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Final Report

SEEK: Sludge to Energy Enterprises in Kampala

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Contents

1. Summary

In Uganda, the demand for electricity greatly outstrips production rates. The SEEK Project (Sludge to Energy Enterprises in Kampala) assessed the electricity production from faecal sludge that accumulates in Kampala`s onsite sanitation technologies through pelletizing and gasification. Such energy recovery options have a high revenue potential in Sub-Saharan Africa and could be used to support complete and financially sustainable faecal sludge management services (Diener et al., 2014; Gold et al., 2014). In Kampala, the capital of Uganda, only 54% of excreta is safely managed, whereas 46% of excreta is not safely managed, which has significantly negative implications for public and environmental health (Hutton et al., 2004; Mara et al., 2010; Peal et al., 2014; Schoebitz et al., 2016).

SEEK was implemented between August 2014 and November 2016 in Kampala by the Swiss Federal Institute of Aquatic Science and Technology (Eawag), Makerere University, Bioburn AG and the Center for Research in Energy and Energy Conservation (CREEC). Project implementation included laboratory, bench-scale and pilot-scale testing, industrial fuel trials, and market research through interviews and stakeholder workshops. A pilot-scale treatment facility was implemented at the Lubigi Wastewater and Faecal Sludge Treatment Plant, operated by the National Water & Sewerage Corporation (NWSC), a collaborator and supporter of the SEEK Project. The different components of the SEEK project are visualized in Figure 1. Key results are documented in reports available on the project website www.sandec.ch/seek.

Waste assessment: In Kampala, faecal sludge has a high ash content and low calorific value. SEEK conducted a market assessment to identify biowastes that can increase the fuel value through co-processing. Sawdust, coffee husks and brewery waste were most suitable for co-processing, but already have market value. Market waste that is currently being landfilled is also suitable considering availability, accessibility and physical-chemical properties.

Waste treatment: Faecal sludge is mostly water, which makes dewatering and drying important treatment goals for the production of energy recovery products. SEEK tested adaption to drying beds, geotubes and pelletizing to increase dewatering and drying. The Bioburn pelletizer can process dewatered sludge at a moisture content ranging from 30 to 60% into pellets. In the pellet form, sludge dried faster compared to sludge on drying beds.

Waste processing: Gasification of pellets was not viable with the small-scale gasifier available to the project. Laboratory results of a gasifier manufacturer indicated that pellets could be converted into electricity with large-scale gasifiers, but these are currently not appropriate for the existing capacities and supply chains in Kampala.

Market development for resource recovery: Crushed dried faecal sludge from drying beds, and char that can be produced through pyrolysis, have immediate markets in Kampala with cement and clay, and briquette companies, respectively. The benefit of pellets was recognized by potential users, but requires more work in market development, and possibly altering existing combustion technologies for compatibility.

Implementation of these findings has the potential to make faecal sludge treatment more efficient and thereby reduce the required treatment space. This is significant considering the lack of space in urban areas and the backlog of treatment infrastructure that needs to be filled to meet sanitation needs (e.g. meeting Sustainable Development Goals (SDGs)). Energy recovery from faecal sludge in Kampala is challenging due to high ash content. Improving onsite sanitation technologies could increase its fuel value, and could provide revenues to offset treatment costs.

