Resource-Oriented Sanitation Technologies in Emergency Settings

Stockholm Environment Institute
Swedish Red Cross

Stockholm, Sweden
January 30, 2019

Contents

List of Figures

List of Tables

Abbreviations

A2T Advanced Aerobic Technology

ATAD Autothermal Thermophilic Aerobic Digestion

BSF Black Soldier Fly

HRT Hydraulic Retention Time

IFRC International Federation of Red Cross and Red Crescent Societies

MAD Mesophilic Anaerobic Digestion

O&M Operation and Maintenance

ROSE Resource-Oriented Sanitation in Emergencies

SDG Sustainable Development Goal

SEI Stockholm Environment Institute

SFP Solid Fuel Production

SLU Swedish University of Agricultural Science

SRC Swedish Red Cross

SuSanA Sustainable Sanitation Alliance

TAD Thermophilic Aerobic Digestion

TS Total Solid

UI User Interface

WASH Water, Sanitation and Hygiene

1 Introduction

Providing safe and sustainable sanitation in emergency settings is a challenge that have often been addressed with standardized solutions without consideration of the potential negative impacts on the environment and natural resources (e.g. contamination of surface and groundwater). Integration of these considerations in emergency response planning and a more systematic approach focusing on resource recovery oriented sanitation could help reduce adverse effects on environmental systems and contribute beyond WASH sector in life saving operations (e.g. food and water security, energy need, job creation... Andersson et al. 2016). Moreover, offering services and building capacity around sustainable sanitation could benefit achieving the 2030 Agenda for Sustainable Development beyond Sustainable Development Goal (SDG) 6.

The Swedish Red Cross (SRC) within its Green Response approach addresses holistic and sustainable interventions without risking damage to the livelihood, health and survival of affected people together with improving the environmental outcomes of life-saving operations (IFRC 2018b).

The Resource-Oriented Sanitation in Emergency (ROSE) project has been a joint initiative by Swedish Red Cross (SRC) and Stockholm Environment Institute (SEI) aiming to bring support documents and guidance on the implementation of resource oriented sanitation systems in emergency settings. The scope has been designed for addressing a gap in the scientific researches, and so emergency response capacity, composing technical training material for relief agencies staff, with emphasis on resource recovery sanitation technologies. A review of the selected resource-oriented sanitation treatment solutions has been exploring different aspects for the implementation of these technologies in emergency settings and exploring some sanitation chains suitable and relevant in such contexts. These researches have been supplemented by the consultation of experts and specialized organizations, through a workshop organized in October 2018 and a revision process taking place until January 2019.

The final production of the ROSE project articulates around two documents: the present report, going in depth on technical aspects of the chosen treatment technologies; and a presentation file, being a more handy, practical and visual material for exploring and building potential sanitation chains.

1.1 Resource-Oriented Sanitation

Constraints of time and resources in emergency sites, isolation, together with issues in operational conditions, in humanitarian response coordination and governance, often complicated by disruptive official institutions usually lead to universalized solutions. Thus, sanitation provision has often been simplest possible alternatives, with no consideration of particular environmental settings. Those standard remedies are often failing due to wrong preliminary considerations, and remain dysfunctional systems, even sometimes exacerbating more the problems already encountered in an emergency setting (Zakaria et al. 2015).

Yet, emphasis could be put on acceptable solutions focusing on resource recovery, aiming a "productive" sanitation contributing to key and vital needs in emergency camps such as reducing food insecurity or creating energy. Hence, sanitation provision shall be seen beyond the implementation of blocs/latrines/toilets, with a clear vision on designing an entire sanitation service chain able to evolve through emergency phases. According to WHO (2018), as camps often practically end up becoming urban settlements, full service chain sanitation with potential on recovering resources and effective treatment should be considered once the immediate disaster phase is over, as the densities are too high to support fill-and-cover pit latrines over a long period.

Growing recognition that water, nutrients, energy and organic matter flows in sanitation systems can be safely managed and productively reused turn to be even more apparent in the particularly challenging situation of emergency settings, facing big gaps in provisions, in addition to health hazard due to poor faecal sludge management. The resource recovery and circular economy vision of sanitation could then contribute addressing key challenges as food security, water scarcity, energy provision and soil degradation (Andersson et al. 2016).

1.2 Scope

The SRC has been co-leading the Green Response initiative, looking for more sustainable solutions to minimize the environmental impact of humanitarian efforts (IFRC 2018b). Aiming to ensure enhanced sustainability of sanitation provision in emergency settings, a particular interest is on technologies that allow resource recovery and improve local resource management.

This report intends to provide a detailed description of three resource-oriented technologies for excreta treatment: Thermophilic Aerobic Digestion (TAD), Black Soldier Fly (BSF) and Solid Fuel Production (SFP). It is important to highlight that these technologies are emerging solutions for faecal sludge management and full scale applications are limited. Therefore, a review of the existing literature around each technology was performed, focusing on the identification of relevant aspects to be considered when implementing them in emergency settings.

The content of each technology review was based on the framework proposed by Gensch et al. (2018) to describe sanitation technologies in emergencies, with major adjustments when considered appropriate. For instance, the Compendium's key decision criteria include technical, financial, socio-cultural, and health and safety considerations, but additional aspects related to resource management and recovery were included in this present study.

Technology reviews were done collecting secondary data from peer-reviewed journals that are part of academic databases. As not all field experiences are published in said journals, searches in Water, Sanitation and Hygiene (WASH) practitioners repositories were included.

As the successful operation of the treatment stage strongly depends on the upstream and downstream stages, a system-thinking approach was taken to built sanitation service chains that suitably complement each technology. The service chains were built and discussed during a workshop, that brought together relief agencies, academic and research institutions, and private companies working on resource-oriented sanitation in emergencies.

Besides plausible solutions for each functional group, a discussion about their feasibility and implications for each built service chain is presented in the Supplementary Material - ROSE.ppt.

2 Sanitation and Emergencies

2.1 Emergency Contexts

With expected increasing number of climate related disasters and massive population displacement arising, emergency contexts address key challenges in guaranteeing the basic needs of people living in crisis situations (IPCC 2018).

Either in camps set for fleeing armed conflicts or in areas hit by natural hazard, humanitarian response through emergency relief agencies, local government or military forces need to adapt to the specific environmental, geographical, security and social situation.

Ensuring safe and proper sanitation provision is an urgent priority in the disaster relief effort to ensure a limited exposure to disease vectors causing mortality and morbidity in emergency settlements that are often overcrowded (Kindstedt 2012). Indeed, unsafe sanitation is a major causative factor in enteric disease epidemics outbreaks with faecal-oral transmission route, e. g. cholera (WHO 2018).

In these crisis context, a special emphasis shall be put on sanitation access for people with disabilities, for children, and for women's privacy, safety and menstrual hygiene needs. A careful planning during emergencies, when women and girls are especially vulnerable, is considered crucial by WHO (2018).

2.2 Emergency Phases

An emergency or disaster settlement is expected to face three different theoretical phases, with changing sanitation challenges (Gensch et al. 2018).

- The first moments of an emergency, considered the "acute response phase", covers the first hours and days following the crisis. Interventions are implementing effective short-term measures to ensure survival of the affected population. Regarding sanitation, the major concern is diseases transmission prevention and humanitarian aid usually focuses on excreta safe management and containment, also avoiding contamination of water sources. In that phase, sanitation and hygiene facilities should be purchased and pre-positioned along with other emergency supplies (WHO 2018).
- The "stabilization phase" usually starts after the first weeks of an emergency and can last to several months. The main focus regarding sanitation is to extent services coverage and upgrade temporary infrastructures to more robust facilities. A shift from communal public sanitation to household-level solutions is common and often intent to drive a change in sanitation facility construction and operation management to community-supported level, with a stronger vision on the entire service chain. Prerequisites for designing the sanitation chain include accurate assessment of the socio-cultural and environmental aspects for increasing long-term resilience and acceptance of the envisioned interventions.
- The "recovery phase" aims to recreate and/or improve the pre-emergency situation of the affected population by incorporating development principles in a 6 month to 5 years time frame. Emphasis is put on active involvement and participation of local partners and authorities in the planning and decision making, aiming capacity building on more sustainable sanitation chains. Interventions in the recovery phase should include a relevant retirement strategy for relief agencies and transition plans to hand-over to local governments, communities or service providers (business based), especially for long-lasting camps turning to permanent settlements.

A forth phase, linking the recovery phase with a potential new emergency and the first acute response phase could be considered, including the enhancement of emergency response planning, preparedness, training, and studies about the specific needs in such settings (Humanitarian Learning Center 2018).

2.3 Sanitation Chains in Emergencies

Recent years have seen numbers of emerging sanitation technologies, but the particular setting and constrains linked to emergency contexts require to look beyond single technologies, with inclusive and holistic regard on the entire sanitation chain.

Provision of toilets is then considered the first step of following functional groups described in Figure 1. Consideration of a sanitation service as an entire chain highlights at each step the potential value of the waste flow, assuming the streams as potential recoverable resources for agriculture or energy production and the societal, ecosystemic or health potential benefits, together with the services offered by the entire chain.

A sanitation chain is then including the following individual processes (items described in Table 1, adapted from Gensch et al. (2018)): User Interface (UI), Collection and Storage/Treatment, Conveyance, (Semi-) Centralized Treatment, and Use and/or Disposal.

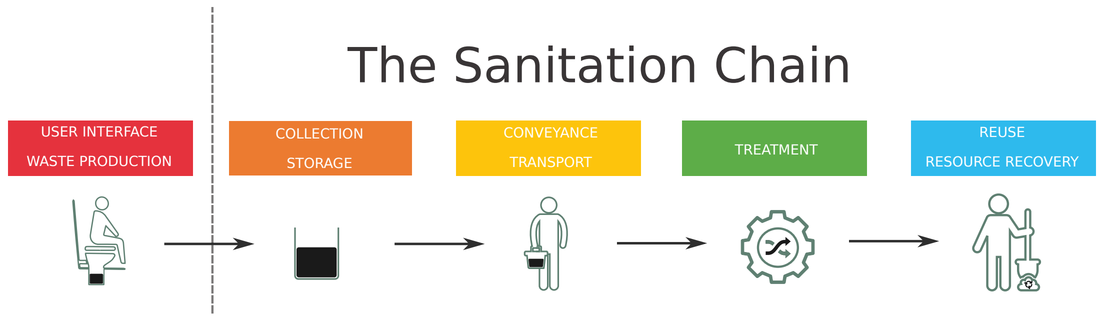

Figure 1

Table 1: Functional Groups in a Sanitation Service Chain

Chain components	Description of the component
User Interface	Describes the type of toilet, pedestal, pan, or urinal that the user comes into contact with; it is the way users access the sanitation system. In many cases, the choice of user interface will depend on the availability of water and user preferences. Additionally, handwashing facilities have been included here with a dedicated technology information sheet as a constant reminder that each sanitation user interface needs to be equipped with handwashing facilities for optimal hygiene outcomes.
Collection and Storage/Treatment	Describes technologies for on-site collection, storage, and sometimes (pre-) treatment of the products generated at the user interface. The treatment provided by these technologies is often a function of storage and is usually passive (i.e. requires no energy input), except a few emerging technologies where additives are needed. Thus, products that are 'treated' by these technologies often require subsequent treatment before use and/or disposal.
Conveyance	Describes the transport of products from one functional group to another. Although products may need to be transferred in various ways between functional groups, the longest, and most important gap is usually between the user interface or collection and storage/treatment and (semi-) centralized treatment. Therefore, for simplicity, conveyance only describes the technologies used to transport products between these two functional groups.
(Semi-) Centralized Treatment	Refers to treatment technologies that are generally appropriate for larger user groups (i.e. neighbourhood to city scale sanitation systems). The operation, maintenance, and energy requirements of technologies within this functional group are generally higher than for small-scale on-site technologies.
Use and/or Disposal	Refers to the methods through which products are returned to the environment, either as useful resources or reduced-risk materials. Some products can also be cycled back into a system (e.g. by using treated greywater for flushing).

