WATER GLOBAL PRACTICE

Safely Managed Sanitation in High-Density Rural Areas

Turning Fecal Sludge into a Resource through Innovative Waste Management

Joep Verhagen and Pippa Scott

WORLD BANK GROUP

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Part 1

Summary Report

Chapter 1 Introduction—Background and Context

"A safe sanitation system is a system designed and used to separate human excreta from human contact at all steps of the sanitation service chain from toilet capture and containment through emptying, transport, treatment (in-situ or offsite) and final disposal or end use. Safe sanitation systems must meet these requirements in a manner consistent with human rights, while also addressing co-disposal of greywater, associated hygiene practices and essential services required for the functioning of technologies." (WHO 2018)

Fecal sludge has been around since the dawn of humankind, and farmers have long recognized its value. But if not safely managed, it can enter the environment in ways that pose serious risks to human and environmental health—as well as human development. Fecal sludge management is a growing problem in rural areas, especially those that are densely populated. However, the problem is rarely addressed because the focus of rural sanitation policies has predominantly been on ending open defecation.

Safely managed sanitation is a focus of the Sustainable Development Goals (SDGs) and central to stunting and early childhood survival, both identified by the World Bank's Human Capital Index (HCI) as critical for humans to develop their full potential. As per the Joint Monitoring Programme (JMP), 4.5 billion people lacked access to safely managed sanitation in 2015.

Meanwhile, climate change and the growing momentum toward a circular economy are providing impetus for efforts to turn fecal sludge into a resource. Waste management and recycling are areas of tremendous innovation around the world: Emerging solutions could become economically viable for fecal sludge with the right support from public and private sectors, including a conducive regulatory environment. While solutions will always need to reflect local contexts, there is considerable scope for learning and cross-fertilization of ideas among waste entrepreneurs in upper-middle-income and low-income economies.

Reference

WHO (World Health Organization). 2018. *Guidelines on Sanitation and Health*. Geneva: World Health Organization.

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Chapter 2 Methods

Aims and Scope

This report explores the challenges of fecal sludge management (FSM) in densely populated rural areas. It presents some typical current practices, examples of financially sustainable FSM services, and global innovations in waste management with potential replicability for FSM. Its aim is to promote dialogue on how to move from the Millennium Development Goals' approach to rural sanitation—effectively, building toilets—to the Sustainable Development Goals' approach: safely managed sanitation systems.

The paper focuses on high-density rural areas because they pose particular challenges: typically, they are traditionally rural areas in which population numbers have swelled. Sanitation technologies that may well work in more sparsely populated areas become less viable when usage increases and space becomes more of a constraint. Traditional FSM systems have not evolved to meet the needs of this growing population.

The paper is based on a desk-based literature review and key informant interviews with sector experts exploring the four research questions summarized in figure 2.1. It presents 18 cases strategically selected to showcase diverse rural FSM issues and potential directions of travel, but do not aim to be exhaustive. In any particular locality, the feasibility of replicating particular business models will depend on contextual factors that are beyond the scope of this review.

High-Density Rural Areas

Although the terms *rural* and *urban* are often used as a dichotomy, in reality there is a continuum—as illustrated by table 2.1, which explains the areas covered in this study. High-density rural areas tend to fall between small towns and rural villages on the

FIGURE 2.1. Objectives and Outputs of Study

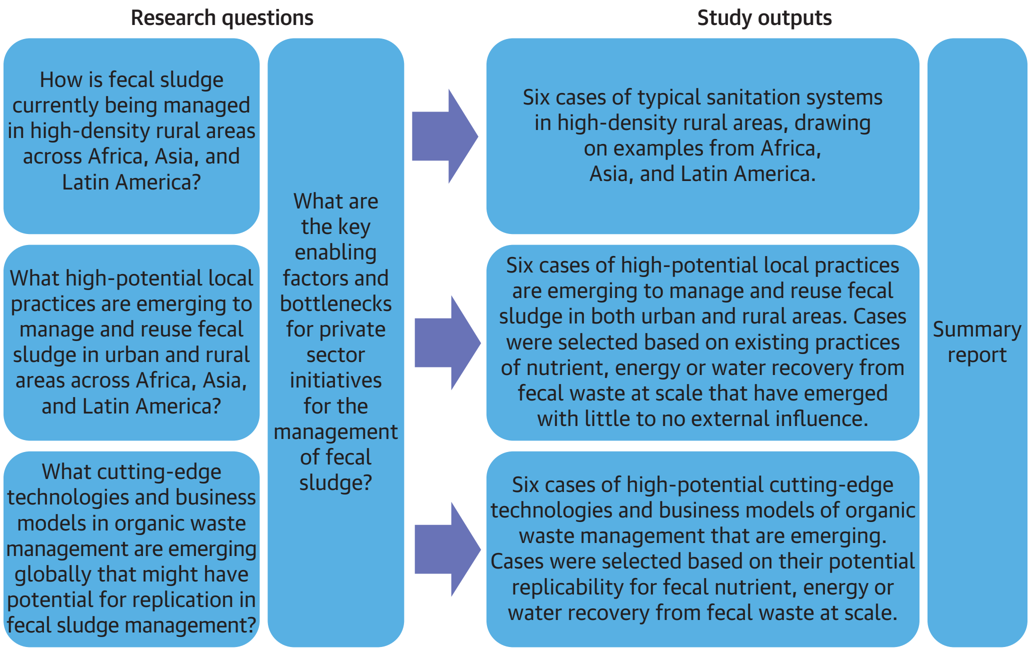


TABLE 2.1. Land Occupation Patterns and Definitions

Description	Characteristics	OECD term	Included in study?	Case study example (chapter)
Prime and secondary cities	Predominantly rural nations with a small population that may have only one important city, while others will have many.	Urban	No	n.a.
Peripheral urban areas	Areas located around primary and secondary cities, often economically linked but with a separate—often weaker—government, and worse water supply and sanitation provisions.	Predominantly urban area[a]	✓	Bolivia (11)
Broad range of urban centers	Small towns, capitals of agricultural districts, clusters along roads or between larger urban areas. Diverse in size, growth rate, governance, and classification as "urban" or "rural." Nations with large populations have thousands of them.	Intermediate close to a city[b]; intermediate remote[c]	✓	Bangladesh (7), India (8, 12), Vietnam (9)
Dense village coverage	Multiple villages of several hundred people located near one another.	Intermediate remote; predominantly rural, close to a city[d]	✓	Egypt, Arab Rep. (10)
Villages	Scattered villages and farmsteads in a low-population area.	Rural remote[e]	No	n.a.

Note: n.a. = not applicable; OECD = Organisation for Economic Co-operation and Development.
a. In which more than 85 percent of the local administration units have a population density that exceeds 150 inhabitants per square kilometer.
b. In which between 15 percent and 50 percent of the local administration units have a population density that exceeds 150 inhabitants per square kilometer and no urban center residents (25 percent of total regional population); or with an urban center of 200,000 exceeding 25 percent of the regional population. Fifty percent of the regional population are within one hour's drive of a town with 50,000 inhabitants.
c. In which between 15 percent and 50 percent of the local administration units have a population density that exceeds 150 inhabitants per square kilometer and no urban center exceeding 500,000 residents (25 percent of total regional population); or with an urban center of 200,000 exceeding 25 percent of the regional population. Fifty percent of the regional population are more than one hour's drive of a town with 50,000 inhabitants.
d. In which less than 50 percent of the local administration units have a population density that exceeds 150 inhabitants per square kilometer, and there is no urban center with 200,000 inhabitants exceeding 25 percent of the total regional population. Fifty percent of the regional population are within one hour's drive of a town with 50,000 inhabitants.
e. In which less than 50 percent of the local administration units have a population density that exceeds 150 inhabitants per square kilometer, and there is no urban center of 200,000 inhabitants exceeding 25 percent of the total regional population. Fifty percent of the regional population are more than one hour's drive of a town with 50,000 inhabitants.

rural-urban spectrum. They would typically be classified as “intermediate” or “predominantly rural” areas by the Organisation of Economic Co-operation and Development (OECD), depending on factors such as the regional density of population and proximity to a town.[1] High-density rural areas are typical in areas such as the Indo-Gangetic Plain; the Mekong Delta; the Nile Valley and Delta; Western China; parts of Indonesia, the Philippines, and Thailand; and parts of West Africa (notably around Kano Nigeria and some coastal areas).[2]

Fecal Sludge Management

The term *fecal sludge* technically refers to the fecal solids and urine that accumulate at the bottom of a dry sanitation system (i.e., a pit, tank, or vault in which no water is used for flushing). The term *septage* refers to fecal solids and liquids removed from a pit, tank, or vault in a wet sanitation system (i.e., water is used for flushing) (Tayler 2018). In practice, however, there is often no clear distinction due to the quality of design and construction of sanitation substructures and local soil conditions. This paper follows the current practice of using the term *fecal sludge* to include *septage,* and the abbreviation *FSM* for the overall management of this waste.