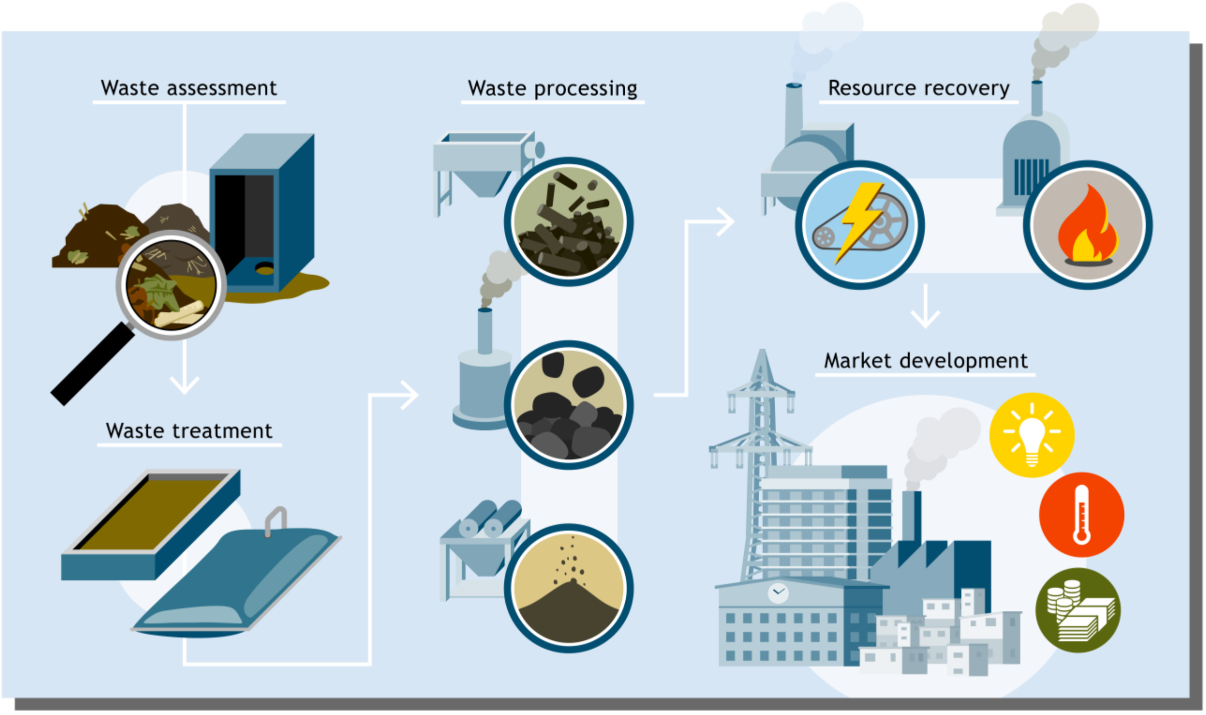

Figure 1: Overview of the Sludge to Energy Enterprises in Kampala (SEEK) Project.

1. Starting Point

In Uganda, the demand for electricity greatly outstrips production rates. Industries have to rely on fuel imports, and the majority of the population relies on unsustainably produced charcoal. Concurrently, urban wastes such as faecal sludge collected in onsite sanitation are discharged directly to the environment jeopardizing public and environmental health (Peal et al., 2014; Schoebitz et al., 2016). Faecal sludge that is defined as the *raw or partially digested, semisolid or slurry resulting from collection, storage or treatment of combinations of excreta and black-water, with or without greywater,* that accumulates in onsite sanitation technologies (Strande, 2014). One challenge in providing faecal sludge management is the lack of financial resources. Revenues from faecal sludge treatment products can have the potential to make faecal sludge management financially more sustainable, for example by offsetting treatment costs In Uganda, it appears that these revenues could be highest for energy recovery products such as solid fuels or electricity (Diener et al., 2014; Gold et al., 2014).

2. Goal

The goal of the SEEK (Sludge to Energy Enterprises in Kampala) project was to work towards resource recovery based solutions to faecal sludge management becoming a reality and thereby provide new business opportunities and increasing access to renewable energy; and improve public and environmental health in urban areas through the provision of sustainable sanitation service chains.

3. Objectives

The objectives of the SEEK project included:

- Adapt proven innovative bioenergy technologies to the context of Kampala, Uganda.
- Show the technical viability and provide operational guidelines for replication of the technologies.
- Produce marketable commodities from faecal sludge: fuel pellets, char and electricity.

- Show that production costs of commodities from waste streams with these technologies is financially competitive.
- Support customers in technology implementation by participatory stakeholder workshops, developing viable business models and value and distribution chains.
- Contribute to improved sanitation provision.
- Contribute to the development of innovative renewable energy technologies, knowledge transfer, capacity building and national energy policies.
- Contribute to reducing greenhouse gas emissions by reducing informal landfilling of waste streams and potential substitution of fossil fuels and use of charcoal.

