Chapter 18

The Way Forward

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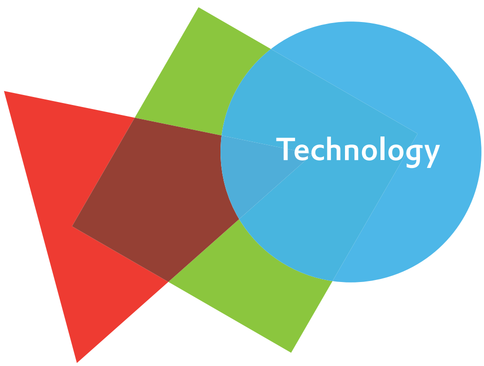
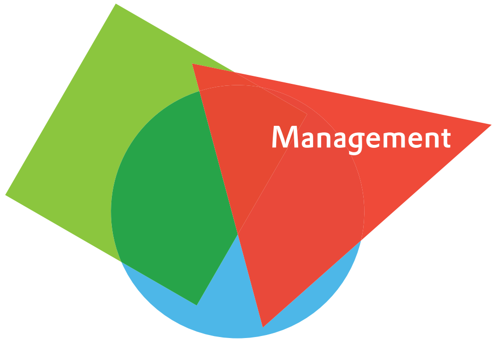
18.1 INTRODUCTION

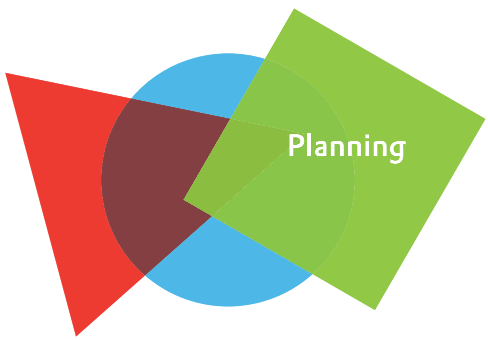
The systems level approach to faecal sludge management (FSM) developed in this book should be seen as a building block for the future design and operation of functional and sustainable FSM systems. FSM is a new and rapidly growing field, and improvements and gains in knowledge are rapidly occurring. These advances will continue to build upon each other and improve solutions and approaches for FSM. Each section of this book has drawn important conclusions and has proposed steps to take in the fields of technology, management and planning to develop sustainable FSM systems. Some highlights include:



- **Designing for the final enduse or disposal option of treatment products.**
  This approach will ensure that effluents and endproducts achieve adequate and appropriate levels of treatment; that systems are not over-designed, wasting financial resources; and that systems are not under-designed, risking public and environmental health.
- **Designing for the actual quantity and characteristics of faecal sludge.**
  This approach will ensure that technologies are effectively designed and that faecal sludge (FS) can be treated on a citywide scale; however, methods for better FS quantification and characterisation still need to be developed.
- **Creating onsite storage technologies and transfer stations, and emptying methodologies.**
  This is a critical link in the FS service chain. Having safe, efficient and affordable collection and transport of FS will help to ensure that FS is delivered to (centralised or de-centralised) treatment plants and not discharged untreated into the environment.
- **Developing an understanding of treatment mechanisms.**
  This will be the basis for developing new FS treatment technologies, and adapting existing ones from wastewater and sludge treatment practice.



- Incorporating management concerns from the beginning of the project planning.
  Linking factors such as management to decisions on technology options and incorporating ongoing operations, maintenance and monitoring procedures into technology design and planning are key to ensuring a long-term sustainable operation.
- Setting up legal and regulatory frameworks for faecal sludge management and introducing funded incentive and enforcement mechanisms.
  This is necessary to ensure that regulation and enforcement of public health and environmental standards occur.
- Considering different models of financial transfers.
  This will help to formalise the sector and make it financially sustainable, and could include incentives as a method of transition to new management models in the short-term.



