GLOBAL CHALLENGES

Research Challenges in Sub-Saharan Africa – Workshop and meeting results

Report prepared by Charles Banks and Angela Bywater

BBSRC bioscience for the future

AD NETWORK Harnessing Anaerobic Digestion

Contents

1 Selection of Workshop Locations

A geographic scan was carried out to identify countries in Eastern and Southern sub-Saharan Africa (ESSA) where workshops could be held. Criteria included:

1. Centres which had good logistics in terms of road or air connections.
2. Locations which were easily accessible by the largest number of workshop participants (identified in Section 2 below) and to which others in neighbouring countries could easily be flown.
3. Centres which were safe.

Within these areas, suitable locations for the workshops were identified.

Formal workshops were held in Nairobi on 25 January 2017 and in Johannesburg on 13 February 2017. Further meetings were held on 15-16 February 2017 in Cape Town at the University of Stellenbosch.

2 Identification of relevant research groups

The approach used to identify relevant research groups working in the field of renewable energy recovery and resource recovery through AAD in ESSA countries was as follows:

1. The senior UK academics involved in the workshops identified a number of contacts working in relevant sectors in ESSA. These academics were also invited to recommend senior colleagues who worked in the relevant topic areas.
2. A literature search was carried out to identify key senior academics active in these fields. These researchers were invited to attend or to suggest senior colleague(s) who might also be interested.
3. Other non-academic contributors were also invited to workshops or private meetings, but in very small numbers. These included representatives from businesses working in the Industrial Biotechnology (IB) related sectors, as well as representatives from electricity companies, the City of Johannesburg, the Province of the Western Cape and others. The ESSA academics felt very strongly that successful projects would need to be proposed within the larger regional framework and would require input from such stakeholders at this early stage.

Participants with a broad range of industrial biotechnology interests were invited, particularly those working in in biomass production, product extraction and waste utilisation. The skills mix was intended to obtain a fair representation of the problems that might be faced at a country/regional level. The workshops were designed to reflect the research/project interests of the participants, as well as to allow them to identify research areas which could be addressed through ODA. The purpose of the workshops was to identify specific problems and challenges and to provide feedback on whether these could be developed into collaborative research programmes for the targeted regions/countries in ESSA, while also in some cases addressing problems of more global significance across the developing world.

The Nairobi workshop included representatives from Uganda and Tanzania, whilst the Johannesburg workshop included representatives from Zimbabwe, Botswana and Malawi (see attendee lists at Appendix 1 – Workshop and Meeting Participants). The following discussion is framed largely around Kenya and South Africa, but it should be noted that participants from other countries felt that they face similar challenges to a greater or lesser degree.

The UK participants included:

1. Professor Charles Banks – University of Southampton and PI of the Anaerobic Digestion Network (attended Nairobi & Johannesburg workshops)

2. Professor Jeremy Woods – Imperial College London (attended Nairobi only)
3. Dr David Leak – Bath University and PI of the Plants to Products Network (attended Nairobi only)
4. Dr Mike Mason – Oxford University (attended Nairobi only)
5. Dr Joseph Gallagher – Aberystwyth University and Co-I of the Plants to Products Network (attended Johannesburg only)
6. Mrs Angela Bywater – University of Southampton and Anaerobic Digestion Network co-manager (attended Nairobi and Johannesburg)

3 Workshop Methodology and Scope

The workshops in Johannesburg and Nairobi were run on broadly similar lines.

Six topic areas were identified before the workshops were held. These were based on the four areas identified in the original proposal to the BBSRC. The topics were designed to:

1. include the widest range of challenge areas in this sector
2. reflect the range of participant skill sets and
3. provide topic areas for focussed discussions

The six areas included:

1. Potential for and benefits of energy production from wastewater
2. Novel non-food-competitive feedstocks for advanced anaerobic digestion (AAD)
3. AD for agro-industry, commercial and municipal wastes
4. Anaerobic biorefineries for new products – beyond biogas
5. Integration of anaerobic digestion and renewable energy technologies
6. Resource recovery and the circular economy

Not all participants debated all six topics selected.

In Nairobi, participants were divided into groups based on their main research interests. Each attendee debated three topics, at least two of which were within their broad areas of expertise and interest. They were also deliberately asked to debate one topic which was outside their main line of interest, in order to act as wild cards to add potentially useful information to the debate. This formula worked quite well as a means of producing a balanced debate around the topic areas.

In Johannesburg, participants self-selected their areas of interest by ranking them in order of importance. These were then collated and participants were divided into groups for the three discussion sessions. Depending upon their choices, each participant was able to discuss their two highest-priority areas and most participants were able to participate in discussions on their third priority area.

Each of the discussions was chaired by a facilitator who

- appointed a rapporteur
- ensured that all participants contributed productively to the discussion
- noted the main problem areas and challenges identified
- clarified/explained any unfamiliar areas and gave examples where necessary

Topic discussions lasted for not more than half an hour, so timescales were challenging and participation was closely managed by the facilitators. After discussions, each rapporteur outlined the findings of their group to the rest of the participants.

In the afternoon session, participants of both workshops were asked to:

1. Write down two projects that they would like to research or which they believed to be important
2. Vote on which of the six topic areas they were most interested in
3. Vote on two projects (not their own) which they felt had merit

The meetings at the University of Stellenbosch were not long enough to run a full-day workshop, but a summary of the problem areas and challenges identified in the previous workshops was presented and discussed and valuable points were made on aspects of these and any potential calls. These are outlined in the results section below.

4 Results Discussion - Nairobi

Figure 1 - Attendees at Nairobi workshop

There was naturally a certain degree of overlap between discussions on the individual topic areas, but the results of the morning session were broadly as described below.

4.1 Wastewater

The outcome of the morning discussions highlighted two areas in particular: the need for better sanitation and for making better use of wastewater as a resource. Based on the NIBB research area focus of advanced anaerobic digestion, the delegates could see the cost savings and potential benefits of switching to energy-producing rather than energy-consuming wastewater treatment technologies. The discussion covered the use of integrated wastewater treatment systems that extend both novel and conventional approaches, for example by using high rate algal treatment where biomass is harvested for use as a bioenergy source or for resource recovery of nutrients and carbon for soil improvement.

It was noted that although there have been many years of effort to improve sanitation through the use of conventional systems, a large number of these attempts have fallen by the wayside, due to the high overall costs of operation. As sanitation was high on the list of participant priorities, it was considered that appropriate research and demonstration activities would provide an opportunity to improve alternative systems and make the process resource recovery orientated, rather than resource consuming. Discussion included not only the production of energy, but also nutrient capture and nutrient recycling to prevent eutrophication and spread of invasive species such as water hyacinth. It was also recognised that an effective wastewater treatment system was fundamental to improving health and to disease eradication and that algal systems could actually improve this functionality. The conclusion was that achieving effective wastewater treatment was still a major problem in ESSA countries and that research and development of alternatives to conventional aerobic treatment systems was needed to provide solutions that were affordable, sustainable and applicable in many of the tropical and sub-tropical regions of Africa for both urban and peri-urban communities.

4.2 Novel non-food-competitive feedstocks

The second topic area attracted considerable interest and debate around the potential for use of appropriate purpose-grown biomass that did not compete with food or feed production. It was felt that not only should we be considering the growth of non-competitive food crops for energy/biomass production, but more importantly these should be used to increase the sustainability of food production systems, by making them economically more attractive, utilising a larger proportion of the land area, maximising the effective use of available water resources, improving nutrient use and recycling and replacing soil carbon.