4. Project team

The SEEK project was implemented by project partners in Switzerland and Uganda, namely:

- Department of Sanitation, Water and Solid Waste for Development (Sandec) at the Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland.
- College of Engineering, Art, Design and Technology (CEDAT) at Makerere University, Kampala, Uganda.
- Bioburn AG, Zurich, Switzerland.
- Center for Research in Energy and Energy Conservation (CREEC), Kampala, Uganda,
- National Water & Sewerage Corporation (NWSC), Kampala Uganda.

5 Conclusions

5.1 Suitable waste streams for energy recovery

Previous research identified that quantities of faecal sludge that is currently being collected and treated is insufficient to meet the needs of industries. In Uganda, one cement company reported that at least 10 tons of dried faecal sludge are required to consider its industrial implementation. Therefore, as part of the SEEK project, a waste assessment was conducted to identify biowastes that could be co-processed with faecal sludge.

Results of this assessment are included in Byrne et al. (2016) and summarized in Figure 2. Sawdust, coffee husks, spent grain and market waste were the most suitable biowastes. However, all of these waste already have a market value. This market value needs to be balanced with the market value of the resource recovery products that can be produced with it (e.g. electricity, fuel pellets, char briquettes).

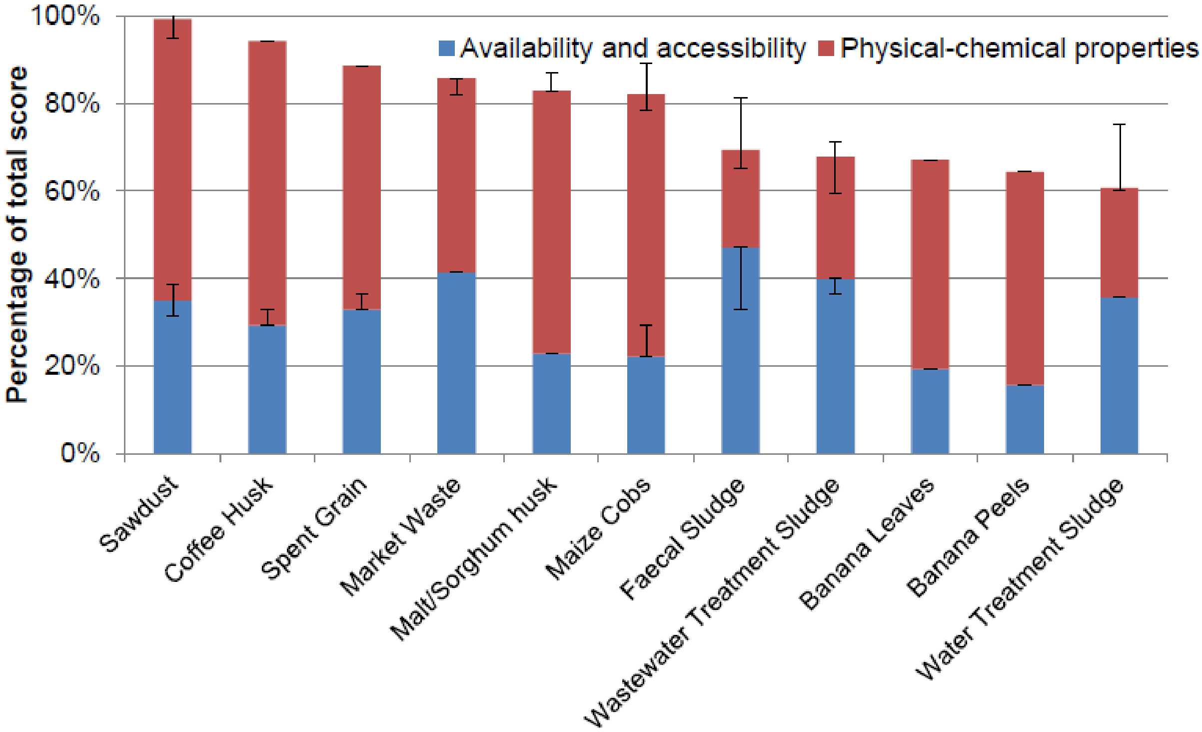

Figure 2: Most suitable biowastes identified for co-processing with faecal sludge in Kampala (Byrne et al., 2016).