- Assessing and understanding the initial situation in a specific contexts.
  Sanitation practices are very heterogeneous, not only between countries and among cities, but also within the cities themselves. Different situations require different solutions. A thorough assessment ensures that solutions are tailored to meet the actual needs, builds on what is existing and takes into account the context-specific strengths and constraints.
- Integrating stakeholders into faecal sludge management and understanding their interests and influence.
  This is key for FSM project design: analysing and engaging stakeholders should be carried out throughout the entire project as it is a continuous and iterative process. This will help to build consensus, identify needs, define capacity building requirements, and empower traditionally

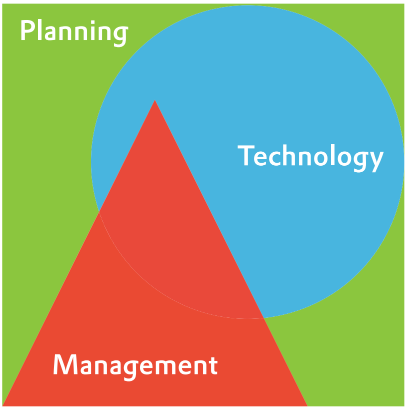
neglected groups. Above all, it will allow the stakeholders to make informed decisions, understand the implications of their choices and be ready to fulfil their roles and responsibilities in the FSM system.

- **Fitting the participatory process within traditional project cycles.**
  Any extra costs resulting from additional meetings incurred during the participatory process are quickly offset by savings during implementation and operation from factors and complications that were identified and alleviated during the process, and success is enhanced by more effective management schemes, better institutional setups and integration of the private sector (FSM Planning Scheme "From A to Z", Table 17.1).
- **Applying an integrated planning approach at the city level.**
  This is imperative for understanding critical factors for selecting context appropriate options. The entire enabling environment must be considered. In particular, management and financial schemes must be defined and validated prior to making final decisions on technical options.

The strength of the approach in this book is considering all three fields technology, management and planning together in deriving sustainable FSM solutions. The FSM Planning Scheme 'From A to Z' as well as the technology selection scheme (Figure 17.10) illustrate this approach and help to navigate through the book; they should be considered as a check-list and as a visual tool to structure planning processes, to include all necessary components and to communicate with non-expert stakeholders.

The successful implementation of each of the above steps requires knowledge of all three fields. Deriving sustainable FSM infrastructures requires tackling large, complicated issues that are interrelated. It is necessary to understand how these fields fit together, and to understand the connections and influences of each field upon the others. Six critical bottlenecks are identified here that are all at the crossroads of technology, management and planning, and which all need to be addressed to successfully move the field forward:

1. Acknowledging the importance of FSM
2. Setting up frameworks and responsibilities
3. Increasing knowledge dissemination and capacity development
4. Creating sustainable business models and fee structures
5. Implementing integrated planning methodologies
6. Developing appropriate technologies



18.1.1 Acknowledging the importance of FSM

For development of sustainable FSM systems, a significant step requires the acknowledgement of its importance by stakeholders in all fields of technology, management and planning. This includes governments taking responsibility for providing FSM, donor agencies providing funding for feasible and appropriate FSM solutions (Figure 18.1), and large intergovernmental organisations promoting FSM together with the goal of ending open defecation. As FSM is acknowledged as a real need and legitimate solution, it will naturally result in significantly greater amounts of attention and resources being focused on FSM. An example of acknowledgement is provided by the Philippine Government, which in 2012 was the first national government in SE Asia to approve a FSM plan (National Sewerage and Septage Management Program (NSSMP)) (Robbins *et al*., 2012). By installing this program, the government not only accepted and acknowledged the importance of FSM, but also that FSM and hybrid forms of combined centralised wastewater treatment and FSM are considered viable solutions.