Major concerns were of course the impacts of extending agriculture into previously unfarmed areas, and the effects on natural environment and the ecology of systems. Any research into the use of drought-resistant plants, for example, should be accompanied by environmental assessment as well as economic modelling and sociological studies to ascertain any impacts on traditional practices. There was, however, general agreement that, subject to careful research prior to large-scale implementation, the agricultural production of non-food crops would not only contribute to energy security but also improve the sustainability of food production by increasing the viability of individual farms. This would be particularly relevant to those areas of ESSA which are prone to drought, and those that rely heavily on traditional fuel materials for their energy supply. Research in this area and implementation of the results might therefore solve a major problem in maintaining the economic viability of drought-prone farming regions.

Aquatic feedstocks were also considered, including duckweed (*Lemna*) and water hyacinth, as these could be cultivated from nutrient-enriched waters or wastewaters; and there is also the potential for the harvesting of already abundant quantities of water hyacinth which are present in water bodies as a result of enrichment. The practical difficulties of doing this were noted, but not fully discussed. This topic illustrated potential synergies between the growth of novel crops and the use of waste/nuisance biomass.

4.3 AD for agro-industry, commercial and municipal wastes

In terms of available biomass feedstock, a number of agricultural wastes were identified that could potentially be utilised and were not currently used as animal feeds. These included sisal, bagasse and pineapple waste, which could be used as substrates for energy production or as feedstocks for bio-refining. There was also a clear demarcation between those agricultural wastes, such as stover, which were traditionally used as animal feeds and were thus as important as food for human consumption in the sustainability of agricultural systems. There were, however, believed to be large tonnage quantities of genuine wastes that could form the basis of a biorefining industry, but the processing and adaptation of technology to these requiresd research and demonstration.

There was a great deal of debate on resource recovery from MSW and an initial lack of understanding as to what can be achieved using separation processes to recover targeted fractions of the waste stream, both to meet the objectives of the waste hierarchy (reuse, recycle, recovery) and to realise a value chain. It was thought that the nature of these waste streams, in particular those with a high organic food waste content, might make them particularly good substrates for anaerobic bioconversion processes with biogas production. The concept of low technology flushing bioreactor cells as an alternative to landfill was discussed by one group who saw some potential in this approach compared to more complex tank digestion systems. It was recognised that current waste disposal practice was environmentally damaging and represented a major problem that could only realistically be addressed through achieving effective and economic resource recovery (including energy) from the waste stream. AD could also play a role in deprived urban populations by helping to nurture self-sufficiency and food security as a part of urban agriculture. Both biogas and composting systems have a potential role in improving urban soil quality and in nutrient recycling, as well as providing energy and fertiliser for mid-sized local community growing initiatives.

In all of the cases examined, including the use of purpose-grown biomass and wastes from agriculture or municipal sources, there was an overwhelming opinion that any energy products derived from these should NOT be considered primarily for electricity production. Kenya in particular was already rich in renewable energy sources, including geo-thermal, solar, wind and hydropower. There was a very strong view amongst the delegates that further research and development of biomass energy resources should be targeted towards making better use of methane, either for replacement of wood and charcoal as a cooking fuel or to displace traditional fossil-based fuels for transport. It was recognised that wood and charcoal burning was a major problem leading to indoor air pollution, with significant impacts on health and increased mortality as a result of this. A figure of 16,000 deaths per year was quoted as a possible benchmark against which improvements might be measured. It was also noted that biogas production needed to be implemented in an effective and efficient way, and to avoid the problems associated with many of the earlier small-scale rural biogas plants which were noted to be inefficient and potentially damaging in terms of GHG emissions.

Whilst there had been some mapping of MSW arisings in Kenya, it was felt that the region required better facilities to provide robust information on the characteristics of potential feedstocks, particularly in terms of regional availability, quantity, and on their potential for energy (biogas or other biofuels) and resource recovery (including biorefinery added value products and nutrients).

4.4 Anaerobic biorefineries

A small number of the attendees had a particular interest in industrial biotechnology for product recovery and manufacture. The discussion explored biotech applications including the recovery of intermediates as value-added products from anaerobic digestion processes, and also through fermentation of biomass, including second generation substrates. It was concluded that there was a committed, if limited, interest in the concepts of advanced industrial biotech for new products derived from local waste biomass materials. A lot of interest was generated by the idea that this potential could be expanded more rapidly and with greater benefit if the initial stages of biomass preparation/pre-treatment could be carried out at a community scale, which then fed into larger-scale facilities for product separation and refining that could be efficiently serviced by a central resource, giving quality assurance to the final product. This previously-unexplored concept could solve some of the logistical problems of transporting low density biomass feedstocks. The discussion progressed to consider the development of this as a concept for lactic acid production (see case study notes)

It was also noted that Africa already produces a number of high value-added products extracted from plant materials for export markets, e.g. artemisin, and that large-scale agricultural production relied on imported seed. Collaborative ventures of this type had worked well, with Africa being the production platform and the developed world providing the seed, rootstock and know-how. It was felt that a similar arrangement for the production and extraction of value-added products through bio-refining could also be encouraged, expanded and improved upon through using locally produced biomass with microbial strains developed elsewhere. This would involve using the whole toolkit of "omics" to better understand the physiology and genetics of targeted species and the conditions required for large-scale production from locally derived biomass resources.

The debate following this indicated that there was an overwhelming need to develop proper databases (mapping exercise) of the bioresources available in ESSA, and also to evaluate the potential for novel plant species which could be used as biomass resources or for value-added product recovery.

There was general agreement that development of new biomass-related processes should have a high degree of community involvement and community benefit, bringing economic wealth to communities, as well as addressing some of the social issues associated with traditional fuel and biomass harvesting

4.5 Integration of AD and renewable energy technologies

Attendees reported that although Kenya, for example, has only approximately 2.3 MW electrical grid capacity, 80% of this was from renewable sources, particularly hydro. Thus, there was little enthusiasm for the concepts of integration of AD with other renewable energy sources, as the limitations to power (electricity provision) are not fundamentally related to lack of capacity, but simply to investment in engineering effective distribution systems. It was also noted that 70% of energy use at a household level came from wood and coal use for cooking, so it was felt that biogas energy from bioresources could generally find much better uses outside electricity production.

This opinion may not have been so strongly held had there not been the earlier debate on the optimum uses of biogas which, as previously noted, was overwhelmingly in favour of substitute fuel uses.

4.6 Resource recovery and the circular economy

It was considered critical that agricultural soils should be protected, and the concept of the circular economy was felt to be of utmost importance in achieving this. Because of the nature of African soils, there was both great potential and a great need for further research into the effects of digestate utilisation in terms of improving soil fertility, nutrient balances, water retention and other factors which are known to be important in European soils.

There was also a very high degree of concern among the workshop delegates on climate change issues. Moreover, although this is not primarily a problem created by the developing nations in northeast Africa, it was one in which they are extremely keen to be able to contribute towards solutions. The beneficial use of agro-industrial residues, wastewaters and municipal solid wastes in order to capture carbon in the form of new products or energy sources for the displacement of fossil fuels was very high on the personal agendas of the delegates and in their own research areas. Thus, the debate on the circular economy extended beyond nutrient recycling and pollution mitigation to the areas of carbon management and GHG emission avoidance.

5 Results Summary - Nairobi

The various issues and problems discussed, debated and reported by the groups are summarised below.