5.2 Faecal sludge dewatering and drying

Faecal sludge is commonly more than 95% water. Therefore, development of cost-effective drying methods are important to make electricity, sold fuel and char briquette production financially viable. In the SEEK project, improving dewatering and drying of sludge was investigated at the NWSC Lubigi Wastewater and Faecal Sludge Treatment Plant in Kampala through adaption to drying beds, geotubes, pelletizing and pellet drying.

Results of the SEEK project demonstrate that adaptions to drying beds (see Figure 3 and Figure 4) can increase drying and increase the resource recovery value of faecal sludge as a solid fuel. Turning of sludge increased the drying rate by 30% which is in line with previous work from Dakar, Senegal (Seck et al., 2015). Sludge treated on a drying bed with a geotextile on the surface of the sand filter layer had an ash content 20% lower than the control. Results of this study are included in Ngobi et al. (2015).

Figure 3: Device turning sludge during on drying beds.

Figure 4: Geotexile on the surface of a drying bed.

Bench-scale experiments were conducted at NWSC Lubigi with geotubes (see Figure 5). Results of these experiments demonstrate that geotubes are more efficient that drying beds. This means that the space required to dewater the same amount of sludge is lower. However, dewatering was only feasible with septic tank faecal sludge as conditioning of pit latrine faecal sludge was not feasible with chitosan, the conditioner considered in this project. This is relevant for urban areas where space for treatment is limited. Benefits of geotubes need to be balanced with higher costs. Results of this study are included in Ziebell et al. (2016).

Figure 5: Bench-scale geotube for dewatering (Ziebell et al., 2016).

Figure 6: Bioburn pelletizer (Englund et al., 2016).

The Bioburn pelletizer (see Figure 6) is the only pelletizer on the market that can pelletize wet biomass. In this project, dewatered faecal sludge could be processed with this pelletizer into pellets (see Figure 8) at a moisture content ranging from 30% to 60% without a binder. Dewatered faecal sludge could also be co-processed with other biowastes such as sawdust or coffee husks. On drying racks and in greenhouses (see Figure 7), these pellets dried faster than faecal sludge on drying beds. Results of this study are included in Englund et al. (2016) and Turyasiima et al. (2016).

Figure 7: Greenhouse dryer (Turyasiima et al., 2016).

Figure 8: Faecal sludge pellets.

5.3 Electricity production through gasification

Due to their homogenous size and high energy density, pellets are an ideal fuel for gasification. In this study, gasification of pellets was investigated at CREEC with a 10 kW All Power Labs Power Pallet gasifier (see Figure 9).

As part of SEEK, faecal sludge pellets and pellets co-processed with other biowastes could not be reliably gasified for electricity production. Reasons are the high ash content and low calorific value. Analysis results of a gasifier manufacturer suggest that gasification of faecal sludge pellets could be possible with other gasifiers. However, these gasifiers are currently not appropriate considering their technical complexity and reliance on established supply service and supply chains for reliable long-term operation. Results of gasification of pellets are included in Tukahirwa et al. (2016).

Figure 9: Gasification of pellets.

5.4 Char production through slow-pyrolysis

In the SEEK project, gasification of pellets was not reliably feasible. Therefore, resources were allocated to slow-pyrolysis of dried faecal sludge. This process produces char that can be co-processed into fuel briquettes for households, institution and industries. Char briquettes produced from char that is made from agricultural waste and charcoal dust are already established in the markets in Kampala.