Highlighting economic costs related to lack of sanitation services, in addition to public health aspects, is another way to promote the value of investments in FSM. The lack of access to sanitation has a global impact of 260 billion USD annually (Hutton, 2013). The Water and Sanitation Program (WSP) of the World Bank has identified through its Economics of Sanitation Initiative (ESI) (www.wsp.org/content/economic-impacts-sanitation) that sanitation also has an economic impact on sectors that are unrelated but important for the economy. For example, in India tourism-related losses due to insufficient sanitation services amounted to 266 million USD per year (Hutton *et al*., 2008).

The Millennium Development Goals (MDGs) have been very successful in raising international attention on the need for sanitation. The inclusion of sludge management as part of the post-2015 Development Agenda with the Sustainable Development Goals (SDGs) would build upon this momentum to increase awareness of the importance of 'environmental sanitation' and the importance of considering all water systems together; i.e. wastewater, drinking water, irrigation and drainage, together with solid waste management (EAWAG, 2005).

Figure 18.1 Drying beds for faecal sludge treatment under construction at Lubigi faecal sludge treatment plant in Kampala as part of the Lake Victoria Protection Stage I Project funded by KfW, EU and Government of Uganda/NWSC (photo: Lars Schoebitz).

18.1.2 Setting up frameworks and responsibilities

Having one entity of a city government solely responsible for sanitation, regardless of technology deployed, increases a sense of responsibility that can be lost in more fragmented management models where different agencies manage parts of the service chain. This also facilitates efficiency in citywide planning. Streamlining eliminates any responsibility overlap between stakeholders, and also avoid gaps in responsibilities (Bassan *et al.*, 2013a). A successful example of defining roles and responsibilities is provided by Indonesia in collaboration with WSP through the Sanitation Sector Development Program (ISSDP). Before implementation of this program, Indonesia had one of the lowest wastewater and FS treatment coverage rates in SE Asia, but now the government has a strong commitment to sanitation with a national strategy. The National Planning Development Agency (Bappenas) plays the lead role in decision making, with local governments implementing urban sanitation within their jurisdictions (WSP, 2011).

Institutional frameworks are necessary to set requirements and ensure compliance. A balance needs to be found between standards that are too stringent and hence prevent any action from being taken because they cannot be met, and providing adequate and appropriate protection of public and environmental health. One possibility is implementing step-wise improvements that are more cost-effective and can continue to be built upon in the future (Parkinson *et al.*, 2013). Metrics are then needed to evaluate the 'effectiveness' of solutions beyond the household level, at the overall outcome level. To this purpose the WSP is currently developing their *Diagnostics and Guidelines for FS Management in Poor Urban Areas*, which are diagnostic and decision-making tools for the development of improved citywide FSM in urban areas (Blackett, 2013).

Resource recovery from FS treatment products can increase management performance by treatment facility operators as they attempt to maximise revenue streams from sale of by-products. However, resource recovery always comes with a certain level of risk regarding safety of the products and enduse. To address this, the World Health Organization (WHO) is currently developing Sanitation Safety Plans (SSPs), to aid the responsible government entity in minimising health risks associated with resource recovery by facilitating the implementation of the 'Guidelines for the Safe use of Wastewater, Excreta and Greywater in Agriculture and Aquaculture' (Medlicott 2013, WHO 2006). Another project by the International Water Association (IWA) includes development of a Participatory Rapid Sanitation System Risk Assessment (PRSSRA) methodology for rapid risk assessment through stakeholder engagement to prioritise interventions that reduce risks. Finally, some countries are establishing guidelines and certification programs to help shape and formalise the resource recovery sector.