2.4 Technical Documentation for Sanitation Planning

A clear pathway to plan and implement WASH interventions in emergencies has been laid out by IFRC (2017), including further sources to support each of the proposed steps. For instance, The Sphere Handbook (which latest version is Sphere 2018) and the resources published by GWC (2016), among others, are referents for technical standards for sanitation in humanitarian response.

Oxfam (2005) and Harvey (2007) have also developed other implementation manuals about sanitation systems in emergency. Being the initial barrier between excreta and disease transmission routes (Sphere 2018), the focus of these technical documents has largely been on the user-interface stage and more specifically on the use of latrines. Another example of this trend is the review done by Grange (2016) on the use of pit latrine in emergency settings and potential additives to reduce the frequency of desludging.

A comprehensive study describing alternatives for all the stages of the sanitation service chain in emergencies has been developed by Gensch et al. (2018), including some resource-oriented treatment technologies, such as vermicomposting, co-composting and anaerobic digestion. Further guidance on the safe use of products from excreta in agriculture can be found in WHO (2006).

Zakaria et al. (2015) developed a decision support methodology based on certain variables, to evaluate the suitability of a technology for the local context and the compatibility with other solutions to complete a sanitation service chain. The main variables used as screening and evaluation criteria in that study are presented in Table 2.

Table 2: Relevant Criteria for Technology Selection

Dimension	**Criteria**
Site Natural Conditions	Water Availability Land Availability Soil Characteristics Groundwater Table/Quality Surface Water Drainage
Implementation Requirements	Materials Availability Road Accessibility Energy Access
Regulatory considerations	National Regulations
Social Perception	Cultural Preferences
Potential Consequences	Costs, Impacts & Benefits

Attention to special needs from vulnerable population are a key component of sustainable sanitation planning. Guidelines on these issues include menstruation hygiene management (IFRC 2018a) (Humanitarian Learning Center 2018), avoidance of gender-based violence in WASH facilities (IASC 2015) and sanitation considerations for people with disabilities (Jones and Reed 2005).

A very well documented repository of resources for WASH field practitioners in emergency settings can be found in the website watsanmissionassistant.org/water maintained by International Federation of Red Cross and Red Crescent Societies (IFRC).

3 Methodological approaches

During the selection of an appropriate sanitation intervention for excreta treatment, a harmony between the local context and the evaluated technology characteristics must be found. This report aims to provide a detailed description of three treatment alternatives through technology reviews, focusing on highlighting the crucial aspects and conditions that should be considered for a successful implementation.

The full list of aspects used to characterise each technology is presented in Table 3. It is based on the aspects proposed by Gensch et al. (2018) to review sanitation technologies in emergencies, where a detailed description for most of the aspects in the technical, health, financial and socio-cultural dimensions can be found. Additional aspects related to environmental and regulatory considerations were added in this report and are represented by an asterisk (*) in Table 3.

The studied resource-oriented treatment technologies were revised through a systematic literature review, collecting secondary data from peer-reviewed journals in academic databases (i.e. Scopus and Web of Science) and WASH practitioners repositories (e.g. Sustainable Sanitation Alliance (SuSanA) Library, EAWAG). The searches were performed between September and December 2018. An extended methodological description of the literature review can be found in Appendix A.

When available, information from experiences treating excreta in emergency settings was preferred. Experiences using the technology to treat other waste streams (e.g. organic fraction of municipal solid waste) were included when gaps existed for faecal sludge or when the process is equivalent for both waste streams.

To build and discuss potential service chains around the selected technologies, SEI hosted the Resource-Oriented Sanitation in Emergencies (ROSE) workshop on the 15th of October 2018 in Stockholm, Sweden. The workshop brought together practitioners with experience working on resource-oriented sanitation in emergency settings through organizations from different sectors such as SRC, Advanced Aerobic Technology (A2T), Swedish University of Agricultural Science (SLU), Sanivation, among others.

Service chains building consisted in proposing plausible complementary solutions for each of the functional groups (described in Section 2.3), having one of the three selected technologies fixed in the treatment stage. The selected chain features do not present an exhaustive selection of possible functional groups but a study case for an exercise putting emphasis on suitable solutions for flooding hazard contexts. The feasibility of the solutions was discussed based on the criteria presented in Table 2. The built sustainable chains and the advantages and challenges that they represent are presented in Supplementary Material ROSE.ppt. The agenda and list of participants of the workshop, as well as the scenario used and the results summary are detailed in Appendix B.

Presentations and insights shared during the ROSE workshop were also used to complement the technology reviews. Even though workshop's support material can be easily attribute to an specific author, that is not the case for certain contribution. In the latter case, the source of the information collected is cited as "(ROSE Workshop 2018)" in this document.

Furthermore, the compiled results of the literature reviews were revised by experts with deep knowledge on the implementation of each technology, who cross-checked, confirm and suggested adjustments, when necessary, to the information presented in section 4. The experts and practitioners feedback was obtained through personal communications during December 2018 and January 2019.

Table 3: Technology Aspects Considered

Dimension	Aspect	Aspect Description
Technical	Phase of Emergency	Suitability for the three emergency phases: Acute Response, Stabilisation, Recovery
	Application Level	Service capacity of one unit: Household (one up to several individual households), Neighbourhood (a few to several hundred households), City (an entire settlement, camp or district)
	Management Level	Main responsible for Operation and Maintenance (O&M): Household, Shared (a person or a committee on behalf of all users), Public (government, institutions or private companies)
	Space Requirement	Estimate of the space required. Strongly dependent on amount of served users or amount of sludge treated.
	Technical Complexity	Level of expertise needed to implement, operate or maintain the technology: Low (no or minimal skills; can be done by non-professionals and artisans), Medium (certain skills; skilled artisans or engineers are required), High (experienced expert, such as a trained engineer, is required).
	Inputs/Outputs	Inputs refer to products that flow into the technology, while Outputs refer to those flowing out of the technology.
	Design considerations	Key design features giving a general idea on sizing and operations as well as the main potential pitfalls.
	Materials	Lists the different materials and equipment required for construction, operation and maintenance of the technology and discuss their local availability.
	Applicability	Describes the contexts in which a technology is most appropriate as well as other physical considerations (e.g. soil conditions, water availability, ground water table). Replicability, scalability, adaptability, speed of implementation and ease of dismantling are also included.
	Operation and Maintenance	Main O&M tasks, and their frequency, required for successful and sustainable technology running.
Socio-cultural	Social Considerations	Potential cultural taboos, user preferences and habits as well as local capacities related to the technology.
Environmental	Resources Consumption*	Consequences of implementing the technology on natural resources, including consumption (e.g. water, energy, treatment chemicals) as well as improved use efficiency or recovery.
	Environmental Impacts*	Level of discharges or emissions of contaminants produced by the technology, e.g. nutrients, organic content, and pathogens.
Regulatory	Institutions and Regulations*	Description of potential enabling or disabling institutional and regulatory factors.

*Aspect not described by Gensch et al. (2018)

4 Innovative Resource-oriented Treatment Technologies

4.1 Thermophilic Aerobic Digestion

TAD is a wet materials in-reactor treatment process producing a nutrient rich by-product usable as soil conditioner. Helped with efficient aeration, microorganisms digestion allow raw wet matter to rapidly sanitize through thermophilic conditions (more than 55°C). In addition, biomass degradation ensures sludge stabilisation with temperature increase.

4.1.1 Terminology

TAD has been discovered not being a universal name in the literature, even having different terminologies for this treatment process. Sometimes called Autothermal Thermophilic Aerobic Digestion (ATAD), this name remains controversial since the process cannot be classified as entirely autothermal. In fact, thermophilic microorganism could not reach the pasteurization temperature until efficient activation and aeration of the processed sludge, in addition to design considerations as an adequate reactor insulation (Layden et al. 2007). During this technology systematic review, more than two times more hits were found for this technology under 'Thermophilic Aerobic Digestion'. Yet, it appears that this denomination mainly refer to co-treatment steps and that the technology called autothermal, autothermic, or autoheated generally stands for stand-alone treatment technologies.

TAD treatment technology has been rarely found described as 'liquid composting' or 'wet composting'. It seems that some Swedish language papers are based on this denomination for blackwater treatment, but this terminology usually refers to Thermophilic Aerobic Digestion of mixed blackwater with organic wastes (Tidåker, Sjöberg, and Jönsson 2007) (Malmén, Palm, and Norin 2004). This process meets here the description of in-vessel co-composting technology, described in Gensch et al. (2018).

Since no consensus on a denomination for this technology treating faecal sludge or blackwater has been found, the non exhaustive name 'TAD' is used in this report. This choice justifies with the inclusiveness of 'TAD' as a query in the literature review, that includes the more broad results (including articles on so called 'ATAD', see the detailed literature review in Appendix A).

4.1.2 TAD Usages in Literature

TAD has been first implemented as a municipal wastewater co-treatment technology in the early 1970's and have been evolved over 40 years with numerous options of combined or single input material (sewage sludge, organic solid wastes, industrial wastewater, agricultural wastes, blackwater, faecal sludge, green wastes).

It became in Europe and the US a recognized, robust and viable technology (Layden et al. 2007) for biosolids creation from sewage sludge (wastewater treatment plants effluents).

Indeed, a large majority of the literature about TAD deal with sewage sludge or with input combinations of sewage wastes with other wastes. Yet, this document intents to give a literature-based overview on TAD process flexibility and possibilities to be implemented as a sanitation treatment solution in emergency settings.
For non sewage served settlements, according to Halalsheh et al. (2011), treatment of faecal sludge without any added flushing water (or septage from sceptic tanks), is more challenging than domestic sewage because of lower biodegradability of the input matter. In this study is also highlighted the lack of literature about faecal sludge aerobic biodegradability and biodegradation rates. Halalsheh et al. (2011) thus points the prior need of feed sludge characterization for designing a treatment plant based on this technology.

According to the literature review, examples of full scale implemented TAD processing blackwater from flushed based toilets remain emerging initiatives that have been only found piloted Sweden:

- One plant located in Kvicksund is running from 1998, treating $1400m^3$ of blackwater per year, mixed with food wastes and faecal sludge from bucket latrines (A. C. Nordin and Björn Vinnerås 2015).

- One plant located in Södertalje municipality, treating from 2012 blackwater with the support of amonia sanitisation (A. Nordin, D. Göttert, and B. Vinnerås 2018).
- In Karby, Norrtälje municipality, a plant is treating blackwater mixed with faecal sludge from bucket latrines from 2003 (Annika Nordin 2019).
- Advanced Aerobic Technology (A2T) currently develops a commercial sanitation system (*SaniC System presentation* n.d.), based on experiences from a TAD plant running in Eskilstuna working on the same settings than the one in Kvicksund. The development of a high performance aeration design allow their treatment treatment facility running with a stand-alone TAD process on single blackwater feed sludge (A2T 2018b).

Despite no implementation of this technology in emergency settings has been found in the literature, A2T, in their partnership with SRC, currently develop an 'in container' facility (TAD treatment plant and sanitation units), adapted to crisis context.

A full review of other possible implementations and trials is limited by the lack of translation of several publications in Swedish language.

4.1.3 Technology Aspects Description

The treatment process of wet material takes place in bio-reactors by aerobic, activated, thermophilic process. Air injection and sludge agitation, in combination with adequate reactor design and insulation allows the material to heat up due to microorganism's metabolism digestion in aerobic condition.

Various minimal temperatures and pasteurization time have been found. USEPA (1994) set minimum standard conditions for safe treatment as retention time of at least 30min for 70°C reached, or 4 hours for 55°C reached. In Sweden, this standards are pushed to 6 hours at 55°C (SEPA 2003). WHO 2006 set health safety sanitisation of excreta threshold as minimum a week for 55°C reached for composting treatment. This process turn feed sludge to low energy pasteurized matter, killing most of the contagious agents (i.e. salmonella, Escherichia coli, enterobacteria; A2T 2018b).

