant biodiversity which are known to provide small lipophilic molecules similar to the highly successful pesticides that are commercially available.

Alternatively, natural products with pest control properties can be extracted from locally-grown plants and used directly, or after some minor processing, as natural pesticides. These green approaches should be especially attractive to resource-poor African farmers because they do not require seasonal applications. In the example shown below, a product isolated from an easy-to-grow plant can be used to produce a compound which is structurally close to a pesticide. This is then converted into the pesticide in three relatively simple steps.

Synthesis of 9-methylgermacrene B from *Geranium macrorrhizum*



Hooper *et al.* (2006), Green Chem. **8**: 513

Research on alternative green crop protection is still ongoing but ultimately it is likely to be delivered through the seed by molecular breeding and genetic modification technologies.

2. MANUFACTURING – SUSTAINABLE CHEMISTRY

2.1. Sustainable production

In a rapidly changing world, with diminishing reserves of economically-accessible oil, a complete reassessment of where future chemical products will come from is required.[6] While energy can be derived from many different sources, the materials upon which the modern world is reliant require carbon. Plant material – biomass – has been identified as the most likely future source of carbon to feed the chemicals industry. Africa has a great opportunity to lead this change because it has climatic conditions which, with appropriate conservation management, could ensure a renewable supply of biomass. This could be a valuable and sustainable resource for Africa. With help from its major investors, Africa is well placed to develop its economy through scientific innovation in sustainable manufacturing. To be effective, it must focus on adding value to its resources through innovation in green technology. The future African economy will then grow sustainably, without damaging the environment, and without relying on diminishing reserves of minerals and energy. This will benefit the African people and major investors in the future.

Widespread and understandable concern has been expressed about the potential competition between the use of land for the production of fuel and chemicals and the use of land to produce food. However, across Africa, there is an abundance of plant-based materials which are unsuitable as food sources. These include a variety of different lignocellulosic materials (plant biomass that is composed of cellulose, hemicellulose, and lignin) such as agricultural residues, *e.g.* the leaves and stalks of maize and other plants, dedicated energy crops, wood residues and paper-based municipal waste. These sources of carbon can be used as the raw materials for this new biomass-based chemicals industry.

The production of chemicals can be approached from two directions:

- **A particular compound is required.** In this approach the target compound is prepared, regardless of the difficulty or the length or complexity of the route. This is typified by drug discovery synthesis in industry and natural product synthesis in academia.
- **This compound can be synthesised.** In this approach, compounds that can be readily made and derivatised are prepared, and uses are then sought for them. Certain transformations in which two intermediates smoothly react with each other to give a pure product in high yield exemplify this approach, and have become known as 'click chemistry'.

With the expected changeover from petrochemicals to biomass as the primary source of raw materials, process chemistry, often seen as the poor relation of organic chemistry, will find a renewed prominence. It is vital that Africa has a trained cadre of process chemists ready to meet these new challenges.

There are three challenges faced by synthetic chemists:

- to make the products already available today using renewable resources;
- to make new products that can act as direct replacements for those derived from petrochemicals;
- to make new products derived from plants that cannot be prepared from petrochemicals.

All of these require new chemical processes.

Oil is currently the most important feedstock for the chemical industry in developed countries. Crude oil has a high density of carbon in liquid form that can be drilled at selected sites, then piped or transported in its raw form in large amounts to a 'cracker' to produce a variety of highly reduced compounds (compounds containing little or no oxygen), including ethylene, propylene and benzene on typical scales of hundreds of thousands of tonnes per year. These crackers are found in facilities that are the results of billions of dollars of investment and are staffed by highly-trained professionals.

Lignocellulosic biomass is very different from crude oil as a raw material and is much less familiar. It is geographically widely and thinly distributed and structurally diverse, even changing with the seasons. The basic components of lignocellulosic biomass are cellulose, a linear glucose polymer (40-60% dry mass); hemicellulose, a polymer often consisting of glucose and xylose or other sugars (20-40% dry mass); and lignin, a highly cross-linked phenolic polymer (10-25% dry mass); plus a few per cent of lipids and terpenes. Much of its mass at the point of harvest is water. Hence, biomass presents very different challenges to oil if it is to be used successfully in chemicals production.

The wide distribution of biomass and its high water content make it very unlikely that it will be transported far in its raw form, but rather it will need to undergo some form of local processing to change it into a form that can be more easily transported. The distributed nature of these early-stage processes means that they will have to operate on a totally different scale to petrochemical facilities, and that the chemistry of the transformations will need to be reliable and robust enough to repeat in many different locations, and to require a minimum of expert intervention once the process is running. The wide diversity in composition of biomass will add the constraint that these processes will need to be optimised to the local materials. Across Africa, different processes will be required in different locations: African process chemists will be best placed to develop these processes.

The main products of crude oil crackers are hydrocarbons. The chemistry that has been developed to deal with these has been based around adding functional groups to these compounds to achieve desired properties. Biomass, in contrast, is already highly functionalised and is particularly rich in oxygen, unlike crude oil. Further to this, it has evolved to resist easy breakdown. This will present new challenges.

One challenge is solid phase reactions that could be explored to transform these resources to less intractable intermediates and products. New solvents will be required that can dissolve these highly intractable materials. Also, it will require different and novel chemistry to produce many of the compounds that are in use today through this new route. Many of the catalysts used for the processing of petrochemicals will not be able to operate in the presence of the highly oxygenated starting materials derived from biomass, and so a particular challenge will be the design of new catalysts.