Case Examples

The case examples are based on key informant interviews or gray literature. They are not intended to be comprehensive, but to illustrate the challenges of safe sanitation in different high-density rural contexts. They are organized into three series.

Series 1. Each case (chapters 7–12) explores whether FSM is an issue in a particular high-density rural area, and why. Series 1 presents an overview of a typical sanitation technology, and highlights key issues related to design, use, and potential public health risks.

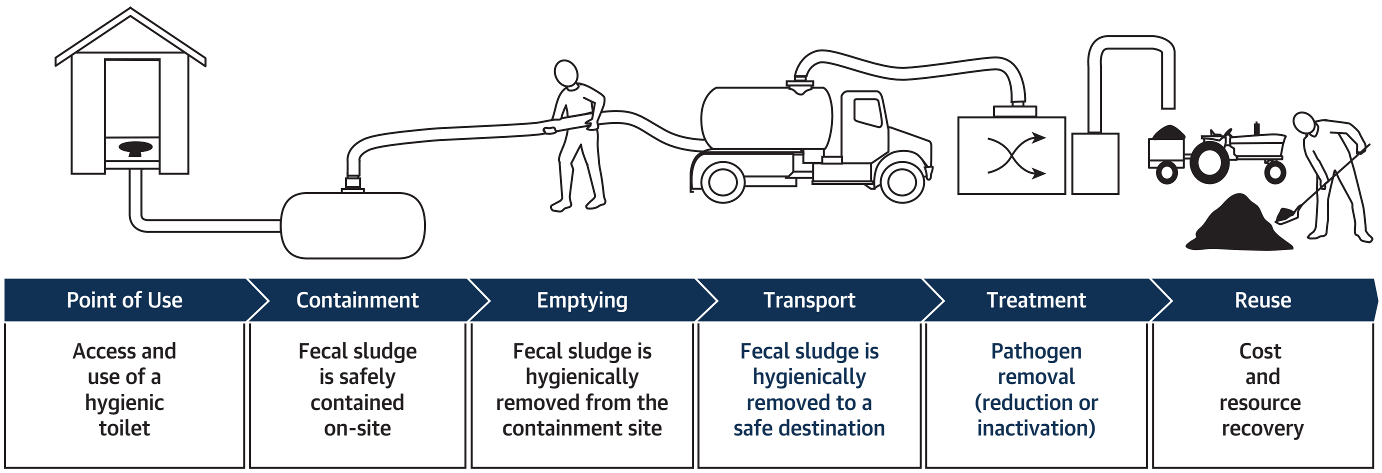
Series 2. Each case (chapters 13–18) explores an entrepreneurial activity related to FSM that has emerged organically, without any external technical or financial support, and is still operating without any form of support. Series 2 describes waste management aspects and explores the potential for scaling or replication in the right conditions, considering limitations and potential enabling actions.

Series 3. Each case (chapters 19–24) explores a waste management innovation that could potentially be applied to FSM. Most of these innovations have reached a level of maturity with other waste streams in upper-middle-income economies and are financially sustainable, though subsidy might have been provided during the initial stages.

Outcome-Based Sanitation Value Chain

In each case, a slightly modified, outcome-based sanitation value chain is used (Scott 2019): the six steps identified in figure 2.2, which start with access to a hygienic toilet and proceed

FIGURE 2.2. Outcome-Based Sanitation Value Chain Framework



through safe treatment of fecal sludge to recovering value from it as a resource. The objectives for each component of the sanitation value chain are informed by WHO (2018):

- For **point of use,** the objective is safe access to and use of sanitation facilities and services for the safe disposal of human urine and feces.
- For **containment,** fecal sludge should not enter the environment. Liquid effluent should either be fully contained for later conveyance or discharged from an impermeable container to a sewer, or to subsoil structures via a soak pit or leach field—not to an open drain or water body.
- For **emptying** and **transport,** the aim is to limit workers' exposure to pathogens, and exposure of locals through inhalation, recreation, drinking water, or the food supply chain.
- For **treatment,** the objective is removing pathogens, or reducing or inactivating them to an acceptable level, depending on the likely exposure of humans.
- For **reuse,** or moving toward a circular economy, the objective is to recover costs or resources from the waste.

Color coding of the figures in chapter 6 and the subsequent case study chapters indicates how well each step achieves the outcomes in each segment: bright blue indicates the outcome is achieved; light blue, partially achieved; gray, not achieved; and no color, not applicable. This categorization is intended to indicate likely scenarios in similar contexts, rather than a definite classification.

Notes

1. The OECD classifies a local administration unit as "rural" if the population is less than 150 inhabitants per square kilometer.
2. High-density rural areas are also termed *desakotas* (McGee 1991) or *ruralopolises* (Qadeer 2000). The OECD defines the rural-urban threshold at 400 persons per square kilometer. Examples are taken from Qadeer (2000).

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Chapter 3 Results

Mismanagement of Fecal Sludge

The first set of case studies (chapters 7 to 12) looks at how fecal sludge is being managed in a typical range of high-density rural locations, typically by sanitation service providers operating informally. In each case, at least one of the six sanitation-chain outcomes is not met, and in many cases, safety is seriously compromised.

POOR DESIGN AND CONSTRUCTION MEETS LACK OF AWARENESS

A case study finds that septic tank owners in Pathar Pratima, West Bengal, like to see the effluent outlet pipe discharging into the drain because they believe this indicates the tank is "working."

On-site sanitation technologies are often compromised, affecting containment and in situ treatment. The studies reveal several examples of unsafe containment (see cases chapters 7 and 8). Sanitation facilities are often poorly constructed and lack fundamental design characteristics, with no or limited rigorous monitoring and enforcement of structural integrity (chapters 7, 8, 11, and 12). This includes significant numbers of on-site sanitation systems that on paper would meet the Sustainable Development Goal definition of "improved." So-called "septic tanks" are often little more than cesspits that discharge directly to the environment. In Pathar Pratima, West Bengal (chapter 8), for example, owners think that effluent discharging from their septic tank is confirmation that it is "working."[1] While there are little quantitative data on the quality of sanitation structures, and verification of underground structures is difficult, this scoping study suggests that many existing facilities are likely to be compromised, with significant implications for public health. for instance, in the Indo-Gangetic Plain, home to 630 million people, large investments would be needed to upgrade all rural sanitation infrastructure to ensure safe management of fecal sludge.

Fecal sludge management (FSM) is not yet recognized as a sanitation sector priority. Behavioral change communications have succeeded in making households aspire to sanitation solutions that are perceived as more "modern," providing personal safety or privacy. A 2017 study by

WaterAid India finds that, as in Pathar Pratima, in India, there seems to be a preference for septic tanks among those aspiring for better toilets. However, behavior change strategies rarely communicate adequately if at all about FSM, which means households do not consider the need to dispose safely of their fecal sludge or the long-term management implications of their household sanitation investments.

Latrines are often emptied by hand, and the contents are dumped locally with no treatment. Outside of urban centers, mechanized emptying, transport, and treatment services are rarely available. Latrines are most commonly emptied manually, either by low-skilled contractors or household members, with little awareness of the risks (chapters 7, 11, and 12). Waste is commonly discharged into the immediate environment, and there is little if any provision for treatment.

Institutional, governance, and administrative capacities are weak. Environment regulation and building codes hardly ever address FSM effectively, and their enforcement is mostly weak. Rural administrations typically lack the mandate and institutional capacity to provide FSM services or to manage procurement, design contracts, enforce regulations, and monitor performance. Households are largely left to their own devices and have little appreciation of the costs and activities required to manage their on-site systems (chapter 11). When households are already bearing costs themselves, the municipality has little economic incentive to assume responsibility.

Markets for FSM services are mostly poorly developed. Lack of regulations, weak enforcement, and limited awareness of the negative impacts of poor FSM have resulted in underdeveloped markets for FSM services. Most FSM services are informal, with unhealthy labor conditions and poor profitability.