1. The use of fossil fuels as a major input in the form of wood and charcoal and the consequent health, economic and resource implications is a major problem and of great concern. Thus, there is potential for research into solutions that can deliver clean renewable fuel from biomass and could thus make a major contribution towards meeting the challenges of improving health, resource utilization and energy security
2. Polluted aquatic ecosystems and poor sanitation are serious problems, often exacerbated by ineffective and expensive conventional treatment systems. Anaerobic digestion and industrial biotechnology could make a major contribution by developing alternative treatment methods, such as high rate anaerobic processes or integrated high rate algal/digestion systems which have the additional benefits of nutrient recovery, thus meeting circular economy aspirations.
3. Sustaining and improving traditional agricultural practice was identified as a critical area for development. Agricultural cultivation is limited by water resources and drought risk. The extension of farming into more arid areas by using drought resistant non-food crops would provide additional crop types which have economic value in their own right. Such crops could strengthen subsistence agriculture in rural communities by providing cropping biomass to feed a real need for clean renewable fuel production.
4. Landfill and land spreading are still the only available options for the disposal of MSW. This has implications for health and resource sustainability, and detrimental effects on the environment through GHG emissions

and impacts on water quality. Improved methods of waste segregation and adherence to the waste hierarchy, coupled with recovery technologies such as anaerobic digestion, could thus make a major contribution to urban waste resource utilisation over and above energy production and recovery of raw materials. There is also potential for more sustainable landfill with biogas recovery through the realisation of concepts such as landfill bioreactors.

5. Increasing the wealth generation capacity of individuals and small communities in rural areas was seen as a key priority. There is potential for diversification of small-scale agriculture into the creation of secondary products from agricultural wastes, non-food and food wastes (e.g. cassava), through the development of small-scale fermentation technologies making products that can be bulked for commodity resale e.g. lactic acid (in a lactic acid 'milk round').
6. AD can play a role in socially deprived displaced urban communities by helping to achieve self-sufficiency and food security through the adoption of urban agriculture.
7. Development of a bioindustry, perhaps with new regionally relevant or social enterprise business models, to maximise biomass production for sustainable economic development through partnership with the developed world to supply the 'enhanced microbial catalysts'. This would create local skilled job opportunities and conserve natural resources compared to the alternative of exporting biomass overseas for processing at a higher cost.

The consensus view was that high tech IB should not be excluded from NE Africa simply because of the low to intermediate level of economic development in the region. In fact, examples show that highly productive agricultural systems can be sustained by the provision of external development aid, e.g. in the form of new seed types suitable for local conditions.

It was therefore concluded on similar lines that modern "omics"-based selection of fermentative organisms and production of high value products could be introduced into NE Africa where the agricultural production of the biomass feedstocks is on a continuous year round basis, thus avoiding the requirements for storage or import which pose barriers to the development of bio-based industries in temperate climates.

6 Results Discussion – Johannesburg

6.1 Wastewater

South Africa, in particular, suffers from rapid urbanisation, with large influxes of people from the countryside and from surrounding countries, much of this into ‘informal settlements’; indeed, it was estimated that 1/3 of the population’s housing is not connected to any form of wastewater treatment system. As in Kenya, it was strongly felt that this was an opportunity to move towards energy-producing rather than energy-consuming wastewater treatment technologies. Solutions which included low-tech options suited to warm and sunny climates, such as high rate algal treatment systems, were also favoured. It was emphasised, however, that training must be involved in any project from the outset: the failure or under-performance of much of the existing infrastructure was due to several factors, including the expense of running and maintaining such systems, but also the lack of skilled personnel at all levels to run the systems. It was felt that there were also opportunities to retrofit energy-producing technologies to existing treatment systems. There was a general agreement that wastewater treatment still posed a major problem even in South Africa where there is a strong record of research and innovation, including development of nutrient removal systems which have been adopted in developed countries. In addition to the lack of treatment capacity there were also problems with water quality in river systems, which have a detrimental effect on agriculture. This was of great concern in the wine growing regions where priority pollutants could enter the wine production cycle and follow through to the final product. On the other hand effective treatment of process wastewater could improve water availability for agricultural production and nutrient recycling. Quality assurance and the provision of appropriate treatment was thus a major concern as a large number of people are employed in agriculture, and damaging the industry through poor water quality would have a significant economic impact.

Water quality and research into effective methods for priority pollutant removal were highlighted as potential areas for collaboration. The development of appropriate wastewater treatment systems for emerging non-sewered communities was also seen as a priority area, and approaching this through the adoption of new technology was considered a challenge worth pursuing.

6.2 Novel non-food-competitive feedstocks

As in Kenya, it was strongly felt that local facilities which could characterise and map existing and potential biomass feedstocks were vital. It was noted that these could be used at all TRLs, from research and development through to commercial projects. In the research sector, such facilities could identify and provide information on novel feedstocks and their potential IB uses. In the commercial sector, the same facilities could provide robust and independent information on biomass supply chains, biogas production, product extraction potential etc; thus decreasing the risk of constructing 'white elephant' facilities. A general distrust of 'European figures' for similar feedstocks was expressed, as well as frustration on the dearth of data on existing locally available feedstocks.

With the effects of climate change, particularly on water availability, it was felt that growing sustainable biomass as part of crop rotation was a way to increase the productivity of subsistence farming, potentially providing a source of energy (or income from a value-added product), returning carbon and nutrients to soils and optimising water usage.

6.3 AD for agro-industry, commercial and municipal wastes

As already noted, the region does have potential for utilisation of agricultural wastes, particularly from large cattle feedlots, the wine growing industries, large urban produce markets (such as that in Johannesburg) and wastes from other process industries.

There appeared to be little in the way of segregation of the organic fraction from MSW, and landfill capacity was running out. Sound data on MSW arisings and composition is not available or is incomplete, and this is compounded by demographic issues such as continuing large-scale immigration into informal urban settlements. It was felt that there were opportunities for research which not only furthered understanding of the arisings of agro-industrial, commercial and municipal wastes, but also identified projects which were 'low-hanging fruit' and easily realisable, as well as for longer-term projects on the creation of value-added products. There was a real appetite to implement one or more demonstrator projects, as it was felt that these could provide a positive focal point for research, an example of 'the art of the possible' to government, and act as valuable early steps towards the bioeconomy.

Participants felt that it was important for government, community and business to be involved in any initiatives in this sector.

6.4 Anaerobic biorefineries

On paper, there appeared to be less participant expertise in anaerobic biorefineries in the Johannesburg workshop than in the Kenyan workshop. In the afternoon topic area voting session, however, the topic received the largest number of votes (14) as being an area of interest. Participants were interested in large range of potential projects in this area and in particular those that could be developed as 'self-contained' systems, as these could be implemented more rapidly; be less dependent on public funding; have commercial potential; provide solutions to increasing environmental legislative pressures; improve resource recovery; and reduce the dependency on imported materials. An example that was developed as part of the discussion was based on a beef feedlot (which can be as many as 80,000 cattle) where closed loop resource recovery through anaerobic digestion coupled to chemical processing or bio-refining could produce either ammonia fertilizer or high quality protein feedstock (see case study). It was concluded that there really was high potential for adopting a biorefinery approach to address both the environmental problems associated with intensive animal husbandry, and the need to make such operations more sustainable and resource efficient.

6.5 Integration of AD and renewable energy technologies

Unlike Kenya, which gains much of its electricity from renewable sources, South Africa in particular produces around 77% of its electricity from indigenous low-grade coal. ESKOM, the largest producer of electricity (95%) also has some investment in hydroelectric, pumped storage, nuclear and wind. Whilst there was some interest from participants in producing electricity from biogas, particularly where there was an on-site demand so that grid connection would not be necessary, many felt that the wider energy uses of biogas would be more appropriate. There was a particular appetite in Johannesburg, for example, to use biomethane/biogas for transport, possibly emulating the Swedish model or the growing Indian model of small-scale production and bottling stations. In common with both of these countries, South Africa does not have a comprehensive gas network, although the country is seriously considering several infrastructure options which include gas piped or transported from fields in Mozambique in order to provide further electricity generation capacity, as ageing coal plants are taken off-line and existing planned power generation projects are delayed.