As our understanding of what can be efficiently produced from biomass grows, new products that can give the same, or even improved, performance will be sought, rather than only trying to make current products from a new feedstock. New products with as yet unachievable properties will also emerge. This will provide new opportunities for transformational wealth generation. All of these will require new processes for this potential to be realised.

With the application of green science and technologies, economic growth can be decoupled from environmental degradation and it will be possible to build a sustainable chemical industry in Africa- one that meets the needs of the current generation without compromising the ability of future generations to meet their needs.

By the end of the 21st Century it is likely that the developed world will be forced to rely on biomass as the source of its chemicals. Thus, by developing routes to chemicals from biomass now, African chemists will place their countries in a leading position to transfer their technologies to developed countries as demand for bio-based chemicals increases. Such technology transfer has already been achieved by Brazil in the field of bioethanol.

2.2. Research collaborations and networks

The challenges that will come from the move to an economy based on a biomass feedstock require nothing short of a revolution in process chemistry. This can only be achieved through collaboration between academics in different disciplines and between academics and industrial partners.

At a post-congress workshop of academics held at Addis Ababa University, one of the key challenges to advancing research was identified as a lack of serviceable and supported analytical equipment. However, when lists were drawn up of the equipment that the researchers needed and of the equipment that they had, it was found that all of the needs could be met by those in the room. Obviously, there needs to be consideration of the location of the equipment and its availability and suitability for use. This illustrates the pressing need for the development of networks of analysts and other scientists, together with the development of centres of excellence in analytical science. These centres of excellence are currently being developed by the PACN and contain advanced equipment and a critical mass of expertise which is being accessed by scientists from across the region. This is also facilitating engineering support and training. Additionally, by facilitating the sharing of expensive equipment within the network, the *quid pro quo* of being able to access other techniques can be gained. Thus inter-university collaboration in different countries is a powerful tool for the development of African academic research. African governments should minimise the bureaucratic barriers, *e.g.* visa applications, to encourage such collaboration.

2.3. Consumer products

Green Chemistry is by its nature very efficient in its use of energy and materials to create added-value products. For this reason, it lends itself very well to cost-effective manufacturing. This is exactly what Africa needs as it develops its future manufacturing industries.

Africa's abundant natural resources include, in addition to staples grown elsewhere, cereals, pulses, and oil seeds; Africa grows a distinctive range of products including bananas, pineapples, dates and other tropical fruits, sugarcane, coffee, tea, plantains, cassava, yams, sorghum, sweet potatoes, spices and nuts. These crops provide the raw materials for countless existing and future consumer products, both foods and non-foods (*e.g.* toiletries, cosmetics, fragrances and flavours).

With all these natural available resources and unique capabilities, the challenge is to apply green manufacturing principles to create attractive and valuable products for both domestic and export markets. Products based on the principles of Green Chemistry have a ready market in many parts of the world, appealing to environmentally and socially concerned consumers and companies alike. Making the products in Africa rather than simply exporting the raw materials will contribute to the growing economy of the continent, as well as being more efficient for the supply chain – shipping higher value products is a better option than shipping lower value commodities.

There is a global market for distinctive tastes and textures in all manner of consumer products. Inspiration for these can come from the natural products and extracts themselves, illustrated by the fast growing "naturals" personal care market in the USA and Europe. Local customs and recipes can also provide inspiration for both products and branding. Development of consumer products suitable for the global market but with an African twist should be a great opportunity for many companies.

An essential requirement for successful innovation – the creation of new products and markets for those products – is networking. It needs people with many different skills and capabilities to come together. Places recognised for being highly innovative always have very good networks (*e.g.* the close-knit Silicon Valley community). Different skills are needed for early-stage invention and proof of concept compared to technology development and piloting, and different skills again are needed for commercial application. But to generate a culture of innovation, people with all these skills need to be present and talking to each other. Scientific, manufacturing and commercial skills (from both start-ups and large corporations) and finance (*e.g.* from venture capital funds) are all necessary. Facilitation of collaborative networks between Africa, South America and other regions which have commercial and technical expertise in this area should be a goal of PACN. Government and regulatory authorities have a role as well in terms of setting standards and facilitating training and business support.

Starting these conversations can take place at meetings and conferences, industry associations and university collaborations. A national and international mix of scientists from academic and commercial organisations should be an effective way of opening up conversations and opportunities. The 1st PACN Green Chemistry Congress was one example of networking which illustrated the pressing need for the development of such collaborations and partnerships.

This collaboration is key to unlocking the potential of Green Chemistry for Africa. However, commercial innovation in products does not confine itself to neatly drawn scientific disciplinary boundaries. It must not be just about Green Chemistry. The chemists need to interact with people from other disciplines, including social scientists, and the communication of the benefits of green technology to the electorate and the politicians can be facilitated by the media.

University alumni who have entered the commercial world in Africa and overseas are a good source of initial contacts. They already have a relationship with the university and are often willing to help in its endeavours. Alumni networks have been shown to be very useful across the world and should be developed for mutual benefit. Local companies can be invited to see what capabilities the university has and to discuss how collaboration can benefit both parties. National chemical societies should also develop stronger links with industry so as to provide opportunities for industrial and academic researchers to meet. PACN, in collaboration with the Federation of African Societies of Chemistry, should be seen as the enabling entity that can bring about closer collaboration between industry and academia at both international and national level.