Improving quality of construction and operation of on-site sanitation solutions is a relatively low-cost solution. Ongoing communication campaigns can integrate empowering and informing customers to carry out adequate supervision of the construction of their on-site sanitation solutions. For example, adding a second pit or ensuring sufficient depth and distance between pits can be done for relatively little additional cost.

Local Entrepreneurs' Promising but Imperfect Solutions

The second set of case studies (chapters 13 to 18) looks at informal livelihoods centered around FSM services. These services have emerged organically and are financially sustainable, though often they provide only a marginal income, pose significant health risks to the workers, and are socially stigmatized. While there are some good practices, the FSM businesses studied in this section are fragile, with variable incomes, and none manages fecal sludge adequately safely. However, they show that there is market potential for fecal sludge and FSM services that future initiatives could build on.

There is potential for entrepreneurship to scale and establish broader markets for FSM services. Many of these activities are simple, require limited investment, offer limited economic return, deliver imperfect results, and depend highly on local market dynamics.

Nonetheless, they show that FSM entrepreneurship can succeed in the right circumstances, and that agriculture (chapters 13 and 14), aquaculture (chapter 18), and energy (chapter 15) offer potentially robust and scalable outlets for reusing fecal sludge.

The demand for FSM services is driven by convenience and not by safety or environmental concerns. In the case studies, customers are interested only in having fecal sludge removed from their household environment. None of the practices reliably achieve good pathogen inactivation, and economic costs related to the negative health impacts are externalized. Improving the safety of FSM services will inevitably increase consumer costs or reduce the entrepreneurs' income.

Informal, local practices often depend on lack of regulation or enforcement. Most of the services take place in the informal economy, below the radar of regulators. This often allows practices to develop on a small scale, but limits their potential for growth. Stronger regulations on pollution and enforcement thereof could make some of these models financially unviable.

Transactions are typically simple and opportunistic. Household members, emptiers, and farmers establish limited business partnerships, but have no economic incentives to situate themselves in a larger sanitation service chain. Their arrangements are vulnerable to collapse if there is a change in supply, demand, or external circumstances, as with the example of dry vaults in Kabul (chapter 14). More sustainable arrangements are likely to need a brokering agent to align incentives and catalyze coordination among multiple actors.

Potential Application of Cutting-Edge Waste Management Technologies

The third series (chapters 19 to 24) focuses on innovations in waste management and recycling. They include organic waste and wastewater management solutions that are emerging at scale in middle- and upper-income economies and have potential applications for FSM in low-income countries. Some are suitable for dry waste and some for water-based material, so their potential in each locality—and whether they require an additional processing step—will depend on the types of sanitation technologies in place and fecal sludge generated.

Commercially viable waste-to-resource innovations in middle- and upper-income economies tend to be high investment and high return, with niche market products. They are likely to be beyond the technical and financial capacity of the entrepreneurs in low-income countries examined in the case studies. There is scope for business-to-business partnerships between waste entrepreneurs in low- and middle-income and upper-income economies, but these will require investment and government support.

Research and development (R&D). For waste-to-resource innovations to develop into viable business opportunities requires focused R&D at each step—proving the concept, maximizing efficiency gains by optimizing the process, and providing the evidence necessary to de-risk private investment and justify regulatory reform. Human excreta may pose additional technical, health, and social stigma challenges that require more R&D than other organic wastes.

Supportive policy and regulatory frameworks. Sweden, home to the case study on farmers and biofuel (chapter 23), is often cited as an example of how clear policy and regulatory frameworks can support innovation in waste-to-resource technologies and business models, though it took decades of reform to achieve. Policy, regulation, and standards can create incentives, improve safety, raise awareness, and mitigate hazards, while government mandates can create market demand. Examples in Europe include viable feed-in tariffs for producers of renewable energy; obligation certificates (energy producers commit to source renewable energy or pay into an allocated fund); and fiscal concessions and tax exemptions for waste-to-resource activities (such as import or capital gains tax holidays).

Long-term purchase agreements to de-risk investment and drive adoption at scale. The Swedish biofuel (chapter 23) and struvite crystallization (chapter 24) case studies show the benefits of guaranteed purchase agreements, either with the public sector or a private utility company. Public-private partnerships require local government capacity, autonomy, and budget authority to delegate and manage service agreements—which are different from those required for building infrastructure.

Safely mixing fecal sludge into other waste streams is likely to increase complexity and costs. The relatively weak nutritional and calorific value of fecal sludge means it may need to be combined with other waste streams. In some cases this will require revision of existing regulations. It is likely to increase costs, which will need to be absorbed by customers or entrepreneurs, or compensated by public support.

Note

1. Septic tank design stipulates septage should be infiltrated through the soil to be safe.

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WaterAid India. 2017. "Quality and Sustainability of Toilets: A Rapid Assessment of Technologies under Swachh Bharat Mission - Gramin." WaterAid, New Delhi, India.

Chapter 4 Conclusions

Policy and Regulations

Rural fecal sludge management (FSM) is a neglected public health issue. Fecal sludge is commonly discharged or leaks into the environment, posing similar environmental and health risks as that of open defecation. If the cases in this study are typical of high-density rural areas, these risks could affect hundreds of millions of people. Because many rural sanitation programs have focused on the first outcome of the sanitation service chain—access to and use of a hygienic toilet—these risks tend to arise further down the chain. Safely managing sanitation systems throughout their operational lifetime is vital in meeting the Sustainable Development Goals (SDGs) and contributing to the formation of human capital.

Inadequate management of fecal sludge can contribute to antimicrobial resistance by releasing antibiotics into the environment, such as through wastewater (Korzeniewska, Korzeniewska, and Harnisz 2013; Varela et al. 2013). WHO (2018) has identified antimicrobial resistance as one of the greatest global threats to human health, and safe sanitation systems can help to slow its spread.

Addressing safe FSM requires government intervention and support. As costs of unsafe FSM services are externalized, there is a clear mandate for government intervention in the sanitation market:

- Policy and regulatory frameworks and enforcement are mostly still geared toward the Millennium Development Goals and do not address the downstream challenges of meeting the SDGs through safely managed sanitation.
- Rural administrations typically lack sufficient capacity, autonomy, and budgets to provide, regulate, or enforce FSM services by managing service agreements for waste

management, including the design of contracts, procurement, regulation, enforcement, and performance monitoring.

- Governments need to raise awareness of the potential negative health impacts of unsafe FSM.
- Improving the safety of existing FSM services is likely to decrease profit margins of private FSM service providers and potentially render businesses unviable without public support.
- The case for public support to meet the technical challenges of ensuring safe FSM services—whether through subsidy or market concession—is similar to that for networked sanitation.

Practice

Most program and project approaches do not provide long-term and sustainable safely managed sanitation services. Ensuring the long-term, sustainable provision of safely managed sanitation requires FSM to be incorporated into aspects of project or program design that may include behavioral change communication strategies, sanitation technology options, capacity building and awareness raising, and financial and other support to vulnerable groups. This might require revisiting some commonly accepted guidelines.

There are opportunities for incremental improvements for existing FSM practices. Both low- and high-technology opportunities exist to improve the commercial viability of FSM services, potentially enabling them to meet the costs of improving safety. They include reducing haulage and transfer costs through optimized logistics (chapter 22) and dewatering and transfer (chapter 17), and improved designs for pit latrines using low-cost materials. Local-level training may be needed. WHO (2018) recognizes that waste-to-resource FSM entrepreneurs' experience should be built on to reinforce safely managed sanitation.

Business Models

Financially viable and scalable innovations in other organic waste streams may be feasible for FSM. To attract large-scale investment, business cases need to be proven. In any given context, appropriate business models will depend on the type of waste available—which, in turn, depends on the sanitation options in place—and the desired waste-to-resource product, which depends on local market demand. There may be scope to pilot more complex waste-to-resource innovations in middle-income countries with conducive institutional environments. However, scaling up will need to tackle:

- **Pathogen risks and taboo.** Awareness on the health risks of fecal sludge is generally low, and in many localities it is a taboo subject. Livelihoods that involve handling of fecal sludge are often socially stigmatized and pursued due only to lack of any other choice.
- **Low commercial value of fecal sludge.** The relatively weak nutritional and calorific value of fecal sludge compromises potential profitability relative to other waste streams, especially

because costs may be increased by the need for additional processing steps to inactivate pathogens.