In TAD process, pasteurization happens with reduction of solid matter volume (within the Total Solid (TS) fraction), usually 50 to 80%. Some investigations have been found potentially reducing sludge volatile solids fraction by 90% (Rozich and Bordacs 2002). International legislation target a volatile solids destruction of 38% (Layden et al. 2007).

It processes liquid sludge (non diverted) with differing input optimal moisture content. The widest range of accepted TS content has been found in A2T (2018b). Their high-performance reactor hardware able to treat with stand-alone TAD liquid material down to 0,5% TS, corresponding to traditional European blackwater characteristics, and up to 10% TS. The full treatment cycle time, also called Hydraulic Retention Time (HRT) has been mainly found running in 6 to 15 days (Layden et al. 2007).

To have an active thermophilic microorganisms flora, some of the treated product may be used as an inoculant for the feed sludge (Dorothee Göttert 2016).

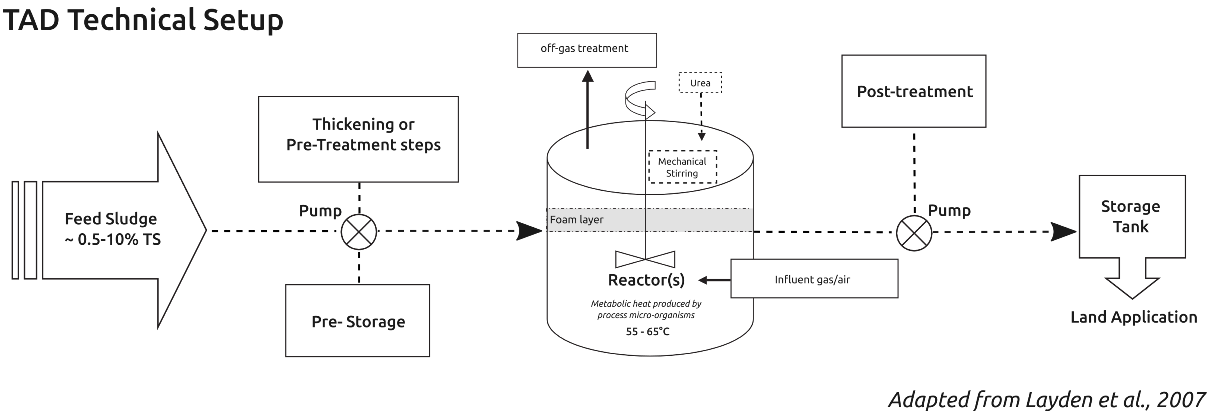

Figure 2: Example of TAD Technical Setup

4.1.4 TAD treatment plants features variety

TAD treatment process has been used with various features.
The number of treatment process stages may differ in the different implementation of TAD. Two-stage train are sometimes operated (first digestion at 45 to 55°C, second at 55 to 70°C), for maximizing pathogens reduction and minimizing short-circuiting risks, that may lead to contamination of already partly or entirely processed sludge by raw input. One-stage TAD train must reach a minimum 55°C for achieving sanitisation, with minimum requirements described in Section 3.1.3 (Layden et al. 2007).

As a wastewater effluent treatment solution, depending on feed sludge characteristics, TAD processing may involve material thickening to meet the plants operating moisture content range. Moreover, post-treatment dewatering may be process on TAD output product for meeting land disposal requirements. Those pre and post-treatment are usually necessary in municipal sewage sludge treatment (e.g. Martín et al. 2018, Bartkowska 2017). As a wastewater co-treatment solution, TAD has also been found relevant as a pre-treatment step in dual digestion systems, upgrading Mesophilic Anaerobic Digestion (MAD) (Jang et al. 2014).

For blackwater treatment, when the thermophilic microorganisms do not achieve heat up the input sludge to a temperature of 55 °C because of input matter low energy content, TAD cans be combined with Urea treatment for completing pasteurization. The combination of heat and ammonia (degraded Urea) complement the digestion process to ensure a sufficient sanitisation level (Dorothee Göttert 2016). This urea is added in reasonable quantity, to meet restrictions linked to ammonia content of the treatment residue as fertilizer (A. C. Nordin and Björn Vinnerås 2015). Literature reports on many other investigations with different chemical conditioners in sewage sludge treatment(Layden et al. 2007).

In addition to those important process scheme differences mainly dependant to input streams, many differing design features have been found in the literature within the usage of TAD in sanitation:

- Hardware aeration design
- Sludge activation technology
- Exhaust gas filtering (ancillary equipment or exhaust gas reuse)
- Foaming control systems
- System operating in batches or semi continuous
- Air or pure oxygen injection

Such important design differences, input feed diversity and wide usage of TAD make a treatment plant design highly context and flows dependent. Indeed, the aerobic digestion occurring in reactors must have unique characteristics (temperature development, degradation rate...), also requiring expert tunning of the system.

Table 4: Data Collection on Thermophilic Aerobic Digestion

Aspect	Features
Phase of Emergency	No proven trials of TAD in emergencies have been found in the literature. 'In container' TAD-based treatment unit is developed by A2T for SRC for implementation in acute response phase (A2T 2018b).
Application Level	Technology claimed to be applicable from household to centralized scale. At the moment only off-site treatment projects have been implemented, with sludge transportation from direct piping system or collection by vacuum truck. At largest scale, TAD plant has treated municipal sludge of 260 000 people (Layden et al. 2007). In-container plant prototype developed by A2T is designed for treating around $150m^3$ per year (With approximately 50 batches per year and around $3m^3$ reactor capacity. Able to support 1000 persons excreta production with 0.5L flush, or around 250 persons with 3L flush) (A2T 2018b).
Management Level	Management level would necessarily be public in the implementation of TAD as (semi) centralized treatment scale in the sanitation chain. For in-container on-site plants or at the lowest semi-centralized scales, there is a possibility that the operationalization of the facility is transferred to a shared level, but users implication might require capacity building for locals (A2T 2018b).
Objectives/ Key Features	High sanitisation level, nutrients recovery, fast treatment (average 6 to 15 days), thermophilic digestion, sophisticated treatment process (Layden et al. 2007).
Space Requirement	Space requirements depends largely on the number of treatment stages considered (one reactor per stage) and on the need of pre, or post treatment storage tanks. A2T in-container plant: Little space requirement (A2T 2018b).
Technical Complexity	High Complexity
Inputs / Outputs	Input: sewage sludge, organic solid wastes, food industry wastewater, agricultural wastes, blackwater, faecal sludge, green wastes. Output: Compost, fertilizer characteristics dependent of the input wet content and of potential post-treatment. Resilient to large variety of organic streams and combined inputs
Design considerations	The smallest quantity of flushing water shall be aimed since the sludge content has to be 0.5 to 10% TS to achieve a sufficient heat up during aerobic digestion to reduce enough pathogens content (A2T 2018b). Designing the treatment facility itself requires also a regard on pre-treatment and post-treatment storage. These tanks shall let the sludge in aerobic conditions and the post-treatment tank shall be sized depending on the agricultural fertilizer need and transport capacity. At a smaller scale, sludge can enter and exit the reactor directly from truck-tanks. Depending on number of stages in the technology, piped connection and heat exchangers can be considered (Layden et al. 2007). National policies give differing recommendation on in-digester sanitisation parameters (temperature and exposure time), while WHO (2006) advises minimal heat up to 50°C for a week to ensure safe sanitisation of windrow solid compost. A2T in-container plant consumes an average of 130 kWh/m^3 (A2T 2018b). A. Nordin, D. Göttert, and B. Vinnerås (2018) uses for comparative computations a standard energy consumption of 28 kWh/m^3 for a stand-alone TAD treatment plant at a larger scale. The treatment technology isn't particularly resilient to menstrual hygiene pads (need of screening, A2T 2018b).

Table 4 continues in the next page

Continuation of Table 4	
Aspects	**Features**
Materials	In-container solutions shall include all-in-one facilities without need of extra-material from the field. Due to the novelty of this technology and the high-technology design, no possibilities of building locally such a plant is explored and the entire facility will need to be imported.
Applicability	For applicable phases see item above. This technology is particularly appropriate where there is a primary need for fertilizer in agricultural activities near-by the plant. If the TAD treatment output cannot be reused, a safe disposal process shall be addressed. Faecal sludge with low water flushing quantity cans be directly use as a single feeding material for TAD, as well as combined with other organic streams such as food wastes. Mixing blackwater or faecal sludge with other organic material may increase the input flow energy content and enhance TAD treatment efficiency (HRT reduction; Annika Nordin 2019). Treatment technology adaptable with a large panel of UI, including flooding resilient systems (contained toilets, vacuum toilets) and water scarcity contexts (dry toilets without urine diversion). For now no trials have been run on TAD of diverted faecal sludge. No regard on technology adaptability for anal cleansing inputs, but the key concerns might be on the water quantity used and the corresponding TS content in the sludge to treat. The container-based sanitation facilities with included sanitation blocs are easily dismantable and transportable for being reused (A2T 2018b). The biggest applicability challenge remains in the first emergency phase the need of energy for running the plant.
Operation and Maintenance	Foaming control, air, supply and feed rate are the main operational variables setting TAD performance (Layden et al. 2007). The treatment process shall be frequently (if not continuously) controlled and monitored regarding temperature, reactor filling level and time measurement (Telge Nät 2014), mainly for preventing foaming to occur. In early phases of implementation, a qualitative measurement on the sludge input shall be performed together with an outflow sanitation control ensuring the reuse material is safe, reaching local regulations and, if necessary, to perform a complementary treatment (i.e. Urea). An average of one hour per day would be necessary for a trained operator to monitor A2T in-container plant in well-working conditions. The O&M need of a TAD treatment plant is pretty low; the most critical components likely to require reparations are the pumps (A2T 2018a). Individual toilets desludging would also have to be operated if they are not connected through pipe to the treatment plant .
Health and Safety	Health risks regarding treatment itself shall be reduced by the use of appropriate safe practices and equipment in the treatment plant (Dorothee Göttert 2016). Since the transfer between tanks and reactors shall be performed by piped or truck pumping system, the highest risks of contacts between contagious material and operators take place in the sludge collection step (or ponctually for sampling). The final product shall achieve a high degree of stabilization and pathogen reduction if no short circuiting have operated during the process (Layden et al. 2007). Due to its high sanitisation performance, disease transmission routes related to crop application aren't important risks in TAD.
Table 4 continues in the next page	

Continuation of Table 4	
Aspects	**Features**
Costs	Capital: A2T (2018b) announces 330 USD/person announced for a large scale centralized treatment plant. Operation: O&M staff (1h/day for one operator), otherwise announced low. Costs linked to energy use are dependant of implementation context (A2T 2018a). A. Nordin, D. Göttert, and B. Vinnerås 2018 uses for comparative computations a standard running cost of 1.27 USD/m^3 for a stand-alone TAD treatment plant. However, is reported that if Urea is used, it could considerably contributes to operation costs.
Social Considerations	There is currently no clear vision on capacity building possibilities for the local population since the technical complexity level is pretty high. Identifying that material for cropping made of human waste is acceptable and that a demand exists (market survey) are prerequisites for implementation of this technology. Populations acknowledgement for Ecological Sanitation movements could be facilitating social acceptance of such sub-products usage.
Natural Resources Management	Water demand for potential flushing depends on the chosen User Interface (UI). Claim is thus on use of limited water quantity and since no other natural resource or by-product is needed for the treatment, stress on natural resources shall be pretty low. In case of usage of Urea, particular environmental considerations for this product are described in Gensch et al. 2018.
Environmental Impacts	A2T announces a nutrient recovery of 70% N, 100% P and 100% K (*SaniC System presentation* n.d.). Soil resilience to extra nutrients adding shall then be checked. Exhaust gases evacuating the reduced volatile solids (containing within others ammonia, sulphur, hydrogen sulphide and carboxylic acids) haven't been found reported as having any environmental impact. As any treatment process, the heavy metal fraction in the material will remain inert during the digestion and its proportion increase. Liu, Zhu, and Li (2011) have computed analysis on the sub-product heavy metals content after 15 days TAD treatment, and found that the fertilizer meets Great-Britain inorganic contents requirements (GB 18918 - 2002). Therefore, is reported that "the content of inorganic elements in the digested sludge increased more slowly that in the original feeding sludge".
Institutional and Regulatory Considerations	Many countries are lacking a sufficiently developed framework facilitating management and use of excreta in agriculture (WHO 2006). The reuse products need to conform the local agriculture practices standards and discharging regulations, together with having a safe product sanitisation process through minimal heating threshold and volatile solids reduction. Reuse product is classified in the US as 'Class A Biosolid', under 40 CFR rule 503 regulation. In Europe discharge regulation is under EU Sewage Sludge Directive 86/278/EEC (Martín et al. 2018); SPCR 178 (SEPA 2013) for Sweden (A. C. Nordin and Björn Vinnerås 2015). For further reading on biosolids and sludge management see W. Parker and Laha 2004.
Business Opportunities	The primary prerequisite of agricultural needs will drive mostly business opportunities linked to the sub-product selling. Public and privates have business opportunities from charging fees at users level to cover the operational costs of the treatment facility. Emphasis could be then put on developing reuse products market, replacing chemical fertilizers.
Table 4 continues in the next page	