The omens are good. Africa has a network of universities, abundant resources, significant home markets and established export markets. Green Chemistry should provide an inspiration to put all this to use in the most efficient and productive way, leap frogging some of the old chemistry of the 20th Century.

Case Study 3 – Efficiency Gains at Uganda Clays Ltd.

Joseph Kawombe
Department of Mechanical Engineering, Makerere University, Uganda with the University of Edinburgh, UK, and Uganda Clays Ltd.

Uganda Clays Limited (UCL) is the leading manufacturer of clay-baked building products in Uganda, with a manufacturing capacity of more than 6,000 tonnes of clay products per month. The company was experiencing significant energy losses at the different stages of production, so there was a need for an investigation into the potential for energy conservation in the production processes. An additional issue was the fact that the major source of fuel used was coffee husks, and this was becoming increasingly expensive as manufacturers made greater use of it, calling for research into alternative energy options for the firing process.

The Africa Knowledge Transfer Partnership scheme (AKTP), a British Council Initiative, allowed Uganda Clays to tap into the knowledge base at both Makerere University and the University of Edinburgh to ensure that research and knowledge was transformed into innovation. The AKTP Associate (a recent graduate) was employed by Uganda Clays to investigate the potential for energy conservation and to identify alternative fuel options for clay baking and manufacturing of building products. This would result in an improvement in production efficiency by reducing operating costs, and would remove the company's over-dependence on a single source of fuel.

The results of the research led to the following improvements between 2007–2008.

- By designing and installing a hot air reheating system and installing insulation, drying times were reduced from 10 to 3 days.
- Productivity was increased by 5%, allowing orders to be fulfilled within two weeks, rather than the former 8-10 weeks, thereby reducing customer complaints.
- Improvement in the performance of the dryers created space for more fresh green products into the drying process, leading to an increase in operating capacity from 70% to 80% and a growth in sales of over 15%.
- A better understanding of the drying process has been gained through using new instrumentation, in this case a thermo-hygro anemometer, to monitor the key factors affecting the rate of drying (airflow speed, humidity levels and prevailing temperature in both artificial and natural dryers), as well as training in control of the drying process and industrial energy efficiency.
- By recording, on a monthly basis, the amount of coffee husks consumed and the corresponding kiln loading a better understanding of the relationship between these two factors has been achieved. This has enabled UCL to determine the specific fuel consumption, a figure that is crucial in establishing the buffer stock of coffee husks to avoid short-term fuel shortages.
- By classifying coffee husks into basic categories that directly affect their performance (namely bulk density, particle size, moisture content, ash and volatile matter content), UCL now has established standards for the coffee husks used, giving better fuel quality control during procurement and consumption.

3. NATURAL PRODUCTS

3.1 Promoting greener natural product chemistry

The use of natural products is a potentially lucrative business for Africa. A great deal of research on natural product chemistry is going on, and there is an abundance of local knowledge of the use of herbal medicines. One key area for innovative product development in natural product chemistry is phyto-pharmaceuticals, (pharmaceutical agents of plant origin).

Extraction of useful materials is a fundamental process in the use of biomass resources in green manufacturing, including producing medicines. Traditionally, extraction procedures use solvents which are toxic, damaging to the environment and derived from crude oil. Their disposal costs are high and are a significant cost of the manufacturing process. If they are not disposed of properly, they enter the air, soil, water systems and the food chain, where they cause damage to the environment and can cause health problems for people living in the area. This is not a sustainable option, either economically or environmentally.

For the reasons outlined earlier in this report, it has become a priority to promote and encourage the application of the 13 principles of Green Chemistry in natural product chemistry.[5] In addition to new phytopharmaceuticals, plant materials are also sources of renewable feedstock for manufacturing a wide range of industrial products, from cosmetics to lubricants and fine chemicals[7] (See Section 2).

Natural product chemistry operations can be divided into broad areas as presented in Table 1. These operations include: (i) extraction, (ii) fractionation/ purification of crude extracts, (iii) structure determination of phytocompounds; (iv) structural modification for compound generation, and (v) synthesis or semi-synthesis of bioactive compounds.

Table 1. Natural product chemistry operations with conventional and recommended Green Chemistry-enhanced methods

Operation	Conventional methods[8]	Recommended Green Chemistry-enhanced methods[9,10]
Extraction	• Maceration (also required for some of the Green Chemistry enhanced methods) • Percolation • Soxhlet extraction • Steam distillation	• Advanced phytonics[11] Microwave and ultrasonic assisted extraction • Steam distillation • Supercritical fluid extraction (SFE) • Solid phase micro-extraction (SPME)
Fractionation/ purification	• Precipitation • Solvent-solvent extraction • Fractional distillation • Chromatographic methods (*e.g.* liquid chromatography, thin layer chromatography)	• High-performance liquid chromatography (normal and reversed phase)[12] • Supercritical fluid chromatography
Structure determination	• Spectroscopic methods (solvent amounts are not significant)	
Synthesis/ semi-synthesis of phytocompounds	• Classical reactions (*e.g.* esterification, oxidation, reduction, hydrolysis)	• Microwave and ultrasonic assisted reactions[13] • Biocatalysis[14]

3.2. Extraction of natural products, including biologically active products, using water and other green solvents

Most solvents currently in use to extract natural products are derived from non-renewable crude oil feedstocks, and are expensive to purchase. They include aliphatic, aromatic and halogenated hydrocarbons, alcohols, esters and ethers. In addition, water and aqueous solutions of inorganic salts may be used as solvents.