- **Knowledge gaps.** Incomplete understanding of fecal pathogens may lead the private sector to prefer other readily available waste sources, such as agricultural, food, or municipal waste.
- **Regulatory environment.** Limiting or obscure regulatory environments are barriers to private sector investment. For example, the ban on feeding processed animal protein to farm animals—an outcome of the bovine spongiform encephalopathy (BSE) cattle outbreak—is negatively affecting the development of using black soldier fly larvae (chapter 19) for FSM in Europe and the United States.
- **Competition and market distortion.** Many potential markets for fecal sludge, such as fishmeal, energy, and fertilizer, are highly competitive and often distorted with subsidy or fiscal support. The relatively low carbon dioxide emission price holds back waste-to-energy products.

Successful sanitation service chains depend on addressing collection and transport costs. Often different entities collect, transport, treat, and recycle fecal waste. In solid waste management, collection and transport costs can take up more than 66 percent of total expenditure in upper-middle-income economies and more than 50 percent in low-income economies. In rural areas, longer distances and lower densities increase the per capita costs, often making these services unaffordable. Solutions may include removing the need for transportation through in situ treatment; reducing the frequency of emptying through better-quality construction of sanitation technologies; and optimizing costs through scheduled emptying in defined areas.

Securing a long-term purchase agreement is critical. Experience from established waste-to-resource practices suggests that viability depends on securing a preidentified customer and establishing guaranteed purchase agreements with a well-defined product and predictable logistics. In mature waste-to-resource market markets, such as in the Netherlands, Germany, and Norway, large-scale private sector entities have emerged after decades of comprehensive policy, regulatory, and fiscal reform. In emerging waste-to-resource markets, municipal authorities can adopt the customer role through concession and purchase agreements, or provide other public funding to de-risk private investment.

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Chapter 5 Recommendations and Ways Forward

Policy Makers

To attain the Sustainable Development Goals' (SDGs') rural sanitation projects, programs and policies should integrate safely managed sanitation by design. Current policy frameworks, regulations, and standard operational procedures are mostly not tailored to deliver sustainable and safe sanitation services to all. For instance, many countries still promote single pit latrines even though they often compromise safety and pose risks to public health.

Fiscal, policy, and regulatory reforms are needed to mitigate investment risks for the private sector. Governments could encourage private sector players to enter the rural fecal sludge management (FSM) market through **fiscal incentives** that have proved effective in countries such as Sweden (e.g., feed-in tariffs; obligation certificates; and fiscal concessions and tax exemptions for waste-to-resource activities). Governments should try to identify specific, local niche markets in which economies of scale are possible if partnerships can be brokered among the necessary stakeholders. **Policy and regulatory frameworks** could create incentives for waste-to-resource practices, raise awareness, and mitigate hazards. However, effective enforcement is often lacking. Many waste-to-resource activities are regulated inadequately or not at all, which is not conducive to private sector investment. Countries such as Sweden have achieved their flagship status in waste-to-resource through long-term comprehensive sector reform.

Public funding will be needed to cover the affordability gap and address safely managed sanitation. The sanitation service chain spans both private and public goods, and market mechanisms are not always adequate to mitigate the safety risks. The case studies notably point to market failures on treatment and transportation, in particular with infrequent users.

TABLE 5.1. Roles for Public and Private Sectors in FSM

Public sector	Private sector
• Regulating and enforcing private sector–led segments of the sanitation service chain. • Creating a supportive policy environment for safely managed sanitation and waste-to-resource activities. • Public awareness raising around construction and practices of on-site sanitation systems. • Ensuring no one is left behind in sanitation service provision, and, if needed, providing financial incentives for poor households. • Ensuring fecal sludge treatment and transport services when the private sector fails to adequately address these. • Supporting R&D. • Instituting regulatory reform and standardization of waste-to-resource products. • De-risking private sector operations through guaranteed purchase agreements of waste-to-resource outputs.	• Constructing latrines. • Providing emptying services, transport, and waste-to-resource services, likely with some public support and partnership arrangements. • Identifying and optimizing waste management business models (logistics, products, clustering, markets). • Investing in iterative R&D to optimize waste-to-resource processes.

Note: FSM = fiscal sludge management; O&M = operations and maintenance; R&D = research and development.

In such cases, public support will likely be necessary to enable existing FSM activities to improve and scale up.

Innovations emerge from commercializing a strong research and development (R&D) base. Focused R&D not only enables technical improvements—optimizing processes and maximizing efficiency gains—but it also provides the evidence base necessary for regulatory reform and to de-risk private investment. Based on this initial assessment, table 5.1 illustrates roles for the public and private sectors.

Rural Sanitation Implementers and Practitioners

Approaches need to be tailored to attain the SDGs. Current approaches to rural sanitation that focus on behavior change do not necessarily ensure safe management of fecal sludge. Programs need to be broadened to address health and environmental outcomes at each stage of the sanitation service chain—promoting more informed choices of sanitation technologies, supervising construction, and addressing the wider institutional issues of safely managing sanitation systems. Behavior change communications strategies need to refocus on the risks of unsafely managed sanitation and create demand for safe sanitation services.

Fecal sludge should be treated as close to the household as safely feasible—for instance, through well-constructed and well-managed twin pit latrines or septic tanks—to keep service chains simple and minimize health risks connected with emptying and transportation. This is in line with the recommendations of Eawag: Swiss Federal Institute of Aquatic Science and Technology (2005).

Where sanitation service chains have to be established, a careful contextual analysis is needed to identify appropriate technical solutions and viable partnership models. First, **institutional analysis** can assess the adequacy of regulations, identify gaps in policy, and determine the existing constitutional capacity to establish successful public-private partnerships. **Market analysis** can identify which markets have potential given local circumstances; for example:

- **Biochar** as a coal substitute (chapter 21) could be considered in countries with a coal deficit, such as India, Bangladesh, or Uganda.
- **Black soldier fly** (chapter 19) could be considered in places where fishmeal is expensive due to transportation costs, such as Nigeria, or landlocked countries, and where there are potential local customers, such as poultry farms.
- **Aquaculture** (chapter 20) is already a widespread informal activity in many parts of Asia, so existing knowledge could provide a basis for commercializing.
- **Phosphate recovery** (chapter 24) may be most attractive in large crop-growing areas.

Market analysis also includes identifying possible stakeholders for public-private partnerships at each necessary point in chain—including companies that can deliver services and long-term, committed customers—and the necessary public support. Tools such as clustering algorithms can help identify potential opportunities to improve efficiency. As shown by the case of clustered farms in Sweden (chapter 23), it is necessary to consider issues of logistics and economies of scale in advance to make multi-stakeholder partnerships viable.

Private Sector

The private sector can potentially play an important role in providing safe FSM services. Private sector development could focus on incrementally improving existing practices or developing business partnerships between local waste entrepreneurs and innovators in upper-middle-income economies. That said, scaling up safe, privately managed sanitation chains is an area of ongoing learning and will require dedicated public support.

Bigger is not always better—optimizing scale for the circular economy. Getting the right scale of operations is key to ensuring commercial viability. In Sweden, 87 percent of waste companies have fewer than 50 employees, and 56 percent have fewer than 10.

Securing a long-term, committed customer during the startup period. Mature waste-to-resource markets, such as those in Sweden, the Netherlands, Germany, and Norway, are driven by the private sector, but less-mature markets will require identifying customers that can commit to a guaranteed purchase agreement, with predictable logistics and a well-defined product, at the right scale and price.

Mitigating risks through public-private partnerships. Local government bodies can play the role of committed customer, de-risking private sector investment while offsetting the costs of municipal waste management. However, this requires a local government authority with enough capacity, autonomy, and budget authority to manage service agreements.

Seek partnerships with other sectors to leverage private funding. Current public finances for sanitation are insufficient to meet the SDGs. There is a need to nurture partnerships with other sectors—such as rural development, climate change adaptation and mitigation, clean development, and agricultural development—to leverage more public and private sector funding. Combining different waste streams through business models that crowd in private finance through public funding (e.g., combining high-caloric agricultural or food waste with FSM) could mitigate financial risks and make a strong case for human capital investment.

Seek partnerships with leading players in disrupted industries. Waste-to-resource technologies often need to compete in highly competitive and established markets—for example, struvite crystallization competes with existing high-value, often subsidized, fertilizers, and black soldier fly larvae competes with fishmeal animal feed. Leading players that have sector expertise and take a long-term view—seeing that phosphorus reserves and fish stocks, for example, are both under pressure—should be treated as potential partners, helping the new technologies to become competitive.