There are a number of off-grid electricity projects in South Africa and several delegates were interested in combining AD with, for example, solar or other renewable energy projects, as appropriate.

During most topic discussions, participants stressed that many varied socio-economic factors would have to be considered, with a particular emphasis that urban and rural situations were vastly different from each other and would require different approaches.

6.6 Resource recovery and the circular economy

There was no time in the workshop to discuss this topic area per se, but it was acknowledged that the previous topic areas all had elements of both resource recovery and the circular (bio)economy inherent in their remit; so a number of potential projects were proposed under this topic area in the afternoon session.

Because of the failure of rains in the region over the previous two winters (generally attributed to climate change), discussions around water treatment and use were covered in all topic area discussions. It was felt that better biomass resource use and water/nutrient recovery in rural regions could cushion farmers somewhat against climatic variation and could improve agricultural production, whilst still producing energy – a model of energy AND food, not energy OR food.

In the urban context, significant challenges still existed around recovery of the organic fraction of MSW, for example; but there were opportunities in areas where some source segregation existed, as well as potential for recovery and use of organic materials from particular industries, such as wine growing.

Figure 2 – Johannesburg workshop

7 Results summary – Johannesburg

The results from the Johannesburg workshops showed that representatives from South Africa were more aware of the restrictions to innovative technological approaches in the water and waste management sectors as a result of a much stricter regulatory regime, the mechanisms of public funding, and the number of stakeholders involved. This made it much more difficult for government, NGO and business representatives who attended the workshop to see a clear path from research to demonstration. There was clearly much greater support for project ideas that only involved a single business or a limited number of private sector stakeholders. This was felt to improve the chance of research being translated into solutions for environmental and economic problems which might otherwise restrict expansion into new markets or put existing ones at risk.

Overall, however, the results from the Johannesburg workshop reflected those from Nairobi in identifying specific problems in wastewater treatment, sanitation, water usage, waste management, productivity and sustainability of agricultural systems, and adoption of new industrial biotechnology to open up economic opportunities at all scales of participation.

One primary difference between the two regions was in the energy mixes, and in particular the electricity mix, with Kenyan electricity coming predominantly from renewables and South African electricity being provided mainly by low quality coal. It was noted that Kenyan gross electricity production is a fraction of that produced in South Africa.

Representatives from all countries recognised the requirement for household energy to move from wood and fossil fuels such as paraffin and coal, to more sustainable and healthier sources; it was felt that AD could play a role in this.

8 Summary of research challenges

After the two workshops, and in preparation for the meeting in Stellenbosch, the original themes of the workshop discussion topics were reviewed to remove any pre-conceptions which might have been present when these were formulated before visiting Africa. The summary topic areas which were discussed and the revised summary concept outputs are shown in the table below

Original workshop conception	Revised conception after 2 workshops framed as IB challenge areas
Novel non-food-competitive feedstocks for advanced anaerobic digestion (AAD)	Improve agricultural sustainability for food production by diversification to energy production or bio-refinery products
Potential for and benefits of energy production from wastewater	Reducing reliance on conventional wastewater treatment systems coupled to improved water management and resource recovery
AD for agro-industry, commercial and municipal wastes	Mapping of biomass resources, characteristics and availability as AD substrates to meet country specific energy mix requirements
Anaerobic biorefineries for new products – beyond biogas AND Resource recovery and the circular economy	Maximising the potential for industry and agricultural residues for closed loop resource recovery through integration of technological approaches
Integration of anaerobic digestion and renewable energy technologies	This was not seen as a priority research area, although case-specific benefits were appreciated

In addition, in all cases, the importance of recognising within these challenges the societal, environmental and economic implications in the development pathway as well as the opportunities for skills development was highlighted throughout the workshops.

9 Meeting Discussion - Stellenbosch

The objective of the Stellenbosch workshop was to test the robustness of our findings, to identify any weaknesses and to start to prioritise the challenges and how these might best be formulated to ensure truly collaborative interdisciplinary work that would address real problems facing development of DAC list countries. The group was asked to consider this in the broader context of Africa, although problems specific to South Africa tended to emerge as these were best known to the participants.

The meeting participants felt that the topic challenge areas presented were general enough to encompass a wide variety of projects/programmes, and that there would certainly be no shortage of ideas for potential projects within these 4 areas. Therefore, much of the ensuing discussion centred on the practical considerations of any potential call to address challenges and how this might be best formulated; this was based on the attendees' previous experiences of both successful and failed projects. Meeting participants felt very strongly that 'white elephant' projects could be avoided by taking into consideration the following points, many of which had also been voiced in the workshops in Nairobi and Johannesburg.

1. **Formative workshops.** It was felt that there should be some opportunity for formative workshops within any call, so that relevant stakeholders could be gathered and robust, workable scenarios outlined in detail. In Africa as elsewhere, projects designed in conjunction with local stakeholders have tended to work better.

2. **Funding**. There was much discussion around funding of projects, and participants noted that ODA country participation should not be on a 'volunteer labour' basis, so the project funding model is important. It was felt that the ODA country should also provide some funding for its own researchers. This means that the UK funding must strategically align with existing research funding in the ODA partner country, or that the UK Government needs to liaise with the ODA country at high level so that sufficient ODA country-based funding is available to researchers there. In the case of South Africa, this would be at Department of Science and Technology (DST) level.
3. **Societal challenges.** Several participants noted that successful projects had social scientists embedded into the research during all phases. Throughout the workshops and at this meeting, failures of various worthy projects were described; a major component of these failures was attributable to a lack of fundamental understanding of the social implications.
4. **Training.** It was pointed out that many technologies introduced into the region had either failed or were working sub-optimally. Whilst it was agreed that the technology must be appropriate to the region, and that materials and parts should ideally be locally available, much of the failure was attributed to poor training of staff at all levels. It was felt that funding and provision for training should be a fundamental part of any research project, even in the early stages. For example, the University of Stellenbosch is currently working with local colleges and training providers to create internationally-recognised training for their wastewater treatment plant personnel, since part of the widespread failure or poor operation of such plants is due to lack of formal training. A further example was given where successful solar and wind projects had built in training from the outset.
5. **Industrial partnerships**. Several participants pointed out that numerous successful projects had 'industry pull' – that is, the industry partner had seen the social and business value of providing strategic long-term support to a given initiative, particularly where government/funding body support was short term. Nevertheless, it was acknowledged that the universities were only just starting to recognise these networking and teaching/research extension possibilities. It was felt that it would be useful for projects to have provision to promote new technologies to industry, particularly where the industrial partner has not seen the value at project initiation stage.
6. **Academic partnerships**. South Africa had adopted the UK model of turning a number of former technical colleges into universities, an example being the Cape Peninsula University of Technology, several members of which were present at the meeting. It was strongly felt, for numerous reasons, that projects where 'old' universities worked with the 'new' universities would provide long-term benefits for both parties and there was a definite appetite for collaboration.
7. **Networking**. There was a great deal of enthusiasm for the principle behind the NIBB networks and some discussion as to whether the funding could be extended to work done overseas. The Networks could provide long-term continuity and a UK focal point; introduce UK academic or industrial partners into potential project consortia; promote alternative international funding initiatives (e.g. Newton fund); provide valuable information on policy and project failures and successes; and even potentially extend BIV, PoC and ECR initiatives to the ODA country for smaller and capacity building projects which might feed into larger GCRF ones.
8. **Government engagement.** In addition to ensuring that funding is available, potentially from government sources in the ODA country, it was recognised that certain projects required governmental support at many levels (strategic, regulatory, access, permitting and social, to name a few). The Stellenbosch Water Institute, for example, has been working closely with the Provincial government and related stakeholders in order to support strategic work in the water/wastewater sector. A case study on water resource utilisation in the Western Cape is outlined in Appendix 1 – Workshop and Meeting Participants.
9. **Legacy**. A legacy element was considered to be an important part of any project. The inclusion of an industrial partner, relevant training, sufficient funding, networking opportunities where participants have learned from the successes and failures of others and the other elements mentioned above should create sustainable long-term projects which will build capacity and achieve the project aims.