Continuation of Table 4	
Aspects	**Features**
Strengths and weaknesses	Strengths: Sanitation system must be resilient to flooding hazard. Almost no health risks for the treatment step. Fast treatment. Adaptable to a lot of UI. Flexibility regarding input material. Weaknesses: Potentially costly due to high-tech process. Requires trained staff to run. Need energy to run. Technology at pilot phase for implementation in emergencies. Need of a primary demand for fertilizer/soil conditioner.

4.2 Black Soldier Fly

Black Soldier Fly - *Hermetia illucens* (BSF) is an insect, which larvae are able to nurture from faecal sludge. Thanks to their high concentrations of protein and fats, the larvae can be used as animal feed or biofuel feedstock (Banks 2014).

There is academic evidence of the use of BSF as an alternative for manure management and poultry feedstock since the 1970's. Beyond animal manures, BSF has been tried for the conversion of fruit and vegetable waste, organic fraction of solid municipal waste, millings and brewery side streams, and human excreta (Moritz Gold et al. 2018). However, BSF for faecal sludge management is not as well established as for other waste streams.

For instance, large-scale industrial facilities selling products from BSF fed with market and food waste have been operated in South Africa, Canada, USA, the Netherlands and China for several years (Joly 2018). The only full-scale facility using BSF for faecal sludge management was reported in Durban, South Africa designed to treat up to 20 tonnes wet mass per day in partnership with the local utility (Mutsakatira, Buckley, and Mercer 2018), however, no evidence of its current operation was found. No experience studying BSF in emergency settings was included in the consulted data sources.

Another relevant publications include the research done by Lalander et al. (2013), demonstrating that BSF was able to reduce pathogen content of the faecal sludge, Banks (2014) who experimented with different operational parameters to optimise BSF production using faecal sludge from pit latrines, and Dortmans, Verstappen, and Zurbrügg (2017) provide a step-by-step guide for BSF implementation using organic solid waste as food source.

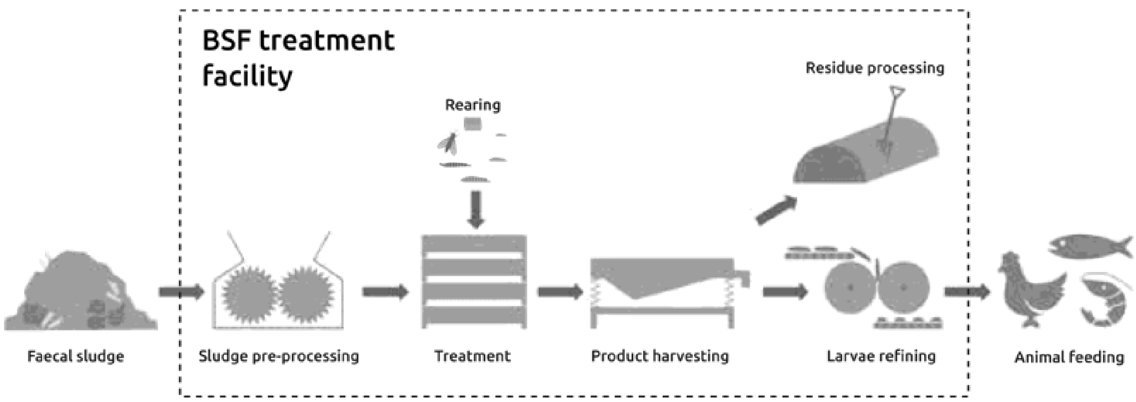

Figure 3: BSF Technical Setup (Modified from Dortmans, Verstappen, and Zurbrügg 2017)

Technology Aspects Description

BSF adults are neither a nuisance species, nor a mechanical vector for disease. The adult females lay eggs close to the larval food sources. While larvae grow, fat stores are created. These stores become the energy source of the fly at the adult stage. BSF larvae can reduce the volume of faecal sludge and its pathogen load Lalander et al. (2013), as well as reduce house fly- *Musca Domestica* development (Banks 2014).

Thanks to their high concentrations of protein and fats, the larvae can be used as animal feed or biofuel feedstock after being freed of pathogen through e.g. heating, drying, freezing. BSF eggs production depends on light, temperature and relative humidity. The solid residue can be refined through composting or anaerobic digestion; It also can be directly used for agricultural purposes after sterilisation (Banks 2014).

Table 5: Data Collection on Black Soldier Fly

Aspect	**Features**
Phase of Emergency	Not adequate for the acute response. More research is needed to establish its feasibility in the stabilisation phase (Grange 2016).
Application Level	BSF treatment can be done through centralised plants (most common approach), where faecal sludge from the surrounding households is transported after manual or mechanical collection(Banks 2014). A semi centralised approach is also an option where BSF is reared in a centralised facility and the young larvae is distributed to local users who will treat the faecal sludge on site.
Management Level	When a centralised treatment level is implemented, the management level is public. In case of semi-centralised treatment level, depending on the business model, each household could harvest larvae and use them or sell/deliver them to a production industry in charge of guarantee the hygienic quality of the feed; distribution of new larvae would be done at the public management level(Banks 2014).
Space Requirement	Centralised: Medium space required. 140-640 m2/daily tonne for medium-scale facilities. 40-50 m2/daily tonne for large scale facilities (Joly 2018). The area required can be reduced by stacking up containers treating faecal sludge (Lalander 2019)
Technical Complexity	Medium Complexity
Inputs/Outputs	Input: Excreta, Faeces, Organic solids. Output: BSF larvae, Solid Residue (Banks 2014).
Design considerations	BSF rearing: To get BSF eggs, adult fly colonies should be established. Successful mating has a positive correlation with light intensity. It is possible to have indoor colonies using artificial light source, however it is less effective than morning sunlight. Eggs are laid in crevices near the food. Artificial crevices ”eggies” could be made out of wood/cardboard or plastic. More egg clutches laid over 26°C and relative humidity over 60%. The ideal temperature for BSF mating and egg development is between 25 and 32°C. Low relative humidity can cause egg desiccation. If the environmental conditions are not favorable a greenhouse could be built (Mutsakatira, Buckley, and Mercer 2018). Faecal sludge treatment: Larvae reach maturity in minimum 3 weeks, depending on temperature and food availability, and a change in colour (i.e. from white to dark brown) suggest that they are ready to be harvested.Faecal matter reduction varies between 27 and 41%, depending on its moisture content (MC), feeding rate (FR) and larval density (LD). FS MC should be between 70 and 80%. In a study in South Africa, optimal reduction was achieved under MC 75%, FR 50mg larvae-1 day-1, and LD 400 larvae per test (Banks 2014). Bed effective depth should be less than 10 cm (5 cm recommended). Avoid the presence of hazardous and/or inorganic material (e.g. Acids, solvents, pesticides, detergents and heavy metals) in the feedstock (Dortmans, Verstappen, and Zurbrügg 2017). Rule of thumb: 10000 larvae in a larvero (40x60x17cm) feeding on 15kg of wet waste (75% water) for 12 days. Larveros can be stacked upon each other to optimize surface area requirements, however they should remain well ventilated (Dortmans, Verstappen, and Zurbrügg 2017).
Materials	BSF eggs, Cardboard/wood, Wood/metal shelves/structures, sturdy mosquito netting, dark fabric, plastic containers, wash sinks, standardized substrate, screens/sieve, plastic walls (cold weather), Faecal Sludge container, dewatering unit (if necessary) (Banks 2014; Dortmans, Verstappen, and Zurbrügg 2017)

Table 5 continues in the next page

Continuation of Table 5	
Aspects	**Features**
Applicability	For applicable phases see aspect 1 above. Two-three weeks for structure construction. Around six months to stabilise the facility's operation (Lalander 2019; Pineda 2018). This technology is optimal for locations with agricultural and animal breeding activity near-by.
Operation and Maintenance	The eggies should be moved close to a hatchling container with a standardized substrate (e.g. chicken food and water) to maintain a stable and homogeneous larvae production. The hatchling container should be replace every 1-3 days. The larvae spends 5 days in the hatchling container. To maintain the population of the fly colony, a fraction (2-5%) of the larvae is grown until the adult stage in nursery containers with a well-defined feed mixture. The remainder larvae goes into larveros. Equal amounts of faecal sludge should be added to the larveros in day one, five and eight. After 12 days in the larveros, larvae are harvested by sieving. Larvae are put into a container with drying material for one day. To reduce pathogen load, larvae could be dipped into boiling water for two minutes. After, they could be frozen or dried for storage (Dortmans, Verstappen, and Zurbrügg 2017). The larveros should be washed before being reused to avoid morbidity among the larvae (Lalander 2019).
Health and Safety	Even though BSF adults do not come in contact with human food, there has been cases of accidental transmission of myiasis on people who ate ripe, unwashed fruits (Banks 2014). To meet the standards set by WHO (2006), larvae and the solid residue should undergo a sanitisation process ; the former usually through heating, drying or freezing and the latter through heating or ammonia addition. An effective ventilation system in the facility is a key health and safety requirement (Lalander 2019). Workers in contact with the faecal sludge should use adequate protection items, such as latex gloves, facemask, boots, lab coat, eye protection. Measures to keep rodents, ants and other vectors away from the sludge, like fences and traps, should be set (World Health Organization 2016).
Costs	Capital: External structure, materials (see aspect 8 above) and ventilation/heat exchange system. Operation: Workforce, utilities, standardized substrate for hatchling containers (Lalander 2019; Pineda 2018).
Business Opportunities	Fees can be charged for treating the faecal sludge. Further revenues can be obtained by selling BSF larvae and the solid residue (Andersson et al. 2016).
Social Considerations	It may increase the livelihood of local farmers and contribute towards food security (Joly 2018). Even though it has not been documented, people may have resistance to use BSF larvae raised from faecal sludge.
Natural Resources Management	Wood/metal may be used as supporting structure to contain the BSF colony and larval trays. Medium amounts of water is needed for hygiene purposes and, if necessary, to reach optimal moisture content. Standardized substrate is necessary during egg laying and early larvae development (Pineda 2018). Energy is needed for larvae refining and residue processing, and for the ventilation system. Additional energy for heating is required in cold climates. As larvae contain 42-45% protein and 31-35% fat (Banks 2014), nutrient recovery would occur when they are used for animal feeding. The solid residue can be further treated through other resource recovery process (e.g. anaerobic digestion, composting).
Environmental Impacts	Pre-treatment screening sludge may be produced. The solid residue should be sterilised to avoid pathogens dispersion. Risk of bioaccumulation of heavy metals (Banks 2014)
Institutional and Regulatory	Europe: BSF is allowed to be used as food for fish, pig and poultry, when reared on plant-based substrate. Manure explicitly excluded.(Joly 2018)
Table 5 continues in the next page	

Continuation of Table 5	
Aspects	**Features**
Strengths and weaknesses	Strengths: Nutrients recovery through animal feeding, Additional revenue, Job creation. Weaknesses: High surface area (can be reduced by stacking larveros), High logistics for BSF rearing Lalander 2019, Potential bioaccumulation of heavy metals.