Further Research

Safely managed sanitation in high-density rural areas is a relatively new field, and experience in providing the necessary services is limited. There is a need for further research, action learning, and building up experience in the following topics.

R&D to optimize the grade of products for profitable returns. Waste-to-resource innovations in middle- and upper-income economies tend to produce niche, high-grade products with strong market value. However, lower-grade products, requiring less expensive technology, could still be safe and profitable in low-income countries. So far, limited R&D has gone into optimizing the grade of product from fecal sludge for different kinds of market.

Development and testing of FSM business models. Finance for safe sanitation services comes from three main sources: **tariffs** from customers, **taxes** from domestic taxpayers, and voluntary **transfers** (Pories, Fonseca, and Delmon 2019). More research is needed on how these sources can be leveraged to enable the private sector to enter other parts of the service chain. Examples might include scheduled emptying services paid through tariffs, public financing of FSM transportation costs, build-operate-transfer agreements, or long-term service purchase agreements for waste-to-resource treatment facilities. Historical examples of the evolution of FSM models and practices in different economic and institutional settings might provide useful lessons.

Improving understanding of health implications, including antimicrobial resistance. More research is needed into health implications of inadequately managed fecal sludge in high-density and low-density rural areas.

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Chapter 6 Case Study Summaries

Series 1: Common Fecal Sludge Management Practices

Each case in the first series (chapters 7 to 12) explores whether or not fecal sludge management (FSM) is an issue in a particular high-density rural area, and why. The cases present an overview of a typical sanitation technology, and highlight the key issues related to design, use, and potential public health risks.

The Fecal Sludge Management Challenge in Bangladesh

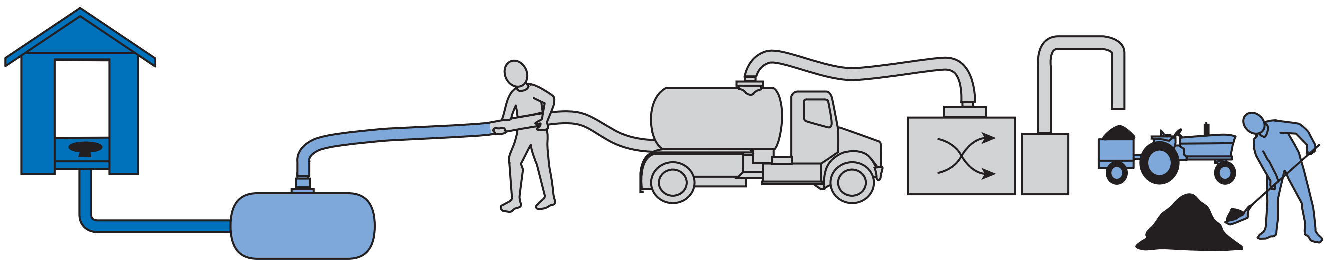
Background. Bangladesh has brought open defecation down to 0.2 percent, but now faces significant public health risks from fecal pathogens not being safely managed. Sixty-seven percent of Bangladesh's 164 million residents use a simple single pit latrine, and 90 percent of pit latrines are emptied manually. Limited technical capacity to safely manage fecal sludge exists in rural Bangladesh. See figure 6.1.

What is the sanitation technology? Single and twin pit latrines, with a removable concrete slab and a flushable latrine pan.

What are the waste characteristics? Wet/septage.

What are the concerns? Single pits are not a safely managed sanitation system because the top layer of sludge retains fresh pathogens. In addition, in most cases, the pits are emptied manually, and sludge is dumped indiscriminately in the environment. Twin pit latrines may not be safe when the moisture content of sludge exceeds 80 percent—which it commonly does in Bangladesh—or when not constructed properly.

FIGURE 6.1. Sanitation Features of Pit Latrines in Bangladesh



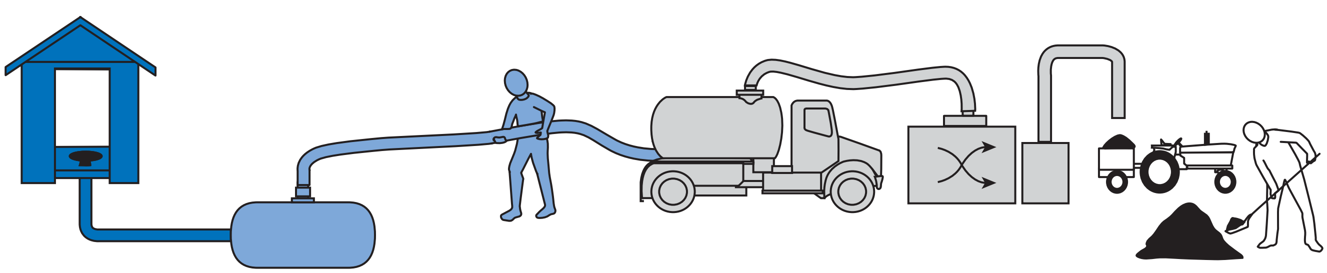
Point of Use	Containment	Emptying	Transport	Treatment	Reuse
Improved sanitation	Compromised sanitation structures and pit contents retain pathogens	Manual pit emptying is prevalent	Fecal waste is dumped in or near homestead	No fecal sludge treatment	Demand for reusing the sludge horticulturally is low because homesteads are often small

Note: Bright blue indicates the outcome is achieved; light blue, partially achieved; gray, not achieved.

Compromised Septic Tanks in India

Background. Affluent, aspirational households in West Bengal are opting for septic tanks: a sample study in 16 districts finds that 21 percent of households have them. However, tanks are often poorly constructed, and households are not well informed on how to manage and maintain them, and associated costs. See figure 6.2.

FIGURE 6.2. Sanitation Features of Septic Tanks in West Bengal



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
Improved sanitation	Compromised construction	Manual emptying is prevalent; some mechanical emptying	Fecal waste is often dumped locally	No fecal sludge treatment	n.a.

Note: Bright blue indicates the outcome is achieved; light blue, partially achieved; gray, not achieved. n.a. = not applicable.

What is the sanitation technology? A septic tank should be watertight, with at least two chambers, allowing solids to settle in one tank. Effluent flows into the second tank and eventually into a soak pit or leach field through an outlet pipe.

What are the waste characteristics? Wet/septage.

What are the concerns? Poor construction compromises the performance of the septic tank and its ability to safely manage fecal waste, leading to higher maintenance costs and health risks. Many so-called septic tanks are actually simple holding tanks. The tanks often discharge septage effluent on a continuous basis to the immediate environment. When they are emptied, this is often done manually using buckets and ropes—an unhygienic, dangerous, and unpleasant job.

Hanging Latrines and Fishpond Toilets in Vietnam

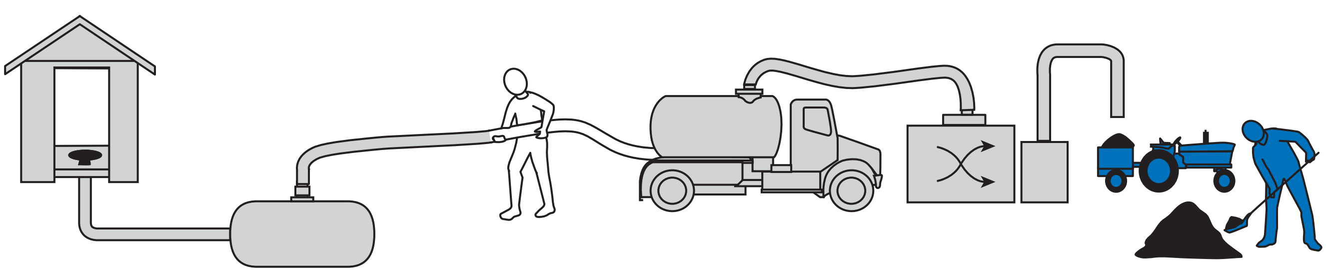
Background. The Mekong River Delta is home to one-fifth of Vietnam's population—approximately 17 million people—and 37 percent of them use hanging latrines. Fishpond toilets are also common in Cambodia, Laos, and China. The fecal sludge feeds the fish, which is a source of family income and protein. Many households are unwilling to upgrade to hygienic latrines if this means giving up the economic benefits of the fishponds. See figure 6.3.

What is the sanitation technology? Hanging latrines are suspended over a fishpond. Fishpond toilets flush directly into a river or fishpond.

What are the waste characteristics? Wet/septage.