Some of these solvents are considered to be hazardous substances. For example, they can be toxic and, when they evaporate, are sometimes powerful greenhouse gases, or they can contribute to the destruction of the ozone layer. As a consequence, the cost of their disposal is a significant proportion of the cost of any process in which they are used. Health regulations and public concern about the use of these solvents in the manufacture of food and pharmaceutical products has led to an increased interest in alternative safer and greener methods of extraction.[15]

The usual methods adopted for research into natural products involve a systematic extraction of plant materials with a suitable solvent to isolate useful chemicals. For many of these plant-derived chemicals, such as the fatty acids and terpenoids, the hydrocarbon hexane is normally used as the extracting solvent, while the halogenated solvent dichloromethane may be used for the isolation of a wide variety of compounds such as alkaloids, flavonoids and terpenoids. The more functionalised compounds include classes such as the glycosides and the lactones. These are extracted with esters such as ethyl acetate and alcohols including methanol or ethanol. However, water and, to a lesser extent alcohols (ethanol in particular), are greener solvents. Ethanol and certain other alcohols can be produced from biomass feedstocks by fermentation, so can be considered as sustainable materials.

Water in many cases can be an effective solvent for certain phyto-pharmaceuticals and other polar compounds, such as flavonoid glycosides and triterpene glycosides. The major advantages of water are that it is not toxic and does not contribute to the emissions of volatile organic compounds to the atmosphere, and that it can be cleaned and re-circulated for reuse in the extraction/fractionation process or other applications. Moreover, if a sufficiently efficient purification process is applied it could even render the water suitable for drinking after use in the process. When water is used as a solvent, extraction or fractionation processes can be done under mild conditions, *i.e.* within the range of liquid water temperatures. With this approach, not only can significant cost savings be realised as the cost of solvent (water) and energy is reduced but also it is known to provide high selectivity, cleanliness, and speed up the process.[16] During the 1st PACN Green Chemistry Congress, it was shown that methods that use only water or water combined with other greener solvents like ethyl acetate and ethanol, to extract compounds from plants materials, have been developed. These have been found to efficiently extract compounds that have a variety of chemical structures. The product recovery obtained by using green aqueous mixtures was found to be comparable to that obtained by using the more toxic organic solvents.

Phytopharmaceuticals have been identified as a potential area of product development in Africa but the lead time to market for this type of product is often long and complex if regulatory considerations are taken into account. However, the investment in extraction facilities that can use green solvents with the widest range of polarity, namely water, ethanol and supercritical carbon dioxide is not insignificant and returns on this investment need to be made in a shorter timescale than can most probably be achieved by relying solely on phytopharmaceuticals.

Plant-derived products, particularly those extracted using green technologies, are becoming highly sought-after for many product areas including cosmetics, personal care and as flavour and fragrance ingredients. These product areas are growing rapidly and export ingredient supply chains from within Africa could be developed much faster with a longer-term objective to formulate end products within Africa for African consumers. African plants can provide a wide range of these ingredients and the technology and equipment would be the same as that required for the development of phytopharmaceuticals. This could also be a longer-term development opportunity, building on the experience gained in the sourcing and extraction of food and cosmetic ingredients from African plants.

Ionic liquids (ILs) are salts which are in a liquid state at relatively low temperatures, often defined as liquids below 100ºC. ILs have made it possible to dissolve cellulose from biomass[17] and have therefore opened up a new source of feedstock for the chemical/pharmaceutical industries. An important feature of ILs is their immeasurably low vapour pressure. In practical terms, this means that they do not evaporate. This eliminates the problem of the emission of volatile organic compounds (VOCs) to the atmosphere. However, the issue of whether ILs are green solvents is highly contentious. In addition to the positive aspects, such as negligible vapour pressure, some ILs are made from toxic ions (and by processes which may not necessarily be green) which could cause harm if released into rivers or soil, where their environmental fate is not yet understood. ILs do however have many additional attractive properties, such as chemical and thermal stability, non-flammability, and others which provide useful technical advantages, including high ionic conductivity, and a wide electrochemical potential window.[18] ILs can be either water- or oil-soluble, depending on their structures.[19]

To conclude, a key step in any work with natural products is to extract them from the plant that produces them.[15] A suitable solvent is chosen on the basis of various criteria, including its ability to solubilise the natural products of interest, toxicity, availability and ease of handling, cost, and ease of removal. Health regulations and public concerns about the use of non-green solvents/chemicals in the manufacture of food and pharmaceuticals have increased the interest in alternative safer and 'greener' methods of extraction. The recently published work by Sinha *et al*[20] is a good example of how Green Chemistry can be applied in natural product chemistry. In summary, natural products are very desirable but they need to be derived from sustainable sources, extracted using green solvents (such as water, ethanol, supercritical carbon dioxide), and modified only by green processes.[21]

Case Study 4 – Natural Product Extracts Show Bioactivity

P. M. Faith
Department of Physical Sciences
Sokoine University of Agriculture
Mazimbu Campus, Morogoro, Tanzania

Plant-derived natural products can offer promising health and socio-economic benefits. They are accessible to and owned by poorly resourced people and are ecologically and culturally adapted to local conditions, thereby underpinning their role as safer bio-resources and part of a 'biodiversity-friendly' industry.