18.1.3 Increasing knowledge dissemination and capacity development

As FSM is a relatively new field, much of the existing knowledge remains with practitioners in the field without a written record, and there is a lack of affordable and accessible reference materials. Developing methods that increase local expertise is imperative as many shortages within the FSM service chain are the result of lack of institutional capacity, management deficiencies, insufficient staff and inadequate technical capacity, and all aspects within the service chain are likely to require support to develop human resources capacity (Parkinson *et al.*, 2013). To address this, there is a need for easy to digest material to enable non-technical people to access information (Parkinson *et al.*, 2013). Hopefully new knowledge-sharing tools can help to bridge the gap in distribution of current research results, for example SuSanA (Sustainable Sanitation Alliance – www.susana.org), which since 2007 has provided through an open international network of members a working platform for sustainable sanitation and a forum for policy dialogue. Additional online resources are presented in Chapter 1. Another highly effective strategy is increased south-south interactions among city officials and practitioners for learning and sharing of experiences. A good example is the professional FS collection and transport associations in Kampala, Uganda and Dakar, Senegal. Based on their success, the directors of these associations are routinely asked to present and share knowledge at conferences and meetings throughout sub-Saharan Africa. Another successful example is the MILE (the Municipal Institute of Learning) in Durban, South Africa which was set up to transfer knowledge and experiences from Durban to other municipalities throughout Africa. MILE offers training courses and field visits on a regular basis with funding from the United Nations Institute for Training and Research (UNITAR) and the eThekwini municipality in Durban. eThekwini Water and Sanitation (EWS) also partners with municipalities throughout Africa to share knowledge and bring about improvements in service provision. The senior management of EWS also interacts and shares experiences with the management of other water and sanitation organisations in low- and middle-income countries with funding provided by the World Bank and the WSP.

The value of capacity building and more applied research in the field of FSM is nowadays widely recognised and the number of ongoing research projects is rapidly increasing (Figure 18.2). For example, since establishment of the Water, Sanitation and Hygiene (WSH) program by the Bill & Melinda Gates Foundation (BMGF), a large number of projects have been funded on FSM especially focusing on the urban poor. One of their projects is the SaniUP project ('Stimulating local innovation on sanitation for the urban poor in sub-Saharan Africa and South-East Asia') which has two principal objectives: (i) to stimulate local innovation on sanitation for the urban poor through research, and (ii) to strengthen the sanitation sector in developing countries through education and training. First outputs of the project included development of a three-week course on FSM (www.unesco-ihe.org) in the curricula of the UNESCO-IHE Sanitary Engineering Programme, editing and publishing this FSM book (with co-funding from the Swiss Agency for Development and Cooperation (SDC), and a full online FSM course that will be available in 2015 (www.unesco-ihe.org/online-course-faecal-sludge-management).

Figure18.2 PhD fellows performing faecal sludge characterisation at the Sanitary Engineering laboratory of UNESCO-IHE under the framework of the project financed by the Bill & Melinda Gates Foundation (photo: UNESCO-IHE).

18.1.4 Creating sustainable business models and fee structures

Overall, depending on local circumstances, FSM can be much less expensive than centralised sewer-based solutions (Dodane *et al.*, 2012). However, there still need to be adequate financial flows throughout the entire service chain or the system will not work. Frequently fee structures are not equitable with the poorest households having to pay often twice for sanitation services, through wastewater treatment tariffs being included in drinking water provision, and when paying to have onsite sanitation facilities emptied. Different business models other than the traditional municipality-driven model for sanitation services need to be considered to reduce the financial burden at the household level.

Although one entity should be responsible for the overall responsibility and framework for FSM, this entity does not have to be responsible for conducting every activity in the FSM service chain. From a business model perspective, different customers and value propositions are possible. Customers for services include the household level user who desires FS removed and taken away, but ultimately is not concerned with its final fate as long as it is removed, municipalities or public entities that are responsible for the protection of public health, and endusers of treatment products who gain value from resource recovery. One model of business development that is effective in the informal sector is 'coopetition', a combination of cooperation and competition, where small scale businesses spring up to fill a need, and even though they are competing against each other they mutually benefit through their association (cooperation). An example is collection and transport of FS in Bangalore where competition amongst companies benefits the household level by keeping prices for emptying services lower. But at the same time, the collection and transport association and the subsequent demand for technology has also resulted in improved supply chains for truck parts and local shops that have the capacity to build and repair vacuum trucks, greatly reducing costs to the businesses. In addition, the providers deliver FS to farmers who appreciate the value of it and are competing with each other to obtain cheap manure, which ultimately increases revenue to their business (Gebauer *et al.*, 2013).