What are the main issues? Fishponds contaminated with fecal matter pose health risks to those living nearby—contaminated water may be used for household use, children may swim

FIGURE 6.3. Sanitation Features of Hanging Latrines and Fishpond Toilets in Mekong Delta



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
Unimproved sanitation technology	No containment	n.a.	Discharge to open rivers and canals	No adequate treatment of fecal waste	Cost and resource recovery in domestic pisciculture

Note: Bright blue indicates the outcome is achieved; gray, not achieved. n.a. = not applicable.

in the water, and there is increased vector breeding due to open wastewater-fed pools being in the immediate living environment. The risk of contamination is exacerbated by seasonal monsoon flooding.

Managing High Volumes of Septage in the Nile Delta, Egypt

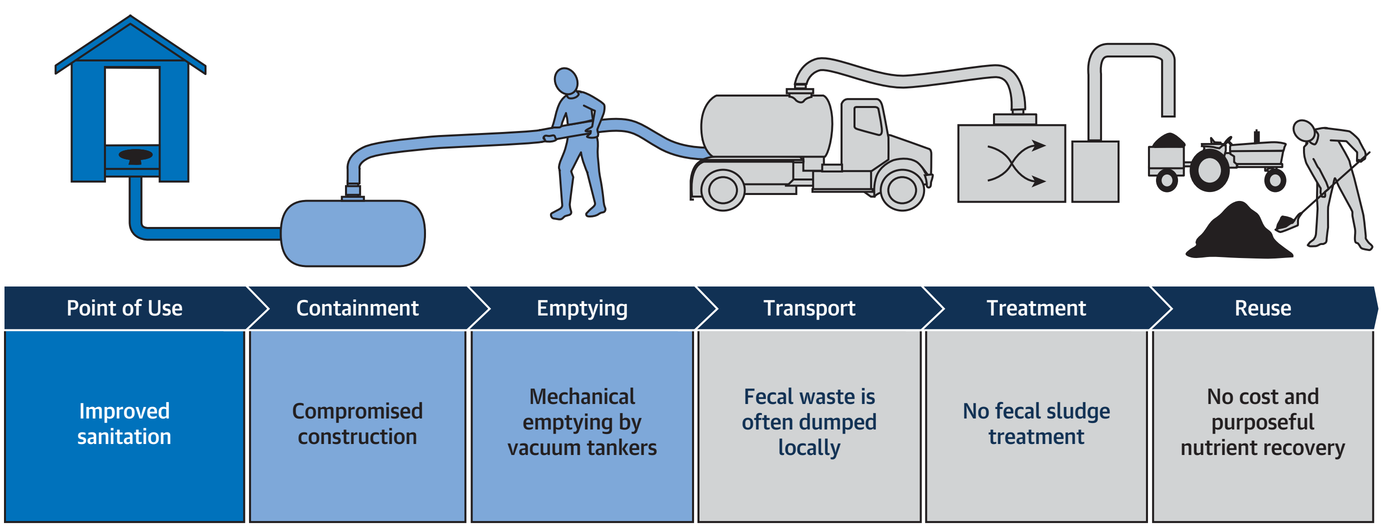
Background. Egypt is institutionally geared toward large-scale, centralized wastewater systems; there is little to no capacity to implement and manage nonnetworked systems. However, many high-density rural areas of the Nile Delta need to rely on nonnetworked solutions. The high water table means that on-site systems need frequent emptying. See figure 6.4.

What is the sanitation technology? Several villages have installed rudimentary, self-built sewers, which often discharge to local open drainage canals. Vehicles that empty the sludge from on-site systems—mostly simple vaults that receive all blackwater, some greywater, and sometimes liquid manure—discharge into these open drains, although this is illegal.

What are the waste characteristics? Wet/septage.

What are the main issues? Due to water scarcity, the drain water is often illicitly used by farmers for irrigation of crops. This uncontrolled practice poses a potential public health risk.

FIGURE 6.4. Sanitation Features of Septage Management in Nile Delta

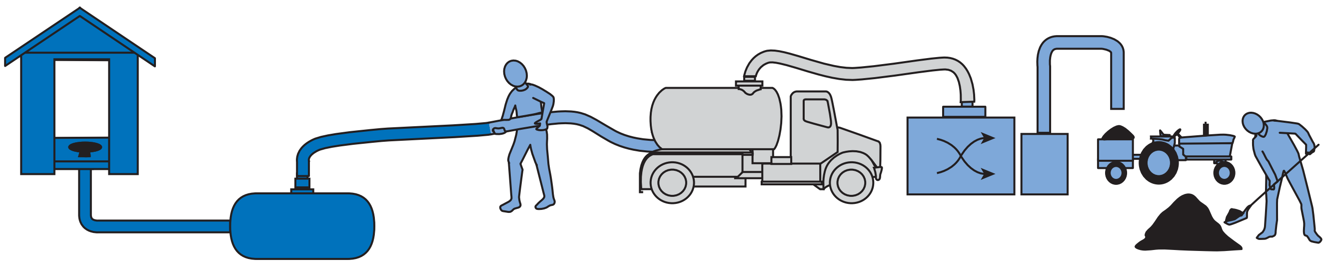


Note: Bright blue indicates the outcome is achieved; light blue, partially achieved; gray, not achieved.

The Challenges of Sustained Fecal Sludge Management for Ecosan Units in Bolivia

Background. In areas without networked sewer systems in Bolivia, sanitation provision and uptake of latrines have generally been low. Water scarcity, minimal governmental support for sanitation, and critical conditions of hygiene and disease have led several nongovernmental organizations (NGOs) to focus on sanitation. See figure 6.5.

FIGURE 6.5. Sanitation Features of Urine Diverting Dry Toilets in Bolivia



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
Improved sanitation	Safely contained	Emptying in context of inconsistent pathogen inactivation presents a risk	Lack of sustained emptying and transport services implemented	Inconsistent pathogen innactivation in situ	Questionable demand for household horticultural reuse

Note: Bright blue indicates the outcome is achieved; light blue, partially achieved; gray, not achieved.

What is the sanitation technology? Urine diverting dry toilets, in which feces is covered with ash, lime, or sawdust to aid composting, and urine is collected separately.

What are the waste characteristics? Dry, fecal sludge; separately, urine.

What are the main issues? The ad hoc, supply-led and largely NGO-driven nature of the sanitation programs has resulted in varying quality and disconnectedness from public institutions. In some cases, NGOs could not or did not adequately support families to safely manage and empty their latrines and use the compost.

Poorly Constructed and Managed Toilets in India

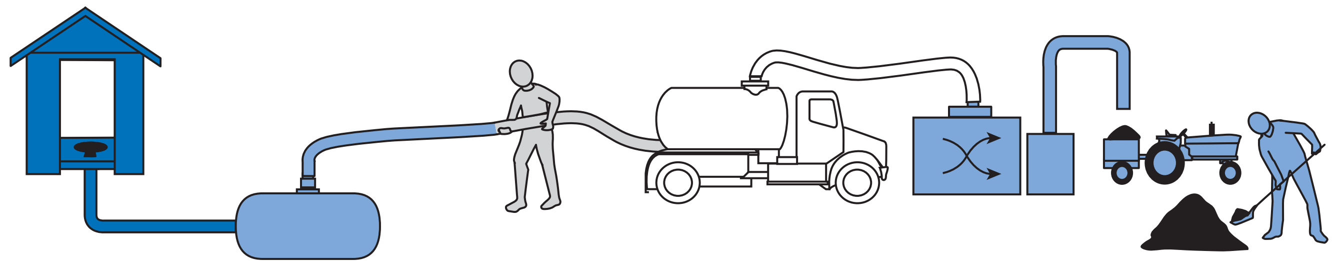
Background. Over 80 million household toilets have been built since 2014 in India, in which the twin leach pit latrine is the technology promoted for rural areas. A well-constructed and properly managed twin pit technology allows households to safely manage fecal sludge. However, household awareness, education, and institutional support to monitor construction and ensure adherence to safe practices have not yet been a central focus, especially in rural areas. See figure 6.6.

What is the sanitation technology? Alternating twin pit technologies should, by design, allow for long-term and safe management of fecal sludge.

What are the waste characteristics? Wet/septage.

What are the main issues? In practice, poor construction practices and lack of quality control mechanisms often severely compromise the functionality of the system and leave the fecal sludge unsafe to handle even after more than a year. One study across eight states found that 31 percent of the toilets do not safely prevent human contact with fecal matter.