Many of the attendees felt that there were excellent opportunities for larger-scale bioenergy projects if the infrastructure could be developed. An example given was that of a local Veolia (Biothane) plant: this is a commercial development that will be operated by the developers for 10 years with capital payback through biomethane sales, and will then be handed over to local operators. The project was initiated from the Netherlands, as the skills to implement a robust business case in this technology sector did not exist within the local research/business community at that point. This type of approach is similar to that seen at Lake Naivasha in Kenya (see case study), where opportunities for commercial development of large-scale industrial biotechnology in Africa can be shown to work without subsidy. There is a clear indication that more research on feedstocks, product utilisation, process optimisation, and process integration could aid in the further development and implantation of a bio-based economy in ESSA

Figure 3 – Stellenbosch meeting

10 Conclusions

A number of research groups across a numerous fields were identified for participation in these workshops and meetings. Almost universally, they identified a lack of knowledge and capability to characterise potential local crop and 'waste' feedstocks for AAD and other bio-refinery processes. Mapping of 'waste' commercial and municipal feedstock arisings was practically non-existent or not well understood.

UK knowledge transfer on technologies and research approaches which both have and have not worked would also appear to be highly valuable, as this is a broad field and such knowledge transfer, even that which occurred at the workshop, was found to be useful.

There was no clear overall preference/priority for a research area; but 4 key research challenge areas were identified:

- Improving agricultural sustainability for food production by diversification to energy production or bio-refinery products

- Reducing reliance on conventional wastewater treatment systems coupled to improved water management and resource recovery
- Mapping of biomass resources, characteristics and availability as AD substrates to meet country specific energy mix requirements
- Maximising the potential for industry and agricultural residues for closed loop resource recovery through integration of technological approaches

These themes would provide a sufficiently broad framework under which research programmes could be formulated to further identify country specific problems in which IB could play a major role in assisting the development process through strategic research partnerships.

From the workshops and meetings, it appeared that the UK had no or very few academic collaborations with the participants involved; indeed, where these had taken place, they were largely down to individual relationships which had been historically established. Participants highlighted interactions between Germany, the Netherlands, the US and other countries which had established strategic, long-term links with target countries, sometimes supported through Chambers of Commerce, Departments similar to UKTI or overseas development. The Network concept was suggested as potentially being a way to effect such long-term links, and to provide a focal point for various funding streams and access to a wide variety of UK academics and industry.

Appendix 1 – Workshop and Meeting Participants

Workshop Participants - Nairobi

Name	University/Organisation	Position
Dr Fredrick Ayuke	University of Nairobi	Department of Land Resource Management & Agricultural Technology (LARMAT)
Prof Charles Banks	University of Southampton	AD Network PI
Mrs Angela Bywater	University of Southampton	AD Network co-manager
Prof Charles Gachene	University of Nairobi	Department of Land Resource Management & Agricultural Technology (LARMAT)
Mr John Gakunga	Kenyatta University	Lecturer Civil Engineering
Mr Barney Gasston	Africa Bio Medica	Director
Dr Joseph Kamau	Kenyatta University	Lecturer in Plant and Microbial Sciences
Dr James Kanya	University of Nairobi	Research associate of Prof Kinyamario
Prof Nancy K Karanja	University of Nairobi – Agricultural biotechnology	Director of Microbial Research Centre, Professor of Soil Ecology
Prof Jenesio I Kinyamario	University of Nairobi	Professor of Ecology and Environmental Sciences
Dr Anil Kumar	Moi University	Dept of Chemical & Process Engineering
Prof David Leak	University of Bath	Plants to Products PI
Dr Mike Mason	Oxford University	Researcher & Chairman, Tropical Power
Prof Dr Anthony Manoni Mshandete	University of Dar es Salaam	Head and Professor of Biotechnology
Dr Benard Muok	Jaramogi Oginga Odinga University of Science and Technology (JOOUST)	Director, Centre for Research Innovation and Technology, JOOUST
Dr Mutemi Muthangya	South Eastern Kenya University	Biological Sciences
Dr Joe Mwaniki	University of Nairobi	Senior Lecturer, Department of Chemistry
Dr Jecinta W. Mwirigi	Agricultural Sector Development Support Programme	ASDSP County Coordinator Kenya
Prof Saul Namango	Moi University	Head of Department Chemical Engineering
Dr George Obiero	University of Nairobi	Director,Centre for Biotechnology and Bioinformatics
Dr Mbeo Ogeya	Kenya Industrial Research and Development Institute (KIRDI)	
Dr Deborah Wendiro	Uganda Industrial Research Institute	Head of Industrial Biotechnology Unit, UIRI

Workshop Participants – Johannesburg

Name	University	Position
Prof Charles Banks	University of Southampton	AD Network PI
Mrs Angela Bywater	University of Southampton	AD Network Network co-manager
Dr Mohamed Belaid	University of Johannesburg	Department of Chemical engineering
Ms Senta Berner	North West University	Unit for Environmental Sciences and Management
Prof Carlos Bezuidenhout	North West University	Professor, School for Biological Sciences
Alex Bhiman	City of Johannesburg	City of Johannesburg Transport Department
Chris Brouckaert	University of KwaZulu-Natal	Pollution Research Group
Manimagalay (Maggie) Chetty	Durban University of Technology	Chemical Engineering
Dr Ezekiel M. Chimbombi	The Botswana University of Agriculture and Natural Resources (BUAN)	Senior Lecturer, Engineering
Mr Eddie Cooke	SABIA (South African Biogas Association)	Vice Chairman (SABIA) and Private consultant (Gas4E)
Dr Michael Daramola	University of Witwatersrand	School of Chemical and Metalurgical Engineering
Dr Johan de Koker	University of Johannesburg	Director of the Sustainable Energy Technology and Research Centre
Prof Christpher Enweremadu	University of South Africa	School of Engineering
Dr Joseph Gallagher	Aberystwyth University	Plants to Products Co-I
Prof Diane Hildebrandt	University of South Africa	Professor, College of Science, Engineering & Technology (Prof of Materials and Process Synthesis)
Dr David K Kimemia	University of Johannesburg	Researcher in Energy, Environment and Society
Dr Tafadzwa Makonese	University of Johannesburg	Research Scientist SeTAR Centre
Dr Tondi Matambo	University of South Africa	
Mr Tshepo Morokong	Asset Research/University of Stellenbosch	Representing Prof James Blignaut, ASSET & University of Pretoria
Dr Yaasin Naidoo	Cape Peninsula University of Technology	Representing Prof Marshall Sheldon, Acting Dean, Faculty of Engineering
Lodewijk Nell	Ecometrix Africa	Partner
Dr Kevin Nwaigwe	University of South Africa	Research Fellow, Dept of Mechanical & Industrial Engineering
Prof Wilson Parawira	Bindura University of Science Education (BUSE), Zimbabwe	Executive Dean and Professor of Microbiology & Biotechnology
Mr Peet Steyn	Botala	Director
Dr Lizelle Van Dyk	University of Witwatersrand	Senior Lecturer
Mr Paul Vermeulen	Johannesburg City Power	Senior Manager