Another possibility is public private partnerships (PPP), which also create new opportunities and challenges in urban planning for municipalities when managing potential conflicts between private and public interests. Strategies include tariffs being set that encourage producers to sell waste-to-energy derived electricity to the grid, guaranteeing a price and market to make financing available for capital investments and technology development. Municipalities could also make multi-year agreements with private sector partners to 'guarantee waste feedstock supply' to ensure the financial feasibility of large scale production/treatment facilities. Public entities could cross-subsidise collection and transport companies to facilitate their revenue generation when emptying and transporting FS, while also setting and enforcing maximum emptying fees at the household level. A reasonably successful PPP is functioning in Kampala, Uganda between the NWSC (National Water and Sewerage Corporation), KCCA (Kampala Capital City Authority), NEMA (National Environment Management Authority) and the PEA (Private Emptier Association). The PEA, registered in 1999, is responsible for providing the critical link for all FS collection and transport in Kampala (although an official PPP agreement has not yet been signed).

Examples of current research in this area include Waste Enterprisers based in Kenya, that is using resource recovery to reinvent the economics of FS treatment and disposal. Rather than thinking of reuse as an add-on to an otherwise costly treatment plant, the company is building 'factories' that will use FS as a raw material and convert it to solid fuel for sale to industries. By streamlining processing costs and designing its system to maximise energy recovery, Waste Enterprisers has created a profitable business model that aims to turn FSM into the by-product of producing renewable energy. They are currently building their first commercial-scale plant in Kenya (www.waste-enterprisers.com). The national sanitation utility (ONAS) in Dakar, Senegal is piloting a call centre, where all household level users call for FS collection and transport services. The call centre then puts out a notification to the collection and transport companies who bid for the job with the lowest bid winning, competitively

Figure 18.3 Implementation of the FAQ method (Faecal Sludge Quantification and Characterisation) in Kamapla, Uganda (photo: Lars Schoebitz).

reducing costs to the household level user. In the future the pilot study plans to implement GPS tracking and SMS notifications. The RRR (Resource, Recovery and Reuse) project is evaluating the feasibility of implementing large scale waste-based business models with resource recovery of water, nutrients and energy. Feasibility studies are currently being evaluated in Lima, Peru; Hanoi, Vietnam; Bangalore, India; and Kampala, Uganda (www.sandec.ch/RRR). Another example is Sanergy, an NGO in an informal settlement in Nairobi that has 260 toilet installations. They are applying a business model that involves manufacturing and selling of toilets to the local community, collection of fees from toilet users, daily emptying and cleaning of individual toilet facilities, transport of urine and faeces to a centralised treatment location, and centralised urine and FS treatment. Sanergy is researching best options for resource recovery, including biogas and compost.

18.1.5 Implementingintegrated planning methodologies

The implementation of integrated planning approaches for citywide FSM systems are imperative to successfully address the urban sanitation challenge. However, they can be quite difficult to implement due to the heterogeneity of urban areas in low- and middle-income countries, characterised by rapid growth rates, and very diverse landscapes in terms of income level, sanitation technologies and formal and informal settlements, in addition to weak enabling environments (Hawkins *et al.*, 2013). Planning methodologies need to continue to be developed that create (Parkinson *et al.*, 2013):

- a vision of the need for sanitation improvements which is shared between different stakeholders within the city;
- a definition of clear and realistic priorities for improvement across the entire city;
- a comprehensive sanitation development plan for the entire city that corresponds to the users' demands and the different physical and socio-economic conditions within the city; and
- an enabling environment with regard to governance, finances, capacity enhancement, technology and inclusiveness.