Species from the genus *Synadenium* are deployed in different parts of the world as traditional medicinal plants. Extracts from *Synadenium grantii* (African milk bush), are used for wound treatment and as an antitheilerial (active against parasitic protozoa) agent. *Synadenium glaucescens pax* (Euphorbiaceae) is claimed to be used in traditional medicine in Tanzania to control and treat viral, protozoal, bacterial and fungal diseases in both humans and animals. An ethnobotanical survey conducted in the southern highlands of Tanzania indicated that 94% of communities are aware of the medicinal value of the plant and the majority (78%) have used its leaves or roots for medicinal purposes.

Synadenium glaucescens was reported to be highly toxic, and this was confirmed by a brine shrimp lethality test which showed LC_{50} of less than 30µg/ml for all extracts. However, crude extracts from the plant showed biological activities against chicken diseases and bacterial pathogens. Extracts of euphorbiaceae reduced the viral load in the chicken and protected chicken embryos (at the most delicate and susceptible life stage) from infection and deformities while promoting weight gain. Furthermore, extracts showed bioactivity against Gram positive and negative bacteria, and funghi of clinical importance. These findings demonstrate a high potential and socio-economic value of *S. glaucescens* validating its traditional use.


African milk bush

4. GREEN WASTE DISPOSAL

The rapid post-war economic development of most countries has led to the generation of billions of tonnes of waste around the world so that the problem of waste management is now acknowledged as a global issue. The African continent is no exception, with its rising levels of urbanisation and rapid population growth.

It is reported that a total of 2.5 to 4 billion tonnes of waste, out of which more than 1.5 billion tonnes is household waste, is produced worldwide annually as a result of urbanisation, industrialisation and increased standards of living. While people in developed countries, especially high income ones, can generate up to 1.5 kg of waste per day, on average, a typical African generates around 0.3 to 0.5 kg of waste per day which has to be collected, transported, treated and eventually disposed of. These operations are expensive. While industrialised nations are creating the technologies and logistics to deal with the problem of increasing waste, Africa has other priorities such as housing, food and education. However, if left untreated, solid waste can rapidly present a threat to public health and to water and air resources. Several studies have shown that organic waste and especially livestock manure, if improperly managed, can result in significant degradation of soil and water quality, due to pathogens as well as nitrogen and phosphorous overloading. Stagnant waste provides a medium in which flies breed and diseases are transmitted. Uncontrolled decomposition of organic waste produces odorous gases as well as the evaporation of ammonia, leading to air pollution, the formation of nitrogen oxides and acid rain.

On the African continent, as in other regions, solid waste consists of municipal wastes, farm waste, agricultural waste, including that due to crop spoilage, and industrial waste. Industrial waste can pose its own problems and regulation of industries will be critical in addressing these. Regulation must be backed up by real-time analysis to ensure that standards are maintained. Agricultural spoilage could be minimised by the adaption of food preservation technologies. Furthermore, rapid urbanisation has led to informal settlements around cities, which often lack the infrastructure for proper waste management and sanitation. In most cities in Africa, until now, solid waste has been dumped into uncontrolled deposits. Open air dumping is still prevalent for many cities like Casablanca, Gaborone, and Maputo, while some cities such as Bujumbura and Windhoek have adopted the controlled sanitary landfill approach, but still with very little energy recovery from the biogas generated. Therefore valuable resources from the solid waste are lost.

4.1. Integrated hierarchy of solid waste management

Land-filling is the last option in the integrated solid waste management (ISWM) hierarchy which is the modern approach to solid waste management. ISWM involves a range of options which lead to the minimisation of waste, a reduction in the toxicity of waste, and the reuse of waste. The only waste that has to be land-filled is that which cannot be reused, recycled, composted or incinerated.

The recovery of waste includes recovering the material content by reuse or recycling, or to obtain energy by burning the wastes or the biogas collected during anaerobic (limited air supply) digestion. Material recovery or recycling is at the top of the ISWM hierarchy of waste treatment methods and, in Africa, informal recycling can play a major role in reducing the use of raw materials. Recycling should be encouraged as it reduces the effects related to the use of resources and the transformation of raw materials, in addition to savings being generated by using the recycled products. Ferrous and non-ferrous metals, for example, have been recycled in the developed world for many years, where they play a key role in energy consumption and are traded as commodities on the international market.

4.2. Composting potential

Waste can prove to be an important resource for Africa, where the waste stream is composed of large amounts of organic material. More than 85% of the waste products in cities like Accra, Kigali and Lagos are rapidly biodegradable. They have high density and high moisture and can be very appropriate for biological treatment methods like composting or fermentation.

Composting the organic portion of solid waste has multiple benefits, such as a reduction in the quantity of waste to be disposed of, a reduction in the negative environmental impact resulting from waste storage and the production of material that is safe for agricultural use. Advantages of composting also include killing pathogens, fly larvae and weed seeds and reduction in weight and volume which makes waste handling more cost-effective.