Results of the SEEK project demonstrate that optimal operating conditions for slow-pyrolysis of faecal sludge are a higher heating temperature of 350°C held for ten minutes. However, the ash content, which does not burn and does not contribute to the energy content, is much higher in faecal sludge char than charcoal dust or char produced from agricultural waste. Char from faecal sludge had an ash content as high as 70% and a calorific value of 7 MJ/kg, while charcoal made from wood has less than 5% ash and 22 to 30 MJ/kg. Results of this study are included in (Bleuler, 2016)

Results of char briquettes produced from faecal sludge and charcoal dust (in a mass ratio of around 1:1) were more promising. In the Regional Testing and Knowledge Center at CREEC, the project compared the performance of three char briquettes produced with faecal sludge, to two char briquettes produced from agricultural waste and charcoal dust, to charcoal as a control (see Figure 10). The results demonstrated that the water boiling performance of briquettes produced with faecal sludge char were similar to char briquettes and charcoal. Briquettes produced with faecal sludge char had a similar emissions compared to char briquettes and charcoal. This study is included in Kiwana et al. (2016).

Figure 10: Fuels used in performance and emission comparison.

5.5 Market implementation

Throughout the project, SEEK worked toward implementation of the treatment and resource recovery technologies and products with NWSC, small enterprises and industries. Two stakeholder workshop were held at Makerere University. In addition research results were shared and discussed, fuel samples distributed and industrial trials implemented. Users recognized the benefits of pellets (e.g. easy to store and transport, high energy density) but do currently not have technologies for their combustion. In contrast, crushed fuel and char could have immediate users with clay companies. For cement industries, fuel quantities would need to be increased to meet their minimum energy demand. More detailed results are included in Getkate (2016); Kakooza et al. (2016); Nantambi et al. (2016).

6. Project Review

6.1 Project Implementation

The SEEK project was carried out through close cooperation between project partners. Students at Makerere University together with students from Eawag carried out individual research thrusts, with direction from Linda Strande and Moritz Gold at Sandec/Eawag, and with support from Wim Getkate at CREEC, Florian Studer at Bioburn AG, Charles Niwagaba at Makerere University, and Christopher Kanyesigye at NWSC.

An initial waste assessment was conducted by CREEC to evaluate the volume of faecal sludge available in Kampala, and to identify a suitable biomass waste material for co-processing to increase available faecal sludge and improve its fuel properties. Simultaneously, an evaluation of improved sludge dewatering methods was undertaken by students from Makarere and Eawag/Sandec at Lubigi faecal sludge treatment plant. Bioburn was responsible for evaluating the effectiveness of pelletizing dewatered sludge at Lubigi. Students at CREEC tested faecal sludge pellets in a gasifier. When results from gasifier testing showed poor performance, the study was expanded to include the evaluation of pyrolyzed faecal sludge char briquettes, and dried sludge as a fuel.

6.2 Achievement of Objectives and Results

Project objectives are listed below with descriptions of achievements. Detailed results are reported in the individual project reports available at sandec.ch/seek, and an overview of results is provided in Section 5 of this document.

- ✓ ***Achieved***: *Adapt proven innovative bioenergy technologies to the context of Kampala, Uganda.*

  Pelletizing, gasification, and pyrolysis were evaluated under the umbrella of this project. Pelletizing, pyrolysis, and direct combustion were found to be adaptable to use with faecal sludge in the context of Kampala.

- ✓ ***Achieved:*** *Show the technical viability and provide operational guidelines for replication of the technologies.*

  <u>Pelletizing</u> - The technical performance results and operational guidelines for pelletizing faecal sludge are outlined in Englund et al. (2016).

  <u>Briquettes and pyrolysis</u> – Emissions and water boiling efficiency performance and operational guidelines for testing faecal sludge char briquettes are reported in Kiwana et al. (2016). Bleuler (2016) reports optimal slow pyrolysis conditions to create the best fuel char from faecal sludge.

  <u>Gasification</u> – Results from gasification experiments and specific description of gasifier operation are outlined in Tukahirwa et al. (2016).

- ✓ ***Achieved:*** *Produce marketable commodities from faecal sludge.*

  Solid fuels, especially char briquettes and crushed pellets, were found to be marketable products. A thorough market assessment can be found in Kakooza et al. (2016), and business models are proposed in Nantambi et al. (2016).

- ✓ ***Achieved:*** *Show that production costs of commodities from waste streams with these technologies is financially competitive.*

  Reports by Kakooza et al. (2016) and Nantambi et al. (2016) outline the financial competitiveness of faecal sludge fuels, comparing production costs to current market value of similar products.