Understanding annual accumulations and characteristics of FS on a citywide scale is a requirement for the design of adequate and appropriate treatment technologies; however, there are no existing reliable methods to achieve this. Characterising and quantifying FS is difficult due to the wide range of existing technologies (e.g. VIP latrines, unlined pit latrines and septic tanks) in use at the household level, in addition to public toilets, commercial entities, restaurants and schools. In addition, there is typically no reliable information available on the number or types of existing technologies. FS characteristics and production are highly variable, and not well understood. Sampling and analysing at a citywide scale is very time and resource intensive. To address this, methods such as FAQ (Faecal Sludge Quantification and Characterisation) are being developed, to provide a logical and affordable approach for quantification and characterisation at the city level. FAQ is based on the assumption that demographic data can be a predictor of FS characteristics (e.g. income level, legal status of housing, population density, and age of building), and that it is also influenced by physical factors (e.g. water table, soil type and elevation). Income, for example, could be a predictor because it impacts diet and quality of construction. This data can be then be analysed spatially with GiS to develop a representative sampling plan based on available resources. FAQ is now being field tested in Kampala, Uganda and Hanoi, Vietnam (Figure 18.3; www.sandec.ch).

Another example of planning is with emergency sanitation. The eSOS® (emergency Sanitation Operation System) is a BMGF funded activity being conducted by UNESCO-IHE (Brdjanovic *et al.*, 2013). eSOS® addresses the entire emergency sanitation chain in situations where external aid is required to meet sanitation demands (Figure 18.4).

Figure 18.4 Example of setting for eSOS® application (photo: Peter Greste, Al Jazeera, smart eSOS® toilet illustration: FLEX/the INNOVATIONLAB).

The core of any emergency management effort is integration, sharing, communication and collaboration.Information and Communication Technologies (ICT) are uniquely qualified to address these core issues and improve them at each step in the service chain. In the future, eSOS® will also be modifiable for (i) sanitation management under challenging conditions usually prevailing in urban-poor areas, such as informal settlements, (ii) sanitation provision to visitors of major open-air events such as concerts, fairs, etc., and (iii) solid waste management. The primary goal of eSOS® is to provide efficient and effective sanitation service during and after emergencies through minimising risk to the public health of the most vulnerable members of society. The secondary goal is to reduce investment, operation and maintenance costs of emergency sanitation facilities and service as a prerequisite for the sustainability of solutions, especially in the post emergency period.

Another important planning tool for the implementation of FS treatment on a decentralised or semi-centralised level are methodologies to evaluate appropriate levels of centralisation and decentralisation. Higher levels of decentralisation are more affordable when considering costs associated with transporting FS, and reducing distribution associated with resource recovery. However, the increased management demands and capital costs can result in less decentralised options being more cost effective. The correlation between scale and cost is not linear, and typically a breakeven point can be found (Gaulke, 2006). All of these factors are dependent on the local context and specificities of each city. Another way to address this need is through improved technologies that can remove/immobilise pathogens onsite, making collection and transport safer, and disposal or resource recovery less complex. This is one of the major goals of the BMGF *Reinvent the Toilet Challenge* (RTTC) (see below).

18.1.6 Developing appropriate technologies

There is a great need for the development of appropriate FSM technologies, even though solutions for entire FSM systems will not rely on technology alone, and must be considered within the local context. New technologies are in general based on pioneering developments in research, and historically research agendas have been driven by countries where centralised sewer-based sanitation solutions are the accepted norm. This points to a need for solution-oriented FSM research to be conducted in countries where it is directly relevant. In addition, for new knowledge to get taken up and influence policy, it requires local researchers working together with the urban governments that are responsible for FSM (Bassan and Strande, 2011). Due to the urgent need for technical solutions, research and implementations need to continue to be conducted in parallel, getting to scale as rapidly as possible. For example, transferring experience from planted and unplanted drying beds for dewatering of wastewater sludge to implementation of full-scale FS treatment, with optimisation of the technology transfer continuing following implementation (Dodane *et al.*, 2011). Technologies also need to be selected not only based on the specific characteristics of FS, but also on factors such as the local market demand for resource recovery of treatment products, or the potential for co-treatment (Diener *et al.*, 2014). Provided here are some examples of current research in the following areas:

- characterisation of faecal sludge;
- collection and transport;
- semi-centralised treatment technologies;
- onsite treatment technologies; and
- resource recovery.