Rich in organic matter, municipal solid waste in urban areas is particularly suited to composting as the market can be stimulated by the growing need for fertilisers in African countries. Alexandria in Egypt, for example, converts around one quarter of its waste into 120,000 metric tonnes of compost per year, which is then used to improve soils, in particular sandy desert soils. Although waste management solutions vary from region to region, such solutions can be applied to other African cities facing similar problems of waste disposal, meeting the need to improve soil fertility.

Composting closes the sustainability loop, with resources being converted to compost and returning back to the soil important components that were taken during crop growing and other agricultural practices. Furthermore, composting can be practiced at several scales and levels of technology. Passive composting, decentralised community composting and source composting in individual units are particularly appropriate for African cities as the basic resources for sustainable composting are readily available.

4.3 Anaerobic digestion

Anaerobic digestion (AD) is very appropriate for livestock manure and wet wastes. It can be used to treat the waste generated by farmers and communities in the rural areas of Africa. The foremost advantage of AD is the generation of methane that can be burnt for energy, and the residue that can be used as fertiliser.

Small-scale digesters should be developed to cater for waste generated in rural areas and to provide a source of renewable energy.

4.4 Conclusions

The issue of waste management must not be oversimplified or viewed only from an economic point of view. Social and cultural factors are important when devising any waste management strategy as there is no one best method of treating waste. Depending on the local circumstances of the country, the population, the culture and its economic resources, a variety of treatment methods which are affordable must be encouraged.

The need to increase soil organic matter in Africa is an important reason for recycling organic waste and returning nutrients to the soil. Composting plays an important role in sustainable waste treatment and organic farming practices. Among other benefits, the use of compost can improve the livelihood of rural communities with higher yields of vegetables and fruit that result from crops grown on more fertile soils. Anaerobic digestion provides a source of energy for various uses including cooking and lighting, and the residues can be used for compost.

Composting and AD are particularly suitable for the type of waste generated by both the urban and rural areas of Africa. They provide a unique opportunity to save valuable materials and will become increasingly important as more chemicals start being made from biomass. Regulation of this industry will be critical if it is to work successfully and the health and safety issues should not be underestimated. Regulation will need to be backed up by suitable monitoring protocols to ensure that the products are fit for purpose and sufficiently free from contaminants, including heavy metals and mycotoxins (toxic substances produced by funghi). It should be noted, however, that good regulation should be to protect the health of people and the environment, while stimulating innovation. It should promote research into AD and composting methods. Research should also ensure that the procedures do not generate more greenhouse gases than other disposal procedures. There are ample opportunities for knowledge sharing between Africa and the developed world to ensure that best practices are adopted. This may include work shadowing and research collaboration.

Case Study 5 – Waste to Energy – A Case Study of Dar Es Salaam City, Tanzania

Michael A. Kishimba
Chemistry Department
University of Dar es Salaam, Tanzania

Poor management of urban waste represents the most serious environmental and public health problem in Africa. The presence of waste in residential areas, *e.g.* at markets and roadsides, presents grave health hazards, in particular to children. Poor urban waste management is primarily due to the lack of sufficient resources. However, energy recovery from waste has the potential to greatly alter the situation – turning an environmental liability into a socio-economic asset for the alleviation of poverty.

Population increase usually correlates proportionally with increased municipal waste, thus providing more feedstock for energy production. Studies have shown that exploitation of energy from waste not only greatly reduces (by over 60%) the amounts of urban waste that need to be disposed of, but also greatly alleviates urban environmental pollution, diseases and poverty.

A case study from Dar es Salaam, Tanzania, has shown the techno-socio-economic viability of sourcing renewable energy from municipal waste (EMW). Estimates show that in the year 2000, Tanzania could have generated about 60 MW of electricity from municipal solid waste alone, substituting about a million tons of petro-fuels. The policy and institutional frameworks have to be moulded to incorporate EMW options into urban waste management strategies. The lessons from the experience gained in Dar es Salaam can easily be adopted by other urban centres, not only in Africa, but also in the rest of the developing world.

Case Study 6 – Composting in Zimbabwe

Romeela Mohee,
Mauritius University, Mauritius

Zimbabwe faces severe issues of decreasing soil fertility, and there is an urgent need to replenish the fertility of the soil by the addition of organic matter. Efforts have been made by the Tropical Biology and Soil Fertility programme (TBSF) at the University of Zimbabwe to explore ways to improve the quality and effectiveness of compost. The project was set up in 2002, with the Regional Compost Network at the University of Mauritius. A pilot composting and demonstration project using household waste was established.