- ✓ ***Achieved:*** *Support customers in technology implementation by participatory stakeholder workshops, developing viable business models and value and distribution chains.*

  Two stakeholder workshops were held in Kampala, where results of this project were shared and discussed. Business models for faecal sludge end products and resource recovery technologies are outlined in Nantambi et al. (2016).

- ✓ ***Achieved:*** *Contribute to improved sanitation provision.*

  Improvements made to dewatering faecal sludge, when adopted by a faecal sludge treatment facility, can increase the treatment capacity of an existing plant like Lubigi, and can decrease the requisite footprint for dewatering operations when designing a new treatment plant. Thus, a larger percentage of faecal sludge in Kampala could be treated. Demand for faecal sludge treatment products as solid fuel can also increase the demand for treatment, improving sanitation provision. NWSC is continuing to evaluate how to improve and increase treatment capacity, and now has a strong commitment to resource recovery.

- ✓ ***Achieved:*** *Contribute to the development of innovative renewable energy technologies, knowledge transfer, capacity building and national energy policies.*

  Information gathered during this project was disseminated strategically in order to transfer knowledge to variety of stakeholders (more information in Section 7 of this report). Innovative technologies were evaluated and determined effective. Workshops were especially useful in disseminating the ideas and results of the project for uptake.

- ✓ ***Achieved:*** *Contribute to reducing greenhouse gas emissions by reducing informal land-filling of waste streams and potential substitution of fossil fuels and use of charcoal.*

  This project, by identifying energy recovery options for faecal sludge with existing markets in Kampala, has contributed to the body of knowledge required for renewable fuels to be adopted in Kampala. There is now a demand for these treatment products, which incentivizes proper treatment of faecal sludge.

6.3 Multiplication / Replication Preparation

Due to the improved drying time from pelletized faecal sludge and the success of co-pelletizing efforts, preparations were made during the project for a continuation of pelletizing research and scale-up of the Bioburn presence in Kampala (SEEK 2.0). More information about the current status of this project is available in Section 8.1.

Positive results from dewatering with geotextiles led to the continuation of geotextile research at the University of Dar es Salaam's faecal sludge treatment pilot facility. Pyrolysis experiments will also continue here, supervised by professors at UDSM and by Linda Strande at Sandec/Eawag.

6.4 Impact / Sustainability

Considerable excitement among larger industries in Kampala has been generated as a result of this project. The final stakeholder workshop, held in Kampala in September, 2016, was well-attended by representatives from Hima Cement, and several other industrial users of solid fuel. The consensus within the business community is that faecal sludge co-processed with other biowastes would be a welcome addition to the fuel market in Kampala. Interest is high, if a consistent supply of processed faecal sludge can be made available.

Faecal sludge char briquette manufacturers continue to succeed in Kampala, and have been bolstered by the efficiency and emissions testing results from this project. One of these companies has subsequently received a small business grant and business coaching/technical backstopping from the RRR project (funded by the Swiss Development Corporation) to grow its faecal sludge char briquetting business.

Additionally, a group of young scientists, students and former students who worked on this project, are now technically proficient and passionate about the intersection of faecal sludge management and renewable energy in Kampala. They will continue to be active in this field and will bring valuable experience to future projects in this sector.

7. Dissemination

Dissemination of results was a key element of the SEEK project. Project results were disseminated through the project website, social media, Sandec News articles (Gold et al., 2015; Gold et al., 2016), a factsheet, stakeholder workshops, a Bioburn product brochure, field visits to NWSC Lubigi, conference presentations and reports. A project movie and two scientific manuscripts (Gold et al., in preparation; Ward et al., in preparation) are in preparation and will be available in the future via the Sandec YouTube Channel (https://www.youtube.com/watch?v=18N2kc8fBfY) and www.sandec.ch/fsm_tools. All outputs of the project can be downloaded from the SEEK project website: www.sandec.ch/seek.