18.2 CHARACTERISATION OF FAECAL SLUDGE

As presented in Chapter 2, FS is highly variable and characteristics of FS are not well understood. To design optimal treatment technologies, this variability and factors that influence it need to be understood (Bassan *et al.*, 2013b). The PURR project (www.sandec.ch) is being conducted to understand factors of onsite technologies and methods of collection and transport that influence FS characteristics. Initial stages of this project include a characterisation study and development of synthetic FS recipes that can be used to evaluate factors that impact biological degradation at the laboratory scale. Other researchers have also developed synthetic sludge recipes to evaluate physical properties that influence mechanical emptying (Radford and Fenner, 2013). Another reason for the current variability for results of FS characterisation is the lack of standardised methods. Methods have been adapted from wastewater and soil analyses, but the accuracy of methods for FS needs to be evaluated, and then standard methods taken up by the sector to ensure comparability of research results. The Pollution Research Group (PRG) at the University of KwaZulu Natal (UKZN) has conducted extensive research in this area and put together a collection of standard operating procedures (SOPs) for the analysis of the chemical (e.g. pH, potassium, ammonia) and mechanical (e.g. thermal conductivity, calorimetric analysis) properties of FS. This type of fundamental laboratory research is necessary to develop a detailed understanding of FS characteristics, and to provide mechanisms for comparable and standardised research to be conducted worldwide.

Figure 18.5 Drying bed research: mixing device for unplanted faecal sludge drying beds at Bugolobi wastewater treatment plant in Kampala, Uganda; evaluating potential plant species for planted drying beds in Dakar, Senegal; and planted drying bed pilot for treatment of drying bed leachate in Yaoundé, Cameroon (photo: Linda Strande).

18.3 COLLECTION AND TRANSPORT

Currently, the best available technology for sludge removal is vacuum trucks, but they are typically expensive and cannot reach households located on narrow streets and alleys. The BMGF-funded Omni-ingestor project aims to develop equipment that is more dexterous, evacuate FS more quickly, can remove dense FS efficiently (> 40% solids) and are able to dewater FS onsite. Water is heavy and therefore expensive to transport; dewatering FS and treating the effluent onsite would allow for the treated water to be directly reclaimed or safely disposed of in drains. This would greatly reduce transport costs and allow for more emptying operations performed between trips to the FSTP, as well as reducing time spent in traffic. Various prototypes are currently being developed by the private sector.

18.4 SEMI-CENTRALISED TREATMENT TECHNOLOGIES

The PURR project is evaluating the potential for co-management of FS together with wastewater sludge in Vietnam. The potential for biogas production from co-digestion of wastewater sludge and FS is being evaluated, together with the feasibility of co-digestion with other high strength waste streams. The DAR (De Déchet à Ressources) project in Dakar Senegal is evaluating drying bed technologies through optimisation of planted and unplanted drying beds (Figure 18.5). Drying beds require relatively low capital and operational costs, but are space intensive. Increasing efficiency could reduce the required space, increasing their applicability in space-limited urban areas. Research is currently being conducted on alternative media (e.g. crushed glass), mixing regimes, and greenhouses to increase drying rates. Research for planted drying beds is being conducted to identify previously unused plant species that could increase treatment performance and increase the potential for resource recovery through production and sale of fodder plants (www.sandec.ch). A steam engine-based community-scale waste processing technology is currently being developed by Janicki Industries. The concept is that a 150 kW combined heat and power plant will utilise FS as the fuel source for electricity generation. The heat generated from combustion within a fluidised sand bed will produce high-pressure steam that is expanded in a reciprocating piston steam engine connected to a generator, producing electricity. The exhaust from this engine (process heat) will also be harnessed to dry the incoming FS. The concept for this treatment plant comes from the careful re-design of basic power plant components, making them economical in mass production for small-scale plants.