The goal of the project was to promote composting through participatory demonstration trials targeting both rural and urban communities. Specific objectives were to:

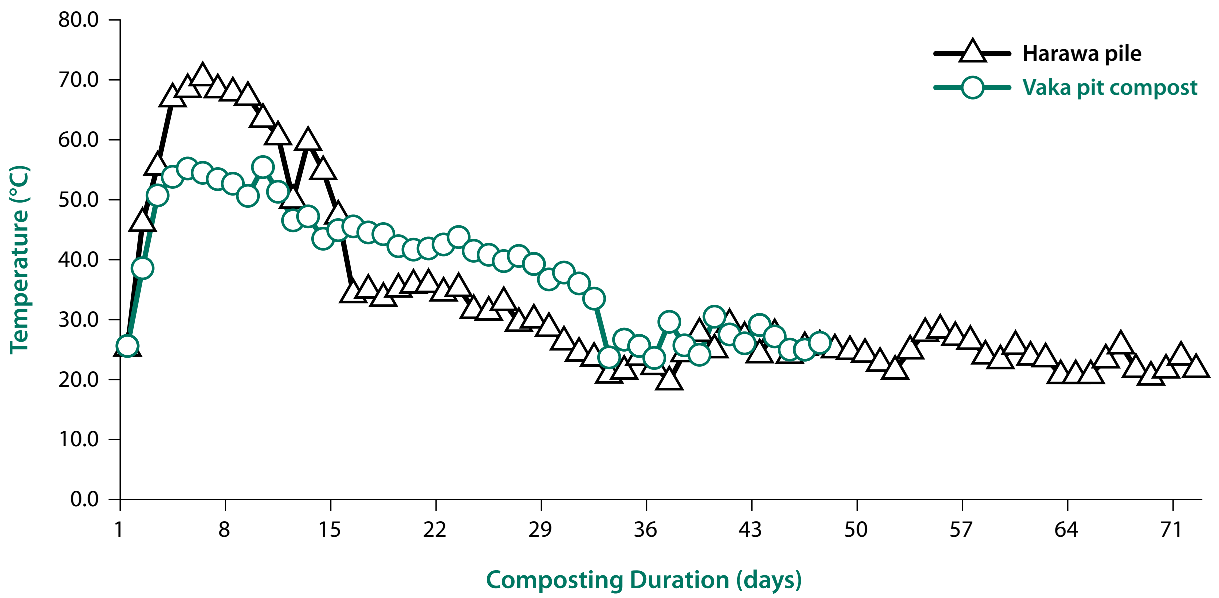
- Enhance the use of locally available organic resources through farmer participatory composting research.
- Identify locally available organic resources in the study area.
- Encourage farmers to assess different composting technologies.
- Identify key criteria used by farmers to identify appropriate composting technologies.

Two rural communities, Harawa and Vukusvo, each comprising groups of farmers, were selected. In addition, an urban secondary school was selected to represent urban and peri-urban environments.

Focus group discussions and presentations were used to identify farming practices and the organic resources required for composting and to compare composting strategies used by different farmers. At each site, farmers gathered materials for composting, stockpiling the materials.

Materials used for composting by the different groups varied. Harawa farmers used maize stocks, partially decomposed tree leaves and garden weeds. Vukusvo farmers used maize stalks, groundnut stalks and goat manure mixed with soil. Harawa farmers constructed their compost in piles on the ground and used twigs as the first layer for improved aeration. Vukusvo farmers composted in pits and covered the piles with soil. The temperature in the centre of the compost was measured daily at three different positions and the moisture content was monitored weekly.

The composting processes were carried out successfully, showing the importance of aeration and biological activity of micro-organisms. This allowed farmers to manage the composting process effectively.



5. GREEN CHEMISTRY EDUCATION FOR SUSTAINABLE DEVELOPMENT IN AFRICA

It is essential that university chemistry departments have an intake of students who have developed an interest in science from secondary school level. The introduction of Green Chemistry themes, which define and explain the benefits of Green Chemistry, at secondary schools is highly beneficial for engaging and enthusing students and attracting them towards science, in particular chemistry, at university.[22] These themes should include for example, the use of biomass as a sustainable feedstock and promotion of Green Chemistry thinking in a wider context within society. Once in university, science and engineering students should be engaged to think about greener chemistry in Africa. Green science and engineering in education has the potential to:[23]

- attract students to the field of chemistry and engineering who otherwise may not have seen themselves as potential scientists or engineers;
- provide chemists and engineers with an essential skill set that will be needed as the basis of a sustainable world;
- inspire a new generation of innovators to tackle some of the greatest challenges that our society and our civilisation face today.

Any model of innovation for sustainable development should therefore ensure that teaching methods are fully integrated with greener technologies. This will ensure that students are motivated to study chemistry and, ultimately, enable them to contribute to the green economy. This will be essential if Africa is to fully utilise its unique position in the world and to become a major player in the field of green science and technology and sustainable manufacturing.

There are three complementary and overlapping approaches in the reform of science education that can contribute to economic and social development. These are the:

- ***knowledge-acquisition approach*** - increasing technological uptake and basic literacy skills;
- ***knowledge-deepening approach*** - increasing the ability of the workforce to add value to economic output by applying this approach to solve complex, real-world problems;
- ***knowledge-creation approach*** - increasing the capability of the workforce to innovate and produce new knowledge through research and by increasing the capability of citizens to benefit from this new knowledge.

Green Chemistry educational programmes should take the African context into account, so as to make the learning meaningful and most useful and beneficial to the needs of the African economies.[24] Syllabi should be written to direct the teaching of Green Science principles to African students at various levels. The application of these approaches in the design of education curricula and teaching/learning strategies will be critical to enable the student to progress through the knowledge approaches as defined, above.

The available information and communication technologies should also be integrated within this approach and teachers will need training and support to develop these competencies.