FIGURE 6.6. Sanitation Features of Poorly Constructed Twin Pit Toilets in India



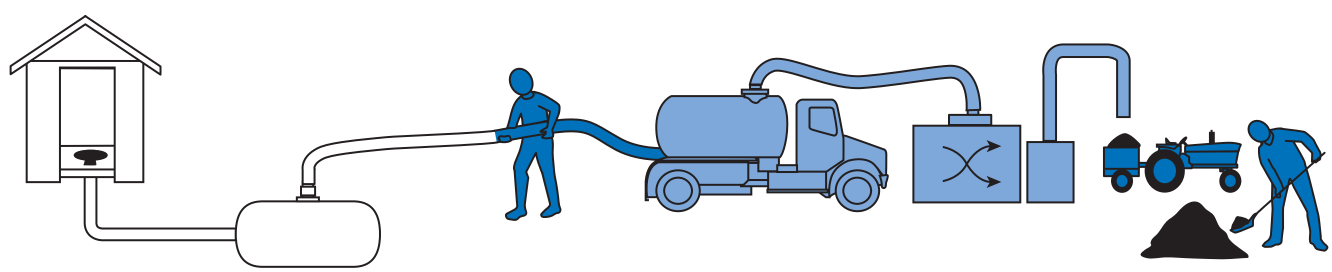
Point of Use	Containment	Emptying	Transport	Treatment	Reuse
Improved sanitation	Construction often does not adhere to standards	Compromised construction can make it unsafe to empty	n.a.	Compromised construction compromises functionality of the system	Questionable resource recovery in practice

Note: Bright blue indicates the outcome is achieved; light blue, partially achieved; gray, not achieved.n.a. = not applicable.

Series 2: Organically Emerged Fecal Sludge Management Services

Each case in the second series (chapters 13 to 18) explores an entrepreneurial activity related to FSM that has emerged organically without any external technical or financial support, and operates without any support. The cases describe waste management aspects and explore the potential for scaling or replication in the right conditions, considering limitations and potential enabling actions. See figure 6.7.

FIGURE 6.7. Sanitation Features of Irrigation by Septage



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	Fecal waste is hygenically emptied mechanically	Fecal waste is removed from living environment;	Basic trench infiltration unlikely to achieve full pathogenic inactivation	Cost and nutrient recovery

Note: Bright blue indicates the outcome is achieved; light blue, partially achieved. n.a. = not applicable

Irrigation by Septage, India

Background. The reuse of untreated wastewater and septage in irrigated agriculture is documented in more than 60 countries. Because it is predominantly an informal activity, the true scale is likely larger.

What is the practice? Informal private tanker operators empty septic and holding tanks and deposit the contents on farmers' fields.

What are the waste characteristics? Wet/septage.

Why does it have potential? Farmers report increased crop yields and cost savings as a result of buying less fertilizer or soil conditioner. There is scope to work with farmers to produce higher-quality compost with market value.

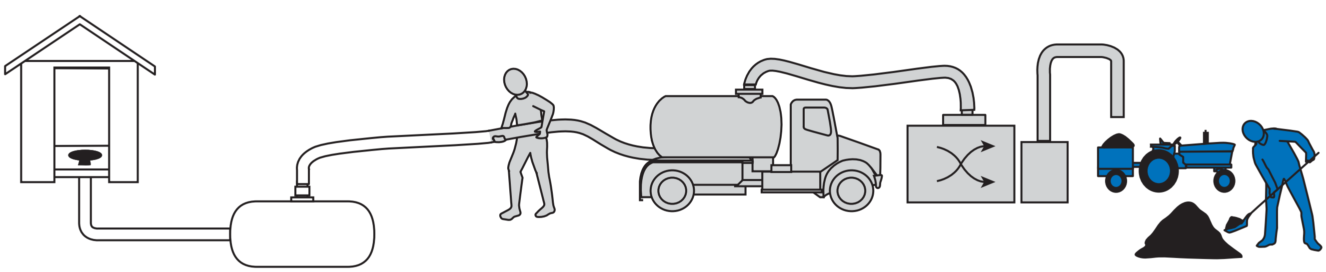
What are the concerns? The sludge is not always safe when applied to soil, posing risks to farm laborers and consumers. Fecal sludge is low-grade fertilizer and may incur social stigma. Regulatory and policy frameworks that ban all use of wastewater in agriculture keep these enterprises in the informal sector, which reinforces the risks of limited awareness and poor practices, and hampers scaling up and technical innovation.

Looking Back at the Traditional Dry Vault Systems of Afghanistan

Background. The dry vault toilet system in Kabul was not perfect, but operated for several decades. Its collapse resulted in very poor sanitation conditions, with fecal sludge contaminating densely populated areas. See figure 6.8.

What is the practice? Entrepreneurs and farm laborers with donkey carts collect dried feces from dry vaults for sale and distribution to nearby farmers.

FIGURE 6.8. Sanitation Features of Traditional Dry Vault Systems in Kabul



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	Likely direct pathogen exposure during manual emptying	Fecal matter is removed by donkey cart, presenting risks	Likely poorly controlled pathogen removal	Nutrient recovery for farmer

Note: Bright blue indicates the outcome is achieved; gray, not achieved. n.a. = not applicable.

What are the waste characteristics? Dry/fecal sludge; urine not collected.

Why does it have potential? By separating feces from urine and water, the dry vault system speeds up the desiccation process. While not well-suited to dense urban areas, ecological sanitation systems that are upgraded to avoid unsafe emptying and handling may be appropriate in rural centers that can build on existing knowledge, practice, and systems.

What are the concerns? The sludge is not necessarily safe for manual handling when collected. As the experience of Kabul shows, these informal private services that do not enjoy any public support are very vulnerable to fluctuations in demand. Once such a system breaks down it is hard to reinstate.

The Cost-Recovery Potential of Domestic Biogas

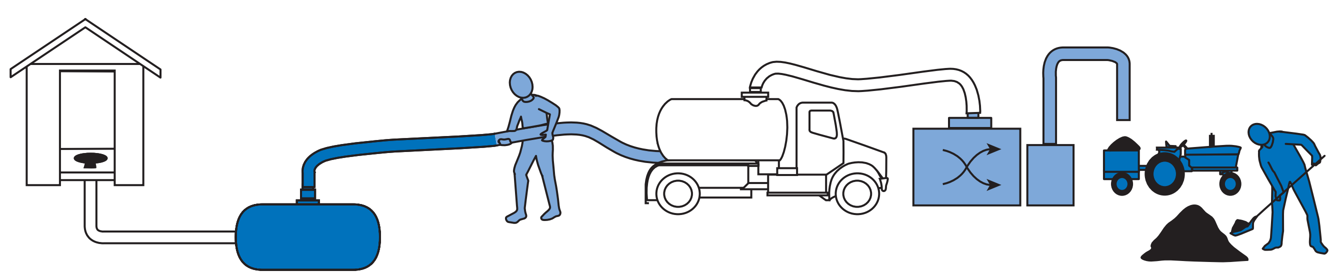
Background. Technology to produce biogas from anaerobic digestion is applied on large and small scales globally. However, its uptake has so far been propelled by the cost-saving potential of energy and fertilizer costs, rather than as a waste disposal solution. See figure 6.9.

What is the practice? Small-scale biogas digestors break down organic waste and septage into methane, slurry, and effluent.

What are the waste characteristics? Wet/septage.

Why does it have potential? Households can use the methane for cooking or heating, and use the slurry and effluent as fertilizer. Partnerships could be made with those working in climate change, clean development, and agriculture interventions.

FIGURE 6.9. Sanitation Features of Small-Scale Biogas Digestors



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	Waste streams are combined on-site	Slurry needs to be emptied from digestor	n.a.	Reduces but does not eliminate viruses, bacteria, and parasites	Cost and nutrient recovery in gas and slurry

Note: Bright blue indicates the outcome is achieved; light blue, partially achieved. n.a. = not applicable.

What are the concerns? Household-scale systems are relatively costly: financing and subsidy mechanisms are required to make the technology accessible at scale. In low-income countries many small-scale digesters are not fed properly, resulting in inefficiencies that reduce cost-effectiveness. The slurry and effluent are not always used safely: the anaerobic digestion process reduces but does not eliminate viruses, bacteria, and parasites.