Outlook / Further Actions

7.1 Multiplication / Replication

Bioburn has obtained REPIC funding to continue research into co-pelletizing faecal sludge with available biomass, specifically coffee and cacao waste. The objective is to develop local manufacturing capabilities for the Bioburn pelletizer in Kampala, and ultimately produce Bioburn pelletizers locally along with pellet-compatible stoves. Bioburn and Sandec/Eawag are also investigating other funding sources to finance SEEK 2.0, for scaling-up of Bioburn pelletizer manufacturing and sales, and expansion to additional markets.

7.2 Impact / Sustainability

This project has successfully disseminated information about the suitability of faecal sludge and biowaste derived fuels in Kampala. The adoption of these renewable fuels by manufacturing industries will reduce the carbon footprint of CO_2 producers (cement and brick plants) by replacing coal with a carbon neutral fuel. The adoption of faecal sludge based fuel briquettes by households will reduce the use of unsustainable, expensive wood and charcoal for cooking, which can reduce deforestation and also allow poor households to save money (charcoal and wood are more expensive than faecal sludge/waste biomass briquettes).

Improvements in faecal sludge dewatering, like the Bioburn pelletizer and the use of geotextiles over sand drying beds, can reduce the footprint of future faecal sludge treatment facilities, and increase the capacity of existing facilities. These innovations, along with the valorization of treatment products, allow more faecal sludge to be safely managed, which will lead to improvements in environmental and public health.

8. Lessons Learned / Conclusions

Following are conclusions and lessons learned during the SEEK project.

- The high ash content and low calorific value of faecal sludge in Kampala is a problem for energy recovery through combustion, pyrolysis or gasification. Preventing inorganic material from entering onsite sanitation technologies, and increasing the construction quality, could increase the fuel value. Other possibilities could include container-based solutions that are currently being implemented at pilot-scale (e.g. Sanivation, Sanergy, SOIL).
- Market research demonstrated that users such as clay and cement companies, fuel retailers, and briquetting companies, have an immediate interest in the faecal sludge treatment products produced by SEEK, and this potential has been recognized by NWSC. Implementation of these resource recovery options will require support during the initial stages for reliable operation, quality assurance and control, marketing, transport and storage (e.g. the RRR project funded by the Swiss Development Corporation, Phase II of this project began after the end of SEEK, and Sandec/Eawag is incorporating lessons learned from SEEK into technical backstopping for RRR). Public private partnerships (PPPs) between companies and utilities could provide a mechanism for upscaling.
- SEEK demonstrated the viability of reliable pellet production from dewatered faecal sludge. A market for pellets does not currently exist in Kampala, and so the market assessment conducted as part of SEEK likely underestimated the market potential. In follow-up projects in Switzerland and Uganda, Eawag will continue to work with Bioburn to develop the technology and markets.

- Gasification of faecal sludge pellets was not viable with the gasifier available to the program. Further work could assess the use of these pellets for gasification technologies manufactured by other companies (e.g. Xylowatt, Entrade, ProCone) specifically designed for gasification of wastes. The high capital costs and high technology complexity of these technologies needs to be carefully balanced with the available resources and supply chains of low-income countries.
- The current use of dried sludge from NWSC Lubigi as soil conditioner also provides resource recovery. However, sludge is likely not adequately treated for pathogen inactivation, which could obviously have negative public health implications. Use of dried sludge in a crushed or pellet form in industries has the benefit that pathogen transmission pathways can be greatly reduced through worker protection and use of mechanical equipment, and pathogens are destroyed during combustion.
- Scaling-up of energy recovery from faecal sludge such as the use of crushed dried faecal sludge in industries will require an increase in the amount of sludge that is collected and treated, thus the construction of planned treatment plants. Land requirements of NWSC Lubigi are intensive, with around 4,000 m^2 for sludge drying beds and 4,000 m^2 for sludge storage. Energy recovery from treated sludge does not require pathogen inactivation, pelletizing and adaption to drying beds could reduce the required land area. Lessons learned from SEEK will be valuable in improving the design of new faecal sludge treatment plants. Sandec/Eawag along with local partners, Makerere University and CREEC, will continue to be involved with NWSC as new faecal sludge treatment facilities are designed and implemented in Kampala.

9. Acknowledgements

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