4.3 Solid Fuel Production

Solid Fuel Production (SFP) can be defined as the conversion of faecal sludge into briquettes or pellets, that can be used as energy source for cooking or heating. Compaction of the sludge helps to increase bulk density, heating value per unit of volume, and homogeneity, which easier handling, storage and transportation (Lohri, Diener, et al. 2017).

SFP is based on practices of coal briquetting, a century-old mature technology and has high flexibility to operate under a wide range of scales (Lohri, Diener, et al. 2017). There are evidence of full-scale experience densifying sawdust in US, Europe and Japan since the 1960s (Grover and Mishra 1996). Later, pilots at the household level using other organic streams as input has been described, mainly agricultural waste (Lohri, Diener, et al. 2017) but also organic fraction of municipal solid waste (Kung et al. 2013) and faecal sludge (Atwijukye et al. 2018).

Faecal sludge pretreatment, before being pressed into solid fuels, typically involve a combination of the following stages: dewatering/drying, carbonisation (i.e. torrefaction/pyrolysis) and mixing. When the faecal sludge is not carbonised, sterilisation is necessary (Asamoah et al. 2016). Beyond the need of sterilisation, there are substantial differences on the requirements for implementation of non-carbonising and carbonising processes. Therefore, the technology aspects description for each type will be presented separately.

Different ways of carbonising faecal sludge have been tried. M. Gold, Cunningham, et al. (2018) presented a bench-scale study implementing slow pyrolysis of faecal sludge in Uganda. Other studies have focused on the hydrothermal carbonisation of faecal sludge (Lohri, Zabaleta, et al. 2018), which advantage is the use of wet feedstock, however this technology has only been proven at the laboratory scale.

Non-carbonising processes are also found in the literature. M. Gold, Ddiba, et al. (2017) described pilot-scale experiences in Senegal and Uganda, where solid fuel was obtained using thickening tanks and drying beds. Non-carbonised faecal sludge is commonly used as a binder of materials with a higher energy content such as sawdust or carbonised biomass (Asamoah et al. 2016).

The only case where solid fuel production was found to occur in a humanitarian setting is a non-carbonising process in Kakuma, Kenya. The process includes thermal sterilisation, mixing with carbonised materials, compression and solar drying (Hakspiel, Foote, and J. Parker 2018).

Section 3.3.1 focuses on the aspects of carbonising processes, while Section 3.3.2 takes a closer look at the experience in a humanitarian setting in Kenya.

4.3.1 Technology Aspects Description - Carbonising process

Typically, faecal sludge is dewatered/thickened and dried before carbonisation, to reduce the energy demand of the process. The separated wastewater should be treated and/or safely disposed. Carbonisation occurs in absence of or limited oxygen conditions, being temperature, pressure and residence time the most influential parameters. The carbonised faecal sludge is often mixed with other materials to enhance energy content and binding properties. The mixture is shaped into briquettes by mechanically or manually operated presses. Briquettes should be further dried to inhibit biological activity and improve mechanical strength (Asamoah et al. 2016). More technology aspects are described in Table 6.

Table 6: Data Collection on Solid Fuel Production

Aspect	**Features**
Phase of Emergency	Adequate for stabilisation phase.
Application Level	Often done in centralised plants. It can also be implemented at the household level (Asamoah et al. 2016)
Management Level	When a centralised system is in place, management occurs at the public level. When the process is implemented on-site, management is done at the household level, and the briquettes are used/sold by the household who produced them (Asamoah et al. 2016).
Space Requirement	Public level: Medium space required. Household level: Little space required. Briquettes solar drying specially increases space requirements.
Technical Complexity	Low/Medium technical complexity
Inputs/Outputs	Inputs: Faeces, Excreta (+ sawdust/charcoal dust, starch/molasses/clay) Outputs: Briquettes (Asamoah et al. 2016) (Atwijukye et al. 2018).
Design considerations	A moisture content below 15% before carbonisation is recommended. When oven drying is used, temperatures over 105°C should be reached (Atwijukye et al. 2018).Carbonisation occurs in absence of or limited oxygen conditions, at temperatures over 300°C for at least 2 hours in reactors or 16-20 hours in kilns. It is often done in batch reactors but household-level carbonisation can be done in kilns/drums. Extra materials (e.g. sawdust, charcoal dust) are mixed with the carbonised faecal sludge to enhance the energy content. To improve the binding properties of the mixture, 10-12% dissolved molasses or starch can be added. Lime is sometimes added to avoid slagging. The moisture content of the mix is usually 6-12%. When the mixture is ready it can be densified with pressures between 5.5-34.5 MPa using mechanically operated rotary/extruder press. In low-scale production, pressing machines can be operated manually. In the open (e.g. drying beds), final briquette drying may last 3 to 4 days depending on weather conditions (Asamoah et al. 2016).
Materials	Drying structures (e.g. oven, beds), reactor/kilns/drums, press
Applicability	The technology can be applied in urban and rural settings. A reliable source of energy is imperative. Access to external machinery (e.g. press) is needed. Availability of additional materials for mixture is advantageous. Low relative humidity and ambient temperatures over 25°C facilitate open drying. Greenhouses can be built to achieve desirable ambient conditions.
Operation and Maintenance	As a batch process, an operator (or conveyance system) should be transferring the faecal sludge from one step to another (e.g. from initial drying to carbonisation). When household-level operations are in place, it is harder to assure high performance and quality control.
Health and Safety	Basic hygiene recommendations and provide appropriate protective equipment (e.g. gloves, facemask, boots), hygiene stations, and training (World Health Organization 2016).
Costs	Capital: Reactor/kilns/drums, machinery Operational: Raw materials acquisition and preparation, Energy for carbonisation and drying (Asamoah et al. 2016).
Social Considerations	People may have resistance to manage their own faeces, especially when household level management is considered.

Table 6 continues in the next page

Continuation of Table 6	
Aspects	**Features**
Natural Resources Management	Small amount of water may be required to achieve appropriate mixture consistency before pressing. Electricity may be needed to operate machines. Several metallic structures, and electric and electronic equipment may be required. Energy recovery is achieved when briquettes are used, with typical calorific values between 13.8-25.6 MJ/kg (Asamoah et al. 2016).
Environmental Impacts	Emission of volatile hydrocarbons (e.g. methane), carbon monoxide and hydrogen sulfide during carbonisation (Asamoah et al. 2016). Depending on the energy source for electricity, the process could have associated GHG emissions.
Institutional and Regulatory	Briquettes standard or certifications, if existent in the country. Regulations against deforestation for charcoal production are favourable for this technology (Asamoah et al. 2016).
Business Opportunities	Fees can be charged for treating the faecal sludge and additional revenues can be generated by selling the briquettes to households or industries.
Strengths and weaknesses	Strengths: Low residence time, Energy recovery, Additional revenue, Job creation, Deforestation reduction. Weakness: Highly energy intensive (if oven drying), imported equipment, land required for drying, dependent on weather conditions

4.3.2 Technology Aspects Description - Non-carbonising process

In Kakuma, Kenya, Sanivation's business operations goes from collection of faecal sludge to briquettes distribution as shown in Figure 4. This section will focus on the solid fuel production stage, which is based on thermal sterilisation and roller press compression. Faecal Sludge is heated through an indirect treatment, using hot water as energy carrier. During a previous pilot, a solar parabolic concentrator was used as energy source but due to technical issues, the process currently rely on a electric boiler powered by a diesel generator (Sanivation 2019). Sterilised faecal sludge is ground and mixed with high-carbon co-waste (e.g. charcoal dust, agricultural residues, carbonised prosopis). If needed additional water is added until the adequate consistency is reached to compress the mixture into briquettes in the roller press. Briquettes are then solar dried. Thanks to their characteristics, dried briquettes are sold for different energy purposes such as cooking (Hakspiel, Foote, and J. Parker 2018). More technology aspects are described in Table 7.

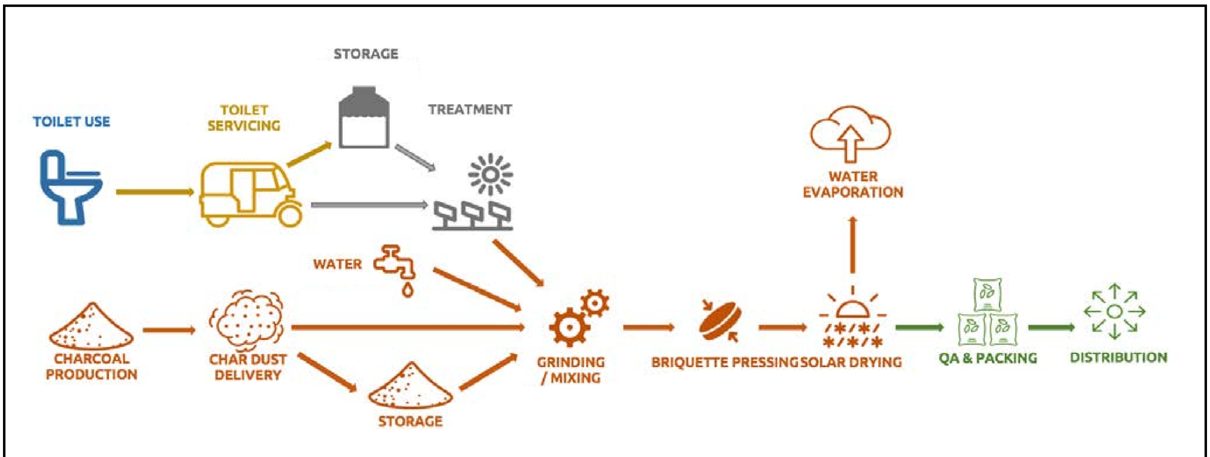

Figure 4: Sanivation Technical Setup (Hakspiel, Foote, and J. Parker 2018)

Table 7: Data Collection on Solid Fuel Production

Aspect	Features
Phase of Emergency	Not adequate for the acute phase. Adequacy in the stabilisation phase depends on the mobility of the settlements. Pilot tests have been done in the recovery phase (Hakspiel, Foote, and J. Parker 2018).
Application Level	Semicentralised level, where FS from the surrounding households is transported after manual or mechanical collection (Hakspiel, Foote, and J. Parker 2018).
Management Level	Public level
Space Requirement	Much space required. 4046 m2 (1 acre) for maximum capacity of 24 ton/d (Aprox. 90,000 people Hakspiel, Foote, and J. Parker 2018) . Briquettes solar drying specially increases space requirements.
Technical Complexity	Medium complexity (Hakspiel, Foote, and J. Parker 2018).
Inputs/Outputs	Inputs: Faeces, Excreta (+ charcoal dust, biomass, water). Outputs: Briquettes (Hakspiel, Foote, and J. Parker 2018).
Design considerations Materials	To assure thermal pathogen deactivation, temperatures over 65 °C for at least three hours is necessary. Various sources of heat can be used, renewable sources are recommended where feasible. If the daily insolation through the year is appropriate, the solar thermal concentrator should be in the orientation that maximises sun hours. Once water has been heated, it is "*... continuously pumped through a closed circuit of pipes running through an insulated jacket. The insulated jacket surrounds a tank into which faecal sludge is loaded. The heating system may be semi-automated with temperature sensors measuring the fluid and sludge temperatures and a controller activating a circulation pump accordingly. Safety mechanisms, including pressure relief valves and temperature alarms, should be incorporated into the design to maximize operator safety and to minimize the potential for user error*" The system can be built offsite and assembled in a standard shipping container to facilitate transportation and deployment. The mixture to produce briquettes should be composed by 10-30% wet faecal sludge by mass (Hakspiel, Foote, and J. Parker 2018). Electric boiler and generator (or solar thermal parabolic concentrator), aluminum tanks, pipes, mixer, roller press, wood, metal mesh (Hakspiel, Foote, and J. Parker 2018).
Applicability	The technology is appropriate in a setting with a demand for solid fuel, biomass availability and electricity access. Low relative humidity would speed up the drying process. Time of implementation has been estimated in 3 months for feasibility assessment, 6-9 months for facility construction and 3 months for stabilisation of operations.
Operation and Maintenance	To assure thermal sanitisation of faecal sludge, minimum two temperature probes should be placed in the tank and calibrated at least once a year (Hakspiel, Foote, and J. Parker 2018). Wet pressed briquettes are distributed in drying racks for 3 days; on rainy days the racks should be covered with plastic. Indoor drying is a possibility, however the process energy intensity would increase considerably (Sanivation 2019). Dried briquettes should pass a quality control test measuring burn time, water boiling time, and resistance to breaking when dropped from a height of 1 meter (Hakspiel, Foote, and J. Parker 2018).
Health and Safety	Basic hygiene recommendations and provide appropriate protective equipment (e.g. gloves, facemask, boots), hygiene stations, and training (World Health Organization 2016). Faecal sludge should be treated until the standards for reuse set by WHO (2006) are met.