Meeting Participants – University of Stellenbosch

Name	University	Position/Interests
Prof Charles Banks	University of Southampton	AD Network PI
Dr Marelize Botes	Stellenbosch University	Researcher, microbiology
Mrs Angela Bywater	University of Southampton	AD Network Network co-manager
Kwame Donkes	Stellenbosch University	
Lalitha Gottumekkala	Stellenbosch University	
Prof Johann Goergens	Stellenbosch University	Department of Process Engineering (biomass processing and bioprocess engineering)
Martin Hamann	Stellenbosch University	
Dr Thanos Kotsiopoulos	University of Cape Town	Centre for Bioprocess Engineering (CeBER)
Dr Tobi Louw	Stellenbosch University	Goergens' group
Dr Bongani Ncube	Cape Peninsula University of Technology	Centre for Water and Sanitation Research
Dr Vincent Okudoh	Cape Peninsula University of Technology	Department of Biotechnology and Consumer Science
Dr Seun Oyekola	Cape Pensinsula University of Technology	Department of Chemical Engineering
Prof Gunnar Sigge	Stellenbosch University	Head of Department, Food Science (food processing wastewater management and sustainable water use)
Dr Mariette Smart	University of Cape Town	Department of Chemical Engineering
Eugene van Rensburg	Stellenbosch University	Department of Process Engineering
Lukas Swart	Stellenbosch University	
Prof Emile van Zyl	Stellenbosch University	Distinguished Professor, Biofuels & Conversion technologies
Prof Gideon Wolfaardt	Stellenbosch University	Director, Stellenbosch Water Institute
Ancillary Meetings:		
Manuel Jackson	Stellenbosch University	Stellenbosch Water Institute, Project Manager (Capacity Building & Training)
Annabel Horn	Western Cape Government	Economics Task Manager
Dr Willem de Clercq	Stellenbosch University	Stellenbosch Water Institute

Naivasha visit

Case Studies

Appendix 2 – Case Studies

Naivasha – Gorge Farm Energy

Figure 2.2 - Gorge Farm Energy Park. Left: The Gorge Farm anaerobic digester, showing CHPs, digester and office/lab complex. Right: An aerial view of the digester, glass houses and circular pivot irrigation growing areas

Gorge Farm Energy Park is an anaerobic digester located in Naivasha, approximately 95 km northwest of Nairobi. It is designed to produce 2.4 MW of electricity and is Africa's largest grid-connected plant.

The plant runs on maize stover and other crop waste, sourced from Gorge Farm. Other potential sources of feedstock include rose waste from nearby greenhouses which can be seen in the aerial view in Figure 2.2, and vegetable processing wastes from packing houses where trimmings are produced and out-of-specification products are rejected.

The venture is partly owned by VP Group which operates Gorge farm and 5 other farms in Kenya as well as managing 1700 smallholder farmers; the company also has substantial agricultural operations in Ghana and Ethiopia. The plant was installed as a means of reducing electricity and fertiliser costs but primarily as a means of improving the sustainability of the operation.

Gorge Farm covers approximately 800 hectares and grows crops all year round. Crops include baby corn, tender stem broccoli, pak choi, salad onions, runner beans, asparagus and more. The farm is on light volcanic ash soil which has a tendency to form a pan. Because much of the produce is provided to UK supermarkets, the farm adheres to all necessary farm assurance schemes. Crop rotation is practiced, beehives are dotted about the farm and herbicide use is kept to a minimum through the use of natural pest controls such as pheromone traps. In order to improve the soil carbon, organic matter is recycled using an impressive mixture of anaerobic digestion (digestate), composting (compost) and vermiculture (liquid). The farm also has trial growing facilities where new plants and varieties can be trialled, for potential commercial growing on the farm.

Farm workers are well-trained, in order to reduce waste and keep quality high. Once picked, crops do not stay on the farm but are sent to a central facility in Nairobi on the same day. From being picked on the farm to arriving on the supermarket shelf takes approximately 5-7 days.

When the project was conceived, there was no facility for testing the feedstock quality or processing requirements although these may differ from European counterparts. For example, as crops are grown all year round they are fed fresh to the digester, whereas in Europe many crops would be ensiled before use. This factor alone may make a considerable difference to digester operation and pre-processing requirements. Although the project used an apparently conventional technology, its implantation into Gorge Farm has involved a considerable learning curve and research support has been necessary to achieve this. Even conventional AD facilities such as this will continue to require adaptation to local conditions, and the establishment of relevant knowledge could have saved time and money. The project has highlighted: the need for better knowledge of the digestion characteristics of different crop types; the need to understand digestate soil interactions to maximise the reuse potential; and how knowledge of indigenous species could be used to increase the area of land under cultivation without additional irrigation. The AD plant itself is now being used as a research tool to provide the answers to some or all of these questions

Western Cape water usage and treatment

In common with many areas in Africa, the Western Cape region in South Africa has suffered from insufficient rainfall over the past 2-3 years, with the main reservoirs currently sitting at approximately 30% full.

One of the Government's aims is to redress some of the inequities of the Apartheid era by, for example, returning indigenous farmers to the land. Whilst there is land available, allocation of further water extraction licenses is nearly impossible against a backdrop of reduced water supply and the uneconomic cost of pumping water long distances. Clean water is an important resource within the area, as agricultural products such as wine, citrus fruits, grapes, apples and pears comprised more than 47% of all export commodities in the Western Cape in 2010[1].

The Government has been working with the University of Stellenbosch Water Institute to map and better understand water use and quality, as this is key to getting farmers back onto the land, as well as to better and more sustainable management of this resource, particularly in the face of climate change. Some interesting work on pollutants, particularly nano-pollutants, was being carried out, and a small suite of CSTR reactors had recently been established in order to further explore AD technology. It was felt that UK AD and IB expertise could definitely contribute to these and other existing and potential projects.

The University is also working with waste water treatment facilities, technical universities and colleges to (amongst other things) provide comprehensive certified training to staff at all levels in the operation, which will have the effect of improving treatment plant operation and effluent quality.

As noted in the main text above, the Stellenbosch attendees felt that training should be at the heart of any project and that collaborations, such as those with the former technical universities, would provide a strong and diverse mix of skills, ethnicities and gender participation.

Johannesburg energy

A number of stakeholders within the City of Johannesburg have been considering anaerobic digestion technology and whether the biogas should be used for electricity production or for vehicle fuels. The large city vegetable market had been identified as a potential project, due to the fact that it was a clean feedstock and available in quantity.

They, too, pointed out the lack of any local research facility and knowledge which could analyse potential feedstocks, either for their use within a potential anaerobic digester or for extraction of higher value products - a fact which meant that a business case could be predicated on totally unsuitable figures and the project risk would be elevated through lack of sufficient local knowledge. Again, it was felt that collaboration with UK research and industrial expertise would be useful in many areas, including feedstock characterisation, higher value product extraction, biogas use, stakeholder engagement and other technical and social areas.