One of the key criteria which determine the extent to which students can move to the knowledge creation and innovation phases is the authenticity of the course content. To facilitate this progression, chemistry departments, particularly those preparing chemistry educators in Africa, will need to introduce outreach programmes for undergraduate and postgraduate students. In these programmes, the candidates should go out to relevant institutions, including primary and secondary schools, where they will enhance their understanding of Green Chemistry by creating and testing Green Chemistry appropriate activities and lessons. African chemical societies should play a key role in facilitating these activities, for example, by designing and implementing professional development programmes for faculty members in terms of teaching, research and community service as related to Green Chemistry.[25]

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7. APPENDIX

List of Presenting Authors at the 1st PACN Green Chemistry Congress

Abdelgader, H.	Agricultural Research Corporation, Crop Protection Research Centre, Wadmedani, Sudan
Abebe, A.	Addis Ababa University, Ethiopia
Adewuyi, A.	University of Ibadan, Nigeria
Agbebi, O.T.	University of Agriculture, Abeokuta, Nigeria
Akegbejo-Samsons, Y.	University of Agriculture, Abeokuta, Nigeria
Arias, K.I.	University of Zurich, Switzerland
Awudza, J.A.M.	Knust, Ghana
Bakavoli, M.	Ferdowsi University of Mashhad, Iran
Beheshtiha, Y.S.	Alzahra University, Tehran, Iran
Bolzani, V.	UNESP, Brazil
Carreira, E.M.	ETH Zurich, Switzerland
Crawford, B.	Unilever, UK
Dodson, J.R.	University of York, UK
du Toit, J.	Stellenbosh Institute, South Africa
Eneh, O.C.	University of Nigeria, Nsukka, Nigeria
Engida, T.	UNESCO and FASC, Ethiopia
Fadwal, R.E.H.	University of Gezira, Sudan
Faith, P.M.	Sokoine University of Agriculture, Tanzania
Finney, N.	University of Zurich, Switzerland
Giner, B.	Universidad San Jorge, Spain
Gongden, J.J.	University of Jos, Nigeria
Han, B.	Chinese Academy of Sciences, China
Heaton, Z.	Glaxo SmithKline, UK
Heravi, M.M.	Alzahra University, Tehran, Iran
Horsfall, M.	University of Port Harcourt, Nigeria
Isife, C.T.	University of Nigeria, Nigeria
Jackson, D.	Yngenta, Switzerland
Jonnalagadda, S.B.	Kwazulu Natal University, South Africa
Jumbam, N.D.	Walter Sisulu University, South Africa
Kamau, G.N.	Nairobi University, Kenya
Karume, I.	Makerere University, Uganda
Kehinde. O.	University of Lagos, Nigeria
Kilulya, K.F.	University of Johannesburg, South Africa
Kishimba, M.A.	Dar es Salaam University, Tanzania

Kuznetsov, M.V.	Russian Academy of Sciences, Russia
Leitner, W.	ITMC-RWTH, Germany
Lugemwa, F.N.	Pennsylvania State University, USA
Mdoe, J.E.G.	Dar es Salaam University, Tanzania
Midiwo, J.O.	Nairobi University, Kenya
Mihigo, S.O.	University of Botswana, Botswana
Moges, G.	ChemTest Consulting, Ethiopia
Mohee, R.	Mauritius University, Mauritius
Motswainyana, W.M.	University of the Western Cape, South Africa
Mubofu, E.B.	Dar es Salaam University, Tanzania
Murungi, J.	Kenyatta University, Nairobi, Kenya
Mutai, C.T.	Kenya Medical Research Institute, Nairobi, Kenya
Mwansat, G.S.	University of Jos, Plateau State, Nigeria
Naicker, P.P.	Kwazulu Natal University, South Africa
Ndom, J.C.	University of Douala, Cameroon
Njagi, J.G.	Kenyatta University, Nairobi, Kenya
Nnabugwu, M.A.	University of Nigeria, Nigeria
Nyamori, V.O.	Kwazulu Natal University, South Africa
Nyamukamba, P.	University of Forte Hare, Alice, South Africa
Obuseng, V.	University of Botswana, Botswana
Olayinka, O.K.	University of Lagos Akoka-Yaba, Lagos, Nigeria
Opoku-Mensah, A.	UNECA, Ethiopia
Osafo Aquaah, S.	KNUST, Ghana
Oyeyiola, A.O.	University of Lagos Akoka-Yaba, Lagos, Nigeria
Parrott, A.	University of Nottingham, UK
Pickett, J.A.	Rothamstead Research, UK
Poliakoff, M.	Nottingham, UK
Siegel, J.	University of Zurich, Switzerland
Sun, C.	Federal University of Petroleum Resources, Nigeria
Taylor, G.J.	Kwazulu Natal University, South Africa
Tebandeke, E.	Makerere University, Uganda
Tum, P.	University of Eastern Africa Baraton, Eldoret, Kenya
Wanjau, R.	Kenyatta University, Nairobi, kenya
Zacharia, J.T.	Kobe University, Japan

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Burlington House
Piccadilly, London
W1J 0BA, UK
Tel: +44 (0)20 7437 8656
Fax: +44 (0)20 7437 8883

Thomas Graham House
Science Park, Milton Road
Cambridge CB4 0WF, UK
Tel: +44 (0)1223 432685
Fax: +44 (0)1223 423623

Email: roadmap@rsc.org
www.rsc.org