Table 7 continues in the next page

Continuation of Table 7	
Aspects	**Features**
Costs	Capital: Treatment tank, mixer, roller press, and drying beds (53500 USD for a system with the capacity of treating 15 tons of FS and producing 40 tons of briquettes per month). Operational: labour, fuel for electricity, carbonised biomass, and personal protection equipment (42500 USD/yr for a system treating 7.5 tons of FS and producing 20 tons of briquettes per month) (Hakspiel, Foote, and J. Parker 2018).
Social Considerations	Smell may be unpleasant for people in the vicinity of the treatment. Handle products made from faeces may be harder to accept in certain cases, due to cultural beliefs. Product may compete with traditional charcoal and affect the livelihood of the local population (Hakspiel, Foote, and J. Parker 2018).
Natural Resources Management	Water may be required to achieve appropriate mixture consistency before compression. Electricity is needed to support the boiler and for pumping, mixing, and pressing. Several metallic structures, and electric and electronic equipment is required. Energy recovery is achieved when briquettes are used, with typical calorific values between 17-25 MJ/kg (Asamoah et al. 2016)
Environmental Impacts	Pre-treatment screening sludge may be produced. Depending on the energy source for electricity, the system could have associated GHG emissions. Charcoal dust and sawdust used as additional materials is usually a waste stream of the charcoal and wood industry (Sanivation 2019). When such industries are not in place, the demand of charcoal dust or sawdust for briquettes may encourage deforestation, however they can be replaced by agricultural waste.
Institutional and Regulatory	Briquettes standard or certifications, if existent in the country. Regulations against deforestation for charcoal production are favourable for this technology (Asamoah et al. 2016). Environmental impact assessment may be required by local government (Sanivation 2019).
Business Opportunities	Production would rely strongly on the reliability of the supply chain. Fees can be charged for treating the faecal sludge and more revenues can be generated by selling the briquettes to households or industries. Briquettes are sold at US$0.20 per kg (Hakspiel, Foote, and J. Parker 2018). Briquettes may be given for free if a relief agency/donor is paying their cost but a market approach helps towards reaching financial sustainability at the recovery phase (Sanivation 2019).
Strengths and weaknesses	Strengths: Low residence time, Energy recovery, Additional revenue, Job creation (Hakspiel, Foote, and J. Parker 2018). Weakness: Energy intensive, imported equipment, relatively high capital investment, land required for drying, dependent on weather conditions, uncertainties about deforestation reduction when no charcoal dust is available.

5 Final Remarks

Beyond ensuring survival and providing the basic needs to populations in emergency settings, a more systemic vision for relief agencies to WASH challenges could lead to design of sustainable sanitation chains contributing to key challenges such as energy or food demand. Approaches such as SRC Green Response targeting a reduced environmental impact in humanitarian response turn to include emphasis on resource recovery sanitation technologies and related sustainable practices for adapting emergency planning to outreaching stress on necessary resources while providing safe and functioning sanitation solutions.

Universalized sanitation systems largely provided with the emergency provision packages have been proved not being efficient and relevant since the chain has to be designed considering the specificity of each context (socio-cultural, environmental, geographical, security...).

The success of a treatment process is highly dependent to the appropriateness and performance of the complementary features and early steps in the entire sanitation chain. Thus a better systemic considerations of sanitation challenges as an entire system are necessary.

The literature review that has been performed in this project highlight a gap in scientific literature to the review on such approaches at the implementation level (pilot projects, socio-economic studies...).

TAD, BSF and SFP remain emerging technologies and adaptation of these sanitation solutions to emergency settings are in early development stages. The implementation feasibility and suitability of these treatment technologies in crisis context need to be explored through more field testing.

References

A2T (2018a). Personal Communication.
— (2018b). “A2T Workshop Presentation, 15/10/2018”. Workshop presentation support material.
Andersson, K. et al. (2016). *Sanitation, Wastewater Management and Sustainability: from Waste Disposal to Resource Recovery.* United Nations Environment Programme and Stockholm Environment Institute. ISBN: 978-92-807-3488-1. URL: https://mediamanager.sei.org/documents/Publications/SEI-UNEP-2016-SanWWM&Sustainability.pdf.
Asamoah B.and Nikiema, J. et al. (2016). *A review on production, marketing and use of fuel briquettes.* Tech. rep. DOI: 10.5337/2017.200. URL: http://www.iwmi.cgiar.org/Publications/wle/rrr/resource_recovery_and_reuse-series_7.pdf.
Asian Development Bank (2016). *Country Water Assessment.* Asian Development Bank. ISBN: 978-92-9257-361-4. URL: https://www.adb.org/documents/indonesia-country-water-assessment.
Atwijukye, O. et al. (2018). “Low cost faecal sludge dewatering and carbonisation for production of fuel briquettes”. In: *Proceedings for the 41st WEDC International Conference.* Egerton University. Water, Engineering and Development Centre.
Banks, IJ (2014). “To assess the impact of black soldier fly (Hermetia illucens) larvae on faecal reduction in pit latrines”. uk.bl.ethos.617786. PhD thesis. London School of Hygiene & Tropical Medicine. DOI: 10.17037/PUBS.01917781. URL: http://researchonline.lshtm.ac.uk/1917781/.
Bartkowska, Izabela (2017). “DROP IN CONDUCTIVITY OF SEWAGE SLUDGE IN THE PROCESS OF AUTOTHERMAL THERMOPHILIC AEROBIC DIGESTION”. In: *Journal of Ecological Engineering* 18.4, pp. 67–75. DOI: 10.12911/22998993/74280. URL: http://dx.doi.org/10.12911/22998993/74280.
Dortmans B.and Diener, S., B. Verstappen, and C. Zurbrügg (2017). *Black Soldier Fly Biowaste Processing: A Step-by-Step Guide.* Tech. rep. URL: https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/publikationen/SWM/BSF/BSF_Biowaste_Processing_LR.pdf (visited on 10/11/2018).
Gensch, R. et al. (2018). *Compendium of Sanitation Technologies in Emergencies.* German WASH Network (GWN), Swiss Federal Institute of Aquatic Science, Technology (Eawag), Global WASH Cluster (GWC), and Sustainable Sanitation Alliance (SuSanA). ISBN: 978-3-906484-68-6. URL: https://www.susana.org/_resources/documents/default/3-3145-7-1523526949.pdf.
Gold, M., M. Cunningham, et al. (2018). “Operating parameters for three resource recovery options from slow-pyrolysis of faecal sludge”. In: *Journal of Water, Sanitation and Hygiene for Development,* washdev2018009. DOI: 10.2166/washdev.2018.009. eprint: /iwa/content_public/journal/washdev/pap/10.2166_washdev.2018.009/3/washdev2018009.pdf. URL: http://dx.doi.org/10.2166/washdev.2018.009.
Gold, M., Daniel Isaac Waya Ddiba, et al. (2017). “Faecal sludge as a solid industrial fuel: a pilot-scale study”. In: *Journal of Water, Sanitation and Hygiene for Development* 7.2, p. 243. DOI: 10.2166/washdev.2017.089. eprint: /iwa/content_public/journal/washdev/7/2/10.2166_washdev.2017.089/2/washdev0070243.pdf. URL: http://dx.doi.org/10.2166/washdev.2017.089.
Gold, Moritz et al. (2018). “Decomposition of biowaste macronutrients, microbes, and chemicals in black soldier fly larval treatment: A review”. In: *Waste Management* 82, pp. 302–318. ISSN: 0956-053X. DOI: https://doi.org/10.1016/j.wasman.2018.10.022. URL: http://www.sciencedirect.com/science/article/pii/S0956053X18306408.
Göttert, Dorothee (2016). “A combination of temperature and urea sanitization of blackwater - optimization of a full scale system in Hölö, Sweden”. MA thesis. Swedish University of Agricultural Sciences.
Grange, C. (2016). *WASH in Emergencies Problem Exploration Report: Faecal Sludge Management.* Tech. rep. URL: https://www.susana.org/_resources/documents/default/3-2455-7-1455802974.pdf.
Grover, P.D. and S.K. Mishra (1996). *Biomass briquetting: technology and practices.* Tech. rep. URL: http://www.fao.org/docrep/006/ad579e/ad579e00.pdf (visited on 10/11/2018).
GWC (2016). *GWC Technical WASH Repository ARCHIVE.* URL: http://washcluster.net/gwc-resources.
Hadipuro, Wijanto (2010). “Indonesia’s Water Supply Regulatory Framework: Between Commercialisation and Public Service?” In: *Water Alternatives* 3.
Hakspiel, Diego, Andrew Foote, and Julian Parker (2018). *Container-based Toilets with Solid Fuel Briquettes as a Reuse Product: Best Practice Guidelines for Refugee Camps.* Tech. rep. URL: http:

//wash.unhcr.org/download/container-based-toilets-with-solid-fuel-guidelines/ (visited on 10/11/2018).
Halalsheh, Maha Mohammad et al. (2011). "Biodegradation and seasonal variations in septage characteristics". In: *Environmental Monitoring and Assessment* 172.1, pp. 419–426. ISSN: 1573-2959. DOI: 10.1007/s10661-010-1344-4. URL: https://doi.org/10.1007/s10661-010-1344-4.
Harvey, Paul (2007). *Excreta Disposal in Emergencies: A Field Manual.* Tech. rep. URL: https://www.unicef.org/cholera/Chapter_9_community/19_Interagency-Excreta_disposal_in_emergencies.pdf.
Humanitarian Learning Center (2018). "Menstrual Hygiene Management in Humanitarian Emergencies". In:
IASC (2015). *Guidelines for Integrating Gender-Based Violence Interventions in Humanitarian Action: Water, Sanitation and Hygiene.* Tech. rep. URL: https://gbvguidelines.org/wp/wp-content/uploads/2015/09/TAG-wash-08_26_2015.pdf.
IFRC (2017). *WASH guidelines for hygiene promotion in emergency operations.* Tech. rep. URL: https://ifrcwatsanmissionassistant.files.wordpress.com/2018/10/1319400-ifrc-wash-guidelines-for-hygiene-promotion-in-emergency-operations_final.pdf.
— (2018a). *Addressing menstrual hygiene management (MHM) needs.* Tech. rep.
— (2018b). *GREEN RESPONSE Snapshot.*
Indonesia - Country fact sheet on food and agriculture policy trends (2017). Tech. rep. Food and Agriculture Organization of the United Nations. URL: http://www.fao.org/3/a-i7696e.pdf.
IPCC (2018). *Impacts of 1.5 deg C global warming on natural and human systems. In: Global warming of 1.5 deg C.* Tech. rep. Authors: O. Hoegh-Guldberg and D. Jacob and M. Taylor and M. Bindi and S. Brown and I. Camilloni and A. Diedhiou and R. Djalante and K. Ebi and F. Engelbrecht and J. Guiot and Y. Hijioka and S. Mehrotra and A. Payne and S. I. Seneviratne and A. Thomas and R. Warren and G. Zhou. URL: https://www.ipcc.ch/sr15/chapter/chapter-3/.
Jang, Hyun Min et al. (2014). "Influence of thermophilic aerobic digestion as a sludge pre-treatment and solids retention time of mesophilic anaerobic digestion on the methane production, sludge digestion and microbial communities in a sequential digestion process". In: *Water Research* 48, pp. 1–14. ISSN: 0043-1354. DOI: https://doi.org/10.1016/j.watres.2013.06.041. URL: http://www.sciencedirect.com/science/article/pii/S0043135413005320.
JMP (2015). *Country Data.* https://washdata.org/data. Accessed: 2018-10-08.
Joly, Gabrielle (2018). *Valorising Organic Waste using the Black Soldier Fly (¡em¿Hermetia illucens¡/em¿), in Ghana.* eng. KTH, Skolan för arkitektur och samhällsbyggnad (ABE), Hållbar utveckling, miljövetenskap och teknik.
Jones, Hazel and Bob Reed (2005). *Water and Sanitation for Disabled People and Other Vulnerable Groups; Designing services to improve accesibility.* Tech. rep. URL: https://wedc-knowledge.lboro.ac.uk/details.html?id=16357.
Kindstedt, Katherine (2012). "The Application of Ecological Sanitation for Excreta Disposal in Disaster Relief: Experience, Selection and Design". MA thesis. Institute of Wastewater Management and Water Protection at the Technical University of Hamburg-Harburg.
Kung, K. et al. (2013). "Low-Cost Production of Charcoal Briquettes from Organic Waste". In: URL: http://web.mit.edu/~kkung/Public/paper.pdf (visited on 11/15/2018).
Lalander, Cecilia (2019). Personal Communication.
Lalander, Cecilia et al. (2013). "Faecal sludge management with the larvae of the black soldier fly (Hermetia illucens) — From a hygiene aspect". In: *Science of The Total Environment* 458-460, pp. 312–318. ISSN: 0048-9697. DOI: https://doi.org/10.1016/j.scitotenv.2013.04.033. URL: http://www.sciencedirect.com/science/article/pii/S0048969713004555.
Layden, Noreen M. et al. (2007). "Autothermal thermophilic aerobic digestion (ATAD) — Part I & II". In: *Journal of Environmental Engineering & Science* 6.6, pp. 665–690. ISSN: 14962551. URL: https://ezp.sub.su.se/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=28751039&site=ehost-live&scope=site,%20https://ezp.sub.su.se/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=28751030&site=ehost-live&scope=site.
Liu, Shugen, Nanwen Zhu, and Loretta Y. Li (2011). "The one-stage autothermal thermophilic aerobic digestion for sewage sludge treatment". In: *Chemical Engineering Journal* 174.2, pp. 564–570. ISSN: 1385-8947. DOI: https://doi.org/10.1016/j.cej.2011.09.043. URL: http://www.sciencedirect.com/science/article/pii/S1385894711011016.

Lohri, Christian Riuji, Stefan Diener, et al. (2017). "Treatment technologies for urban solid biowaste to create value products: a review with focus on low- and middle-income settings". In: *Reviews in Environmental Science and Bio/Technology* 16.1, pp. 81–130. ISSN: 1572-9826. DOI: 10.1007/s11157-017-9422-5. URL: https://doi.org/10.1007/s11157-017-9422-5.

Lohri, Christian Riuji, Imanol Zabaleta, et al. (2018). "Improving the Energy-Related Aspects of Biowaste Treatment in an Experimental Hydrothermal Carbonization Reactor". In: *Waste and Biomass Valorization* 9.3, pp. 429–442. DOI: 10.1007/s12649-016-9746-3. URL: https://doi.org/10.1007/s12649-016-9746-3.

Malmén, L., O. Palm, and E. Norin (2004). "A collection and treatment system for organic waste and wastewater in a sensitive rural area". In: *Water Science and Technology* 48.11-12, p. 77. DOI: 10.2166/wst.2004.0808. eprint: /iwa/content_public/journal/wst/48/11-12/10.2166_wst.2004.0808/3/77.pdf. URL: http://dx.doi.org/10.2166/wst.2004.0808.

Martín, M.A. et al. (2018). "Application of ATAD technology for digesting sewage sludge in small towns: Operation and costs". In: *Journal of Environmental Management* 215, pp. 185–194. ISSN: 0301-4797. DOI: https://doi.org/10.1016/j.jenvman.2018.03.062. URL: http://www.sciencedirect.com/science/article/pii/S0301479718302950.

Mutsakatira, E., C. A. Buckley, and S. J. Mercer (2018). "Potential use of the black soldier fly larvae in faecal sludge management: a study in Durban, South Africa". In: *Proceedings for the 41st WEDC International Conference*. Egerton University. Water, Engineering and Development Centre.

Nordin, A., D. Göttert, and B. Vinnerås (2018). "Decentralised black water treatment by combined auto-thermal aerobic digestion and ammonia – A pilot study optimising treatment capacity". In: *Journal of Environmental Management* 207, pp. 313–318. ISSN: 0301-4797. DOI: https://doi.org/10.1016/j.jenvman.2017.10.064. URL: http://www.sciencedirect.com/science/article/pii/S0301479717310617.

Nordin, Annika (2019). Personal Communication.

Nordin, Annika C. and Björn Vinnerås (2015). "Sanitising black water by auto-thermal aerobic digestion (ATAD) combined with ammonia treatment". In: *Water Science and Technology* 72.12, p. 2112. DOI: 10.2166/wst.2015.432. eprint: /iwa/content_public/journal/wst/72/12/10.2166_wst.2015.432/4/wst072122112.pdf. URL: http://dx.doi.org/10.2166/wst.2015.432.

Oxfam (2005). *Guidelines for Excreta Disposal in Emergencies.* Tech. rep. URL: http://ec.europa.eu/echo/files/evaluation/watsan2005/annex_files/OXFAM/OXF7%5C%20-%5C%20Guidelines%5C%20for%5C%20exceta%5C%20disposal%5C%20in%5C%20emergencies.PDF.

Parker, Wayne and Shonali Laha (2004). "BIOSOLIDS and SLUDGE MANAGEMENT". In: *Water Environment Research* 76.6, pp. 1266–1342. ISSN: 10614303, 15547531. URL: http://www.jstor.org/stable/29763692.

Pineda, Julian (2018). Personal Communication.

Rofi, Abdur, Shannon Doocy, and Courtland Robinson (2006). "Tsunami mortality and displacement in Aceh province, Indonesia." In: *Disasters* 30.3, pp. 340–350. ISSN: 03613666. URL: https://ezp.sub.su.se/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=21784769&site=ehost-live&scope=site.

ROSE Workshop (2018).

Rozich, A.F. and K. Bordacs (2002). "Use of thermophilic biological aerobic technology for industrial waste treatment". In: *Water Science and Technology* 46.4-5, p. 83. DOI: 10.2166/wst.2002.0557. eprint: /iwa/content_public/journal/wst/46/4-5/10.2166_wst.2002.0557/3/83.pdf. URL: http://dx.doi.org/10.2166/wst.2002.0557.

SaniC System presentation (n.d.). Advanced Aerobic Technologies. URL: https://a2t.se/files/pdf/sanic.pdf.

Sanivation (2017). URL: https://www.chivas.com/la-la/the-venture/alumni/2017/ke-sanivation (visited on 11/30/2018).

— (2019). Personal Communication.

SEPA (2003). *Naturvårdsverkets författningssamling (SEPA Statutes book), In: 2003:15.* URL: https://www.naturvardsverket.se/Documents/foreskrifter/nfs2003/nfs2003_15k.pdf.

Social Factors Impacting Use of EcoSan in Rural Indonesia (2010). Tech. rep. Water and Sanitation Program. URL: https://www.scribd.com/document/122541608/Social-Factor-Impacting-Use-of-Ecosan-in-Rural-Indonesia.

Sphere (2018). *The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response.* Fourth edition. Sphere Association. ISBN: 978-1-908176-707. URL: www.spherestandards.org/handbook.

Telge Nät The Federation of Swedish Farmers - LRF, SLU Uppsala (2014). *The Södertälje Model Recycling of housing sewages*. Youtube. URL: https://www.youtube.com/watch?v=HHlR4zIOMuw.

Tidåker, P., C. Sjöberg, and H. Jönsson (2007). "Local recycling of plant nutrients from small-scale wastewater systems to farmland—A Swedish scenario study". In: *Resources, Conservation and Recycling* 49.4, pp. 388–405. ISSN: 0921-3449. DOI: https://doi.org/10.1016/j.resconrec.2006.05.004. URL: http://www.sciencedirect.com/science/article/pii/S0921344906001248.

UNHCR (n.d.). *Emergency Situations*. http://www.unhcr.org/. Accessed: 2018-10-08.

USEPA (1994). *A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge, 40 CFR Part 503*. URL: https://nepis.epa.gov/Exe/ZyPDF.cgi/20004007.PDF?Dockey=20004007.PDF (visited on 11/13/2018).

WHO (2006). *GUIDELINES FOR THE SAFE USE OF WASTEWATER, EXCRETA AND GREYWATER*. Vol. 4. ISBN: 92 4 154685 9. URL: https://www.who.int/water_sanitation_health/publications/gsuweg4/en/.

— (2018). *Guidelines on sanitation and health*. World Health Organization. ISBN: 978-92-4-151470-5. URL: http://apps.who.int/iris/bitstream/handle/10665/274939/9789241514705-eng.pdf?ua=1.

World Health Organization (2016). *Sanitation safety planning: Manual for safe use and disposal of wastewater, greywater and excreta*. Tech. rep. URL: https://www.who.int/water_sanitation_health/publications/ssp-manual/en/.

Zakaria, F. et al. (2015). "Decision support system for the provision of emergency sanitation". In: *Science of The Total Environment* 512-513, pp. 645–658. ISSN: 0048-9697. DOI: https://doi.org/10.1016/j.scitotenv.2015.01.051. URL: http://www.sciencedirect.com/science/article/pii/S0048969715000662.

Appendix A Literature Review Methodology

This section specifies the methods and strategies followed to develop the literature review about the three resource-oriented treatment technologies.

A.1 Search questions composition

Determination of open-framed questions gave key elements to look at in articles and helped narrowing down the search from general queries for technological and technical understandings to more accurate searches focusing on the study interests.

Based on the aspects and criteria presented in Table 3 and Table 2, the literature review has been framed around the following search questions:

- What are the main technological features of each treatment solution?
- What considerations are relevant/key when implementing each technology?
- What are the inputs & outputs characteristics?
- What are the terminology disparities for each technology?
- Where has this technology been implemented, at what scale?
- Has this technology already being used in emergency settings?

A.2 Sources

To answer the search questions, secondary data was collected from peer-reviewed journals in academic databases (i.e. Scopus and Web of Science), WASH practitioners repositories (e.g. SuSanA Library, EAWAG) and relief agencies WASH resources (e.g. by UNHCR and IFRC). The searches were was limited to the English language and performed between September and December 2018.

A.3 Search strategy

The search strategy was based on a step-by-step, systematic literature review. The first step aimed at understand the general principles of each technology (even treating different organic waste streams), the second step dug into experiences where faecal sludge was the input and the final step explored whether the technology has been implemented in emergency settings.

For each of this steps different search strings were used in the databases based on common search terms. The search terms and strings, and the number of hits obtained are presented in Table 8.