[1] https://www.westerncape.gov.za/assets/departments/treasury/Documents/2015_pero_final_to_web_15_otober_2015.pdf and https://en.wikipedia.org/wiki/Economy_of_the_Western_Cape#Imports

Uganda Industrial Biotechnology

Dr Deborah Wendiro, the Head of the Industrial Biotechnology Unit at the Uganda Industrial Research Institute, has been looking at ways to integrate IB into Uganda. She is keen that industry is involved, even in the very early stages of the project, so that they understand the economic value of IB, and also to provide potential investment, long-term sustainability and routes to commercialisation. In addition to searching for and identifying IB opportunities, she is currently exploring ways to improve the reach of the Unit into industry. Dr Wendiro also believes that, for projects to be successful, understanding the requirements and challenges of the community of farmers and growers is critical.

One project being explored at the moment is for local farmers (predominantly women) to ferment the cassava that they grow. This could then be taken to a local, community-owned facility for extraction of lactic acid, which currently has to be imported into the country.

Appendix 3 – Selected projects by challenge topic area

Topic area priorities

As noted in the Section **Error! Reference source not found.** (Methodology), participants were asked to vote for a maximum of three topic areas which they felt were a priority for future research. This data is likely skewed by several factors, including the interests of the participants and their perceived value of discussions which took place within the groups and via the rapporteurs. It should also be noted that participants did not suggest any topic areas *outside* those given, as it was felt that these were general enough to work with a wide variety of potential projects.

It can be seen from Figure 3.1 that the participants in Nairobi favoured research in wastewater and novel non-food-competitive feedstocks, reflecting both the importance of agriculture and sanitation in the area. It is notable that integration of AD and renewable energy technologies was not considered important by participants in the discussions and this was reflected in its score which was second lowest as a topic area of importance.

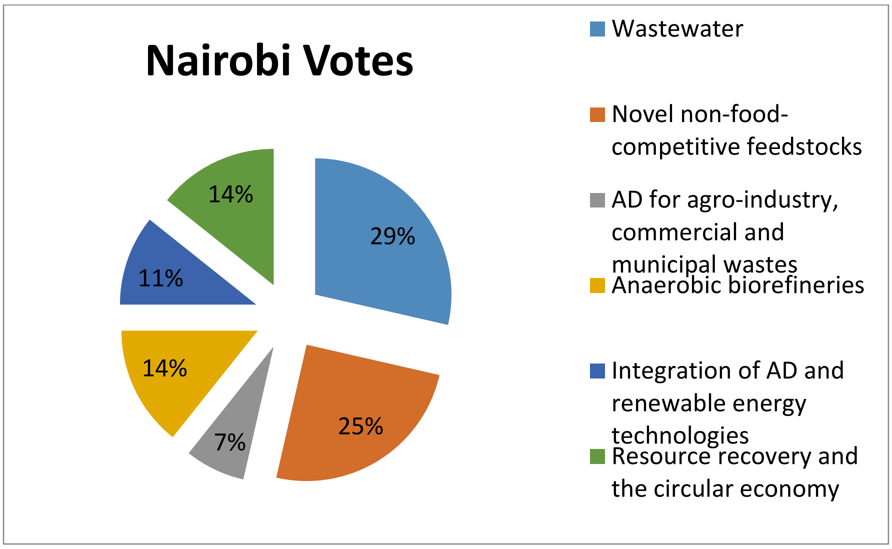

Figure 3.1 - Votes by topic area from Nairobi workshop

Voting in Johannesburg reflected different slightly different interests, in that the topics of anaerobic biorefineries and AD for agro-industry, commercial and municipal wastes attracted the highest support (see Figure 3.2).

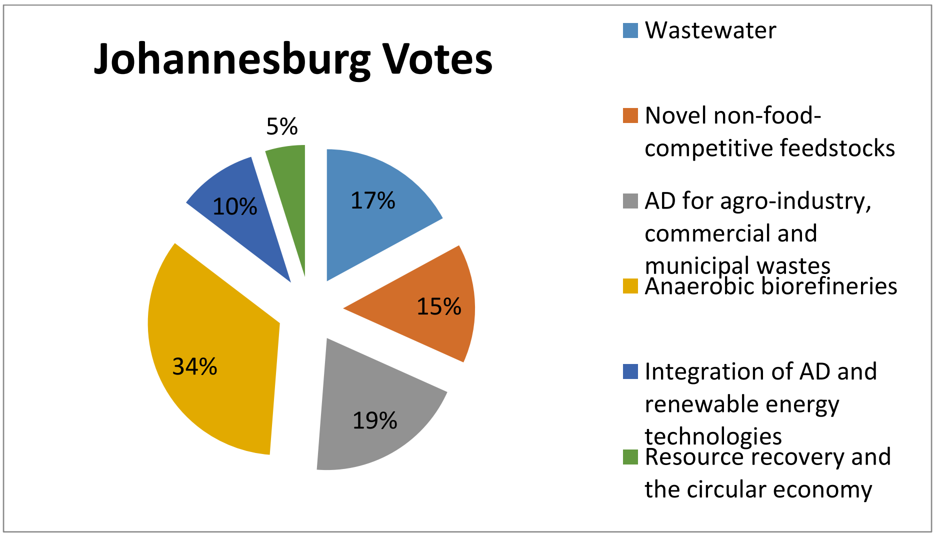

Figure 3.2 - Votes by topic area from Johannesburg workshop

In the Nairobi workshop, participants had been allocated to discussion groups by the workshop organisers, who put them into at least two groups that they felt the participant would be interested in; in Johannesburg, the participants ranked their interest from 1 to 6. An analysis of this is shown in Figure 3.3 which sums the top three topic areas of interest for all participants. There were few votes in the 'Resource recovery and circular economy' topic and this correlates with the participant interest. Cumulatively, the three topics of 'wastewater', 'novel feedstocks' and 'AD for … wastes' gathered over half the votes (51%) and this was reflected in the participant topic interests (59%), with 'Anaerobic biorefineries' in particular receiving increased interest after the group discussions.

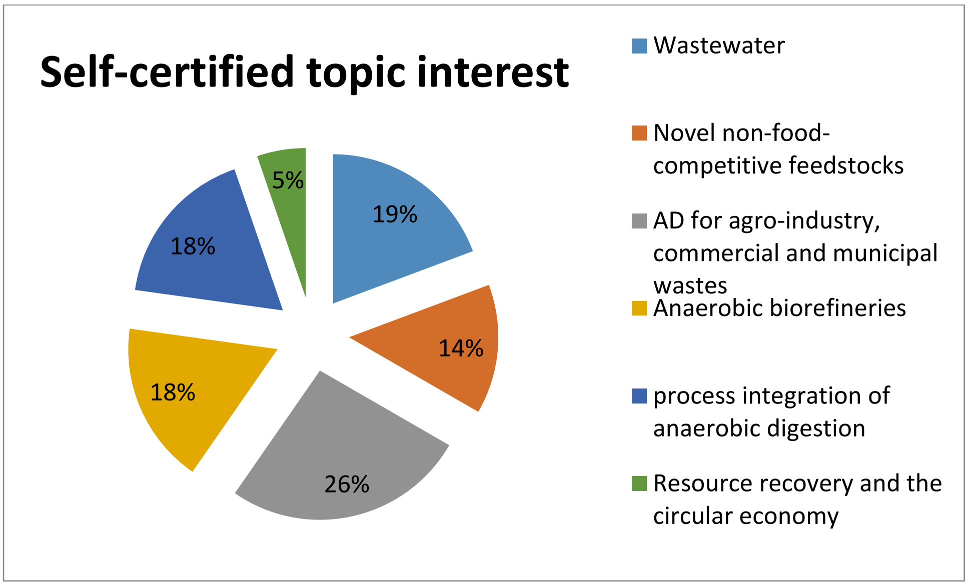

Figure 3.3 - Area of interest as self-certified by Johannesburg attendees

Potential Projects

In both workshops, participants were asked to provide a short description of two projects that they would like to work on or that they believed were important, then to categorise their projects under topic areas. There was naturally some duplication of these projects, and the data in Figure 3.4 and Figure 3.5 are based on the raw data only.