18.5 ONSITE TREATMENT TECHNOLOGIES

Achieving reliable levels of treatment with onsite sanitation technologies presents a very challenging problem due to factors such as the lack of technical management, demands for reliable energy and high costs. The RTTC currently has multiple research projects addressing this challenge. The first round of technologies were presented at the RTTC fair in Seattle in 2012 and the second in Delhi in March 2014.

Some examples of technologies include hydrothermal carbonisation, microwave technology, supercritical oxidation, pyrolysis, and electrochemical processes. The Research Triangle Institute (RTI) is developing an integrated toilet technology that will separate solid and liquid waste, dry and burn solid waste using a combination of mechanical, solar, and thermal energy (primarily driven by down-draft gasification), disinfect liquid waste, and convert the resulting combustion energy into stored electricity (www.rti.org). The California Institute of Technology (Caltech) is developing a comprehensive, human waste treatment and toilet system that has at its core a photovoltaic-powered (PV), self-standing electrochemical chemical reactor that generates hydrogen for energy and nitrogen for fertiliser as by-products of treatment. The treatment process is a multistep oxidation of the organic waste and the bacteria present in the mixture. The fully integrated treatment system will include:

in-situ waste disinfection, residual solid waste processing, by-product extraction, generation of hydrogen as a by-product of waste treatment, a solar energy battery storage system, solar arrays, and a microfiltration component for final polishing of the water before reuse and recycling. Loughborough University is developing a system that is comprised of a draining balance tank; filters; high temperature pressure reactor; and evaporator-sodium chloride separation. The system operates in three stages: solids-liquid separation, followed by auto-thermal treatment of the solids to provide heat for water and salt separation. The main part of the solids treatment and the liquid evaporator will be constructed within the same unit as plug-together modules.

Figure 18.6 FaME (Faecal Management Enterprises) project pilot scale kiln for co-combustion of faecal sludge in brick production in Kampala, Uganda (photo: Pitman Ian Tushemezibwe).

18.6 RESOURCE RECOVERY

Research in this area includes the FaME (Faecal Management Enterprises) project, which is attempting to identify large-scale markets for resource recovery to provide a significant and reliable cash flow for enduses (Figure 18.6). The project is identifying innovative methods of resource recovery, and is also focusing on scaling up the use of dried sludge as a fuel in combustion. Results of the FaME research project are providing evidence of the promising technical and financial potential of FS products and filling knowledge gaps for the full-scale implementation of its use as an industrial fuel sludge based on calorific value (Murray Muspratt *et al.*, 2014), market demand of end products (Diener *et al.*, 2014), viable financial flows for collection and transport, and optimisation of drying bed technologies (www.sandec.ch).

18.7 FINAL REMARKS

Creativity is essential in every aspect of technology, management and planning to continue to advance solutions that are globally transferable and applicable for the currently 2.7 billion people worldwide served by onsite sanitation technologies and the billions more that will need to be served in the decades to come. Keeping an open mind will be key to developing innovative and optimal solutions, learning from the past, but also not limiting future possibilities through biases of what has or has not worked in the past in other situations. As highlighted by this chapter, there is currently lots of innovative research being conducted at scales of laboratory, pilot, and implementation level. There is a wealth of information rapidly becoming available, some that is scalable for implementation, and much more that is still in the development pipeline. Recent efforts put into research and capacity development will no doubt result in innovations concerning all aspects of the FSM chain and will create a new generation of scientists and engineers as a driver of change towards integrated FSM. Undoubtedly, this is a very exciting and promising time for the advancements in FSM research and education and their application in practice. The FSM field will continue to advance, and hopefully the next edition of this book will contain much more information on success stories on design and implementation of comprehensive FSM systems based on the newly acquired experiences.

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