Technology overview with general query

As a first step, a general query provides a first overview on the technology. After narrowing down quickly through a title screening, articles are briefly explored with the aim of having a better general understanding of the technology key features and design considerations.

The different input possibilities (material entering the treatment system) are faced and give an idea of the technology flexibility.

Since the technology reviewed are quite emerging, terminology is not necessarily well established and several denomination are tried during this general query.

Finally, this first phase allows the variety of literature not being adequate to look at for the present study. Thus the literature review limits are defined combining the panel of different features for a technology, adequacy of these features for emergency settings and the amount of available literature.

Technology applied to the relevant waste streams

The most relevant way to narrow down the search and increase results appropriateness to faecal sludge management in emergency settings has been to focus on a particular input stream.

Indeed, the review is focusing on technologies as a sanitation solution. Including search terms as "Faecal Sludge" or "Blackwater" limits getting articles on technologies used in, for instance, solid wastes, other organic wastes or drinking water treatment processes i.e.

Results at this second review level usually give results in which the technical aspects can be directly explored for each technology.

The number of hits in step 2 compare to the number of hits in step 1 might also give a good idea of the well-spreading or outreach of this technology in sanitation domain.

Technology applied to emergency settings

A second-bis phase in the literature review has been to look at the possible existing experiences or studies on application of the studied technologies in emergency settings.

Table 8: Literature Search

Research step	**Search String**	**Database**	**Hits**
	Black Soldier Fly		
1	Black Soldier Fly	Scopus	247
	Black Soldier Fly	Web of Science	233
2	Black Soldier Fly AND (Sanitation OR "F*cal Sludge")	Scopus	6
	Black Soldier Fly AND (Sanitation OR "F*cal Sludge")	Web of Science	4
3	Black Soldier Fly AND (Emergency OR Humanitarian OR Camp)	Scopus	0
	Black Soldier Fly AND (Emergency OR Humanitarian OR Camp)	Web of Science	0
	Solid Fuel Production		
	Solid Fuel F*cal Sludge	Scopus	17
	F*cal Sludge AND (Briquette or Pellet)	Scopus	23
	Solid Fuel F*cal Sludge	Web of Science	14
	F*cal Sludge AND (Briquette or Pellet)	Web of Science	7
	Thermophilic Aerobic Digestion		
1	Thermophilic Aerobic Digestion NOT autothermal	Web of Science	268
	Thermophilic Aerobic Digestion AND NOT autothermal	Scopus	284
	Thermophilic Aerobic Digestion	SuSanA Library	1
	Autothermal Thermophilic Aerobic Digestion	Scopus	123
	Autothermal Thermophilic Aerobic Digestion	Web of Science	95
2	Thermophilic Aerobic Digestion Sanitation	Scopus	9
	Thermophilic Aerobic Digestion Sanitation	Web of Science	5
	Thermophilic Aerobic Digestion AND "F*cal Sludge"	Scopus	26
	Thermophilic Aerobic Digestion AND 'F*cal Sludge'	Web of Science	17
	Thermophilic Aerobic Digestion AND Blackwater	Scopus	25
	Thermophilic Aerobic Digestion AND Blackwater	Web of Science	0
	Liquid Composting AND ("F*cal Sludge" OR Blackwater)	Scopus	7

Table 8 continues in the next page

Continuation of Table 8			
Research step	**Search String**	**Database**	**Hits**
	Liquid Composting AND ('F*cal Sludge' OR Blackwater)	Web of Science	13
3	Thermophilic Aerobic Digestion AND (Emergency OR Humanitarian OR Camp)	Google Scholar	133
	Thermophilic Aerobic Digestion AND (Emergency OR Humanitarian OR Camp)	Scopus	2
	Thermophilic Aerobic Digestion AND (Emergency OR Humanitarian OR Camp)	Web of Science	0

A.4 Data extraction

To collect in a systematic way the relevant information found, a two-column table template was designed. The first column included the aspects outlined in Table 3 and the second column provided space to describe the aspects' features. Pertinent data was retrieved by filling the second column. One table template was used for each technology and the results of the literature review are presented in section 3.

Appendix B Workshop

A workshop has been led at SEI's office, Stockholm, with the aim of collecting information about experts experiences linked to different technologies, specific knowledge of technical characteristics, and their regard on the implementation process of these solutions in emergency or similar settings. The list of participants is presented in Figure 5.

The workshop contained two main parts. The first one was a presentation from the WASH practitioners, while the second part consisted in group activities to analyze appropriateness of the chosen technologies in different context scenarios. The complete agenda is presented in Figure 6.

Scenarios

We have selected scenarios aiming to picture different emergency situations. Thus, different environmental, social and geographical, as well as different types of crisis and camps structure has been chosen. Our focus went on two realistic scenarios based on beginning October 2018 situations in Al-Zaatari refugee camp, Jordan, and facing the crisis at that time in North Sulawesi Island, Indonesia, where a disaster triggered in late September 2018.

Group discussions led to the choice of focusing on the Indonesian scenario (developed in Table 9) as being a relevant up-to-date and concrete context. This case is interesting to look at for the numerous challenges to the design of sanitation solutions (especially the flooding hazard).

In the workshop, emphasis have been put on building chains based on a core technology selected for group works to study. Selection of the relevant parameters have been done for composition and evaluation of sanitation chains suitable for the Indonesian scenario context.

Table 9: Indonesia Scenario, ROSE Workshop, October 2018

Context	
Type of crisis	Natural hazard disaster relief (Earthquakes, Tsunami)
Geographical location	Indonesia, North Sulawesi Island, Capital: Palu, 335 000 inhabitants
Urban/rural settlement	Urban settlement
Amount of people affected	70 000 temporary refugees in 141 locations at that time (UNHCR n.d.)
Seasonal climate	Rainy season between December and March (Asian Development Bank 2016)
Emergency project characteristics - Set for the Workshop activity	
Amount of people in the camp	10 000 persons
Density	Highly dense area
Estimated lifespan of the camp	2 years
Relevant site conditions	
Water availability	Abundant (Asian Development Bank 2016, Hadipuro 2010)
Land availability	Limited space for both on-site and off-site management (Set)
Soil characteristics	Excavation is possible (Set)
Groundwater table/quality	Groundwater table approx at 5m, top groundwater layer and shallow water is contaminated, undrinkable without treatment (Set based on Asian Development Bank 2016)
Surface water drainage	Risks for flash floods in the rainy season (Set)
Accessibility (emptying trucks)	Partly limited access (Set)
Energy access	Connection to electricity grid (Set)
Landfill/ Discharge regulations	Unknown national regulations for pathogens content of discharging wastewater and compost application
Locally available materials (nearby)	Debris, charcoal, sand (cement), wood (tropical rain forest nearby) (Set)
Internal logistics	Good connection to closest airports/ harbor; most equipment may be shipped to cities then spread in camps (Set)
Agricultural activities	Predominant agricultural activities (more than 50% working force), growing mainly Paddy Rice, Coffee, Coconut, Cacao, Clove, Maize, Fishing in Rivers Channels and Lakes, Fishponds (based on *Indonesia - Country fact sheet on food and agriculture policy trends* 2017)
Relevant socio-cultural conditions	
Sanitation preferences	Predominantly washers (*Social Factors Impacting Use of EcoSan in Rural Indonesia* 2010)
Sanitation coverage before emergency	URBAN: 5.47%OD, 2.47% unimproved, 14.79% limited, 77.26% basic RURAL 20.56%OD, 8.04% unimproved, 14.40% limited, 57.00% basic (JMP 2015)
Average household composition	4.4 persons per household according to Rofi, Doocy, and Robinson 2006 on a similar setting
Cooking practices	High use of charcoal as stove fuel (Set)
Willingness to reuse compost/waste	According to *Social Factors Impacting Use of EcoSan in Rural Indonesia* 2010, in rural settings more than 80% of the respondents are willing to use a urine or feces-based fertilizer, but only 50% of respondents were willing to process the urine and feces themselves to make compost.

ROSE Workshop participants
15/10/18

Organisation	Name
A2T	Tord Söderberg
A2T	Gösta Andersson
SLU	Annika Nordin
WRS Uppsala	Maja Granath
RC	Caroline Gårdestedt
RC	Chelsea Giles-Hansen
RC	Patrick Fox
RC	Malin Denninger
RC	Sara Andersson
SEI	Kim Andersson
SEI	Sarah Dickin
SEI	Daniel Ddiba
SEI	Axel Wurtz
SEI	Jairo Mosquera
SEI	Kristoffer Westman
Online participants	
Sanivation	Catherine Berner
Sanivation	Emily W
EAWAG/SLU	Christopher Friedrich

Figure 5

RödaKorset

SEI Stockholm Environment Institute

ROSE Workshop
(Resource-oriented sanitation in Emergencies)

Oct 15, 2018

Venue: Stockholm Environment Institute, Linnégatan 87D, Stockholm

WORKSHOP AGENDA

10:00	Welcome and Introduction to the Workshop - SRC/SEI
10:15	Introduction to Sanitation in Emergency Camps - SRC
10:35	Emerging technologies: Effective Microorganisms – WRS
10:50	Fika
11:05	Emerging technologies: Wet-Composting/Urea – A2T
11:20	Emerging technologies: Black Soldier Fly – SLU
11:35	Emerging technologies: Solid Fuel Production – Sanivation
11:50	Introduction to group exercise *Exercise: We will construct potential sanitation service chains around resource-recovery technologies and screen their feasibility in different emergency setting. We will be divided in groups, which assignment rotates to enable inputs from participants on all the selected technologies.*
12:00	Group work (Part 1) *Each group will build a sanitation chain around one of the technologies appropriate for one of the scenarios.*
12:30	Lunch
13:10	Group work (Part 2) *Each group will build a sanitation chain around another technology appropriate for a new scenario.*
13:30	Group work (Part 3) *Each group will evaluate some of the previously built sanitation chains considering sustainability criteria.*
14:00	Fika
14:10	Presentations and discussion of group work results
14:50 – 15:00	Concluding remarks

Figure 6

Results

Figure 7 is a summary of the chain possibilities discussed during the workshop. Note that the outcomes of the workshop activities are detailed in the supplementary material ROSE.ppt.

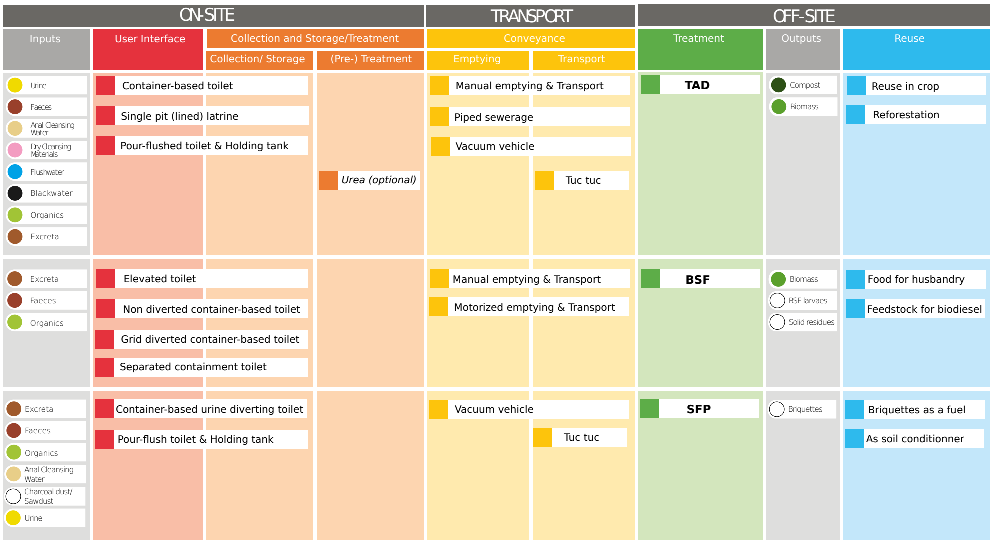

Figure 7