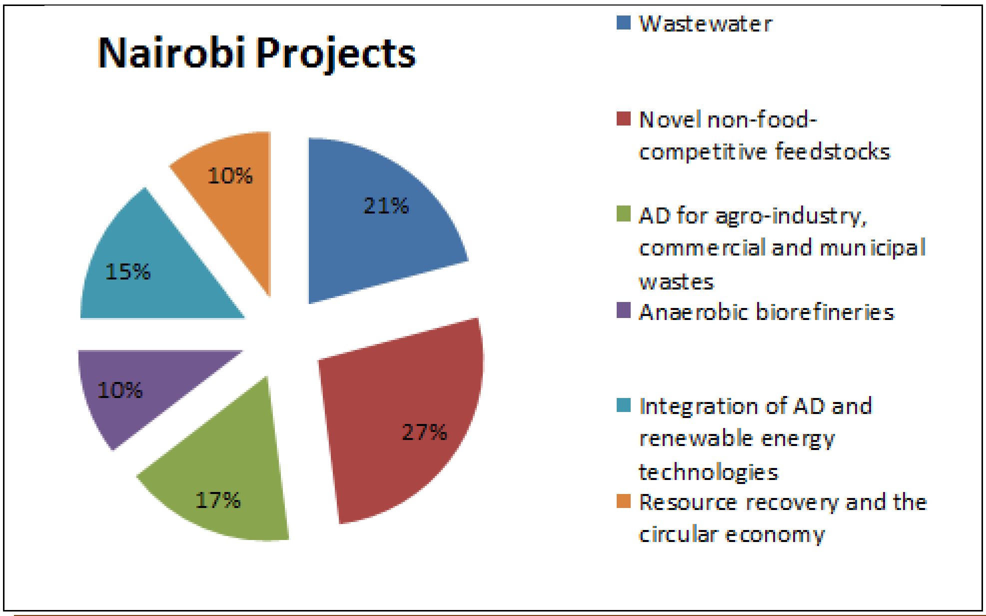

Figure 3.4 – Number of projects proposed for topic areas - Nairobi

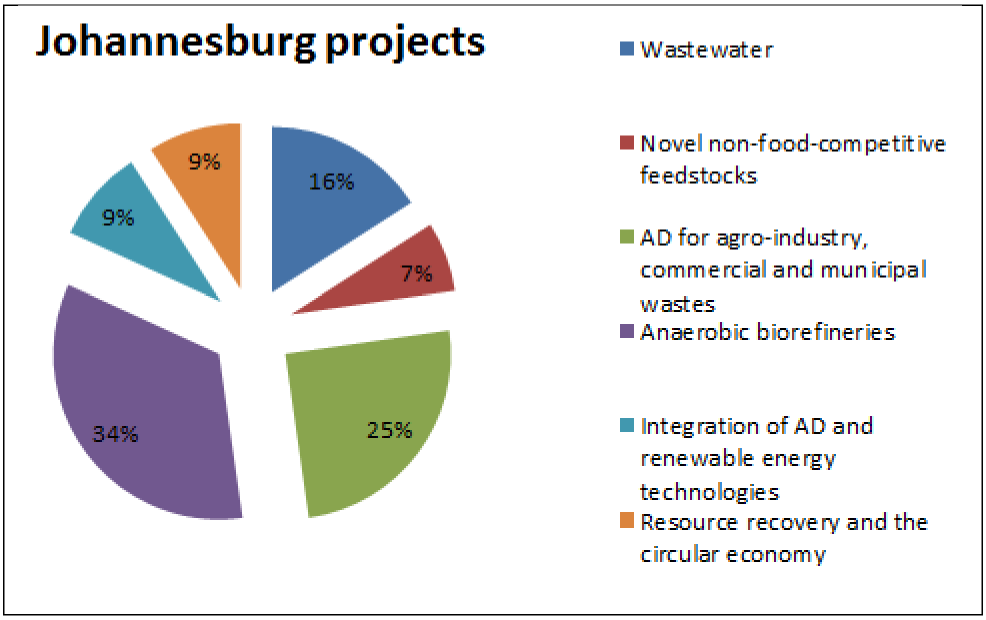

Figure 3.5 - Number of projects proposed for topic areas - Johannesburg

Altogether, almost 100 potential projects were suggested, although a number of these could be grouped together as they covered very similar subjects. Whilst it is not helpful to list all projects here, a selection of some projects that attracted the greatest support in each topic area is shown below:

Wastewater

1. Algal energy production from wastewater using raceways/algal ponds and AAD for simple and energy-positive wastewater treatment. There is a particular requirement for treatment/management of wastewater in temporary/ad hoc communities, which requires new approaches.
2. Mapping/modelling of wastewater arisings and sludge management for optimal nutrient use.

Novel Non-food competitive feedstocks for AAD

1. Creation of a 'resource database': characterise existing resources of non-food (including multi-purpose leguminous trees/legume cover crops, indigenous plants, grasses (such as thatch grass), CAM plants and invasive species) or food 'waste' materials in terms of availability (distribution), composition (including water) and yield, with a strong emphasis on ensuring that impacts on local agro-ecological systems are taken into account.
2. Establishing local collaborative facilities in order to carry out the above research on resource characterisation, collation and potential commercialisation.
3. Investigating options for hybridisation of targeted species in order to optimise desired traits.
4. Investigating options for integrated treatment systems using novel feedstocks and AAD for treatment of contaminated land.

AAD from Agro-Industry commercial and municipal sources

1. Conversion of cellulosic agricultural waste/municipal solid waste into carboxylic acids and alcohols through enzymatic catalysis.
2. Optimisation of AD for local wastes (e.g. sisal waste) and value addition to biofertiliser.
3. Addition of AD to bio-ethanol production facilities for improved economic viability and additional product creation as well as improved resource recovery and pollution control.

Anaerobic biorefineries

1. AD as part of a biorefining production system producing polyacids and materials such as bioplastics.
2. Fermentation of biogas to produce higher value products; for example, feedlot and farm cattle manure could be put through an anaerobic biorefinery to create fertiliser, with the biogas being fermented in order to produce single cell protein feeds for cattle.
3. Identify locally unique microbial consortia e.g. from ruminants (bio-prospecting). Optimise microbial communities in AD to produce predominantly ONE product e.g. a single organic acid for product extraction.
4. Assess possibilities of using CO2 from biogas for greenhouse crop production.

Integration of AD with other renewables / process integration

1. Biomethanation or low-cost biogas upgrading coupled with a market-based socio-economic system for production, packaging and distribution to provide gas as a replacement for wood/charcoal for cooking/household energy use.
2. Integration of AD with other renewable energy technologies using solar PV/thermal solar, e.g. in a hospital setting in rural areas to provide organic waste management combined with energy for lighting, cooking and refrigeration.
3. Integration of AD into industrial processes in order to overcome current barriers of government policy and energy supply, with additional research on the extent to which such systems can play a role in grid stabilisation due to the increasing proportion of variable renewable energy sources in the grid.

Circular economy and resource recovery

1. Feasibility study on gas infrastructure development (pipeline or virtual systems) for prioritising application of compressed natural gas for public transport and mobility.
2. Understanding and maximising the value of locally-produced AD by-products (liquid and solid digestate) to enhance local soil fertility, improve soil health/crop productivity.