Improved Product Design of an Established Technology

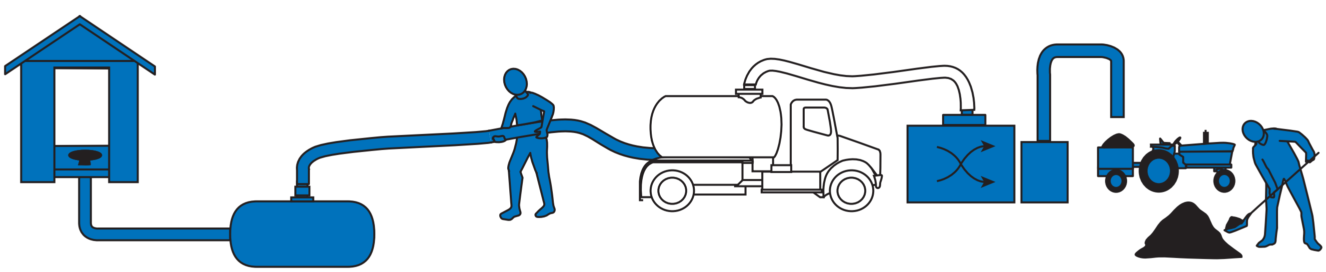
Background. If it is well-designed, constructed in a suitable location, well-maintained, and socially acceptable, a double pit pour-flush latrine technology can be a viable, long-term improved and safe sanitation option. While the second pit is filiing up, the first should become safe to empty after 12 to 18 months. Many sanitation efforts and mainstream behavioral change communication approaches—such as community-led total sanitation—focus on the superstructure of the latrine, which is associated with social status, convenience, privacy, and safety. However, the technical functionality of the substructure is fundamental to the ongoing operation and use of the units. See figure 6.10.

What is the practice? Private sector innovation is bringing low-cost, purpose-designed plastic sanitaryware for alternating pour-flush pit latrines including sealed pans, Y-junction boxes, and slabs.

What are the waste characteristics? Wet/septage.

Why does it have potential? Low-cost and purpose-designed sanitaryware addresses common problems with use and maintenance of double-pit latrines, which improves their functionality and the user experience. Can be coupled with improved incentives or subsidies for the poorest households, and household education on proper operations and maintenance (O&M).

FIGURE 6.10. Sanitation Features of Improved Twin Pit Technologies



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
Improved sanitation	Waste is safely contained in situ	Alternating pits allow for the pit to be emptied once safe	n.a.	In situ	Nutrient recovery

Note: Bright blue indicates the outcome is achieved. n.a. = not applicable.

What are the concerns? Health and environmental safety is still often compromised by poor design, construction, placement of the latrines in unsuitable terrains, or failure to understand the long-term communication needs and potential social barriers around sustained operation.

Reducing Haulage Costs through Dewatering and Transfer

Background. Haulage is a significant part of waste management costs. In solid waste management, optimizing haulage costs through vehicle fleets, transfer stations, and decentralized processing are well-known practices. See figure 6.11.

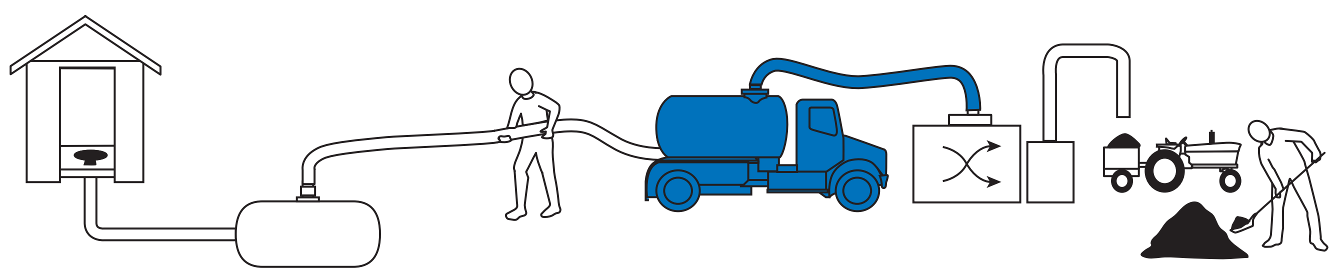
What is the practice? Septic tanks and other on-site systems are emptied by small vehicles, which transfer to large vehicles for disposal.

What are the waste characteristics? Wet and dry, septage, and fecal sludge.

Why does it have potential? Solid waste management practices have proven that transfer to larger vehicles improves efficiency compared to small vehicles making multiple long journeys to disposal grounds. Smaller vehicles can access narrower areas, and the ability to transfer to larger vehicles reduces the incentive for localized disposal. Suitable for public-private partnerships.

What are the concerns? Difficult to organize—fleet management and operations need a strong regulatory environment and aligned incentives. FSM is often hampered by poor operational management: fuel, maintenance, and spare parts are continuous expenses in managing a fleet of vehicles, and budgeting and planning are required to sustain operations.

FIGURE 6.11. Managing Haulage Costs in Fecal Waste Removal



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	Systems that safely transport fecal waste away	n.a.	n.a.

Note: Bright blue indicates the outcome is achieved. n.a. = not applicable.

Fishpond and Duckweed Aquaculture

Background. Aquaculture—the farming of fish, plants, algae, and other organisms—is widely practiced across parts of Asia, on both domestic and large scales. Wastewater containing organic matter can be used to feed these farming systems. See figure 6.12.

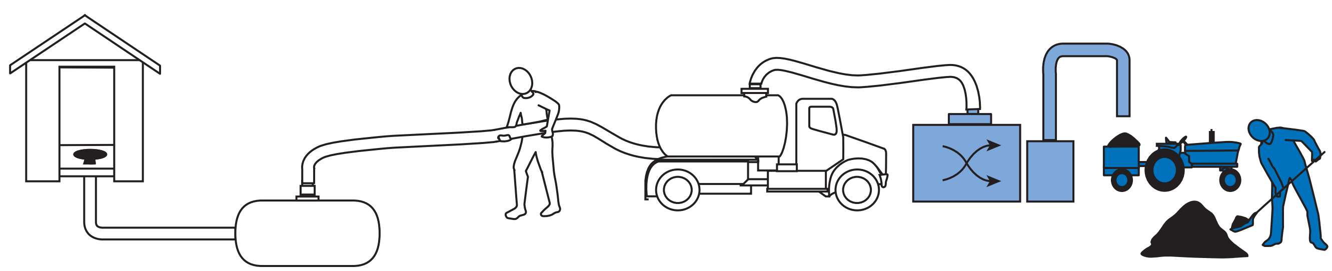
What is the practice? Farming fish as part of wastewater treatment systems, or with the use of duckweed.

What are the waste characteristics? Wet/septage and wastewater.

Why does it have potential? The process offers little benefit in terms of pathogen removal, but if the risks can be managed away from living environments, aquaculture offers a reliable income source for rural families or commercial enterprises and can offset costs for larger-scale production and treatment of wastewater or fecal waste. May be suitable for public-private partnerships.

What are the concerns? Needs to be managed properly, rather than fishponds simply being fed with untreated wastewater and septage. Substantial land requirement. Likely to need an external broker or catalyst.

FIGURE 6.12. Sanitation Features of Fishpond and Duckweed Aquaculture



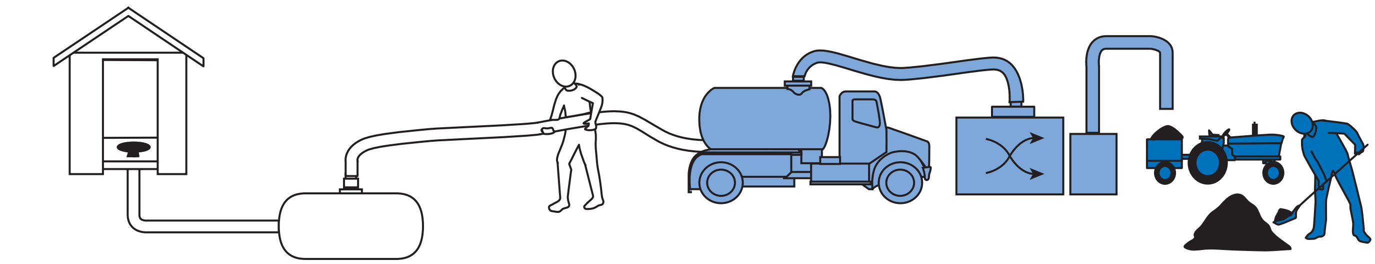
Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	n.a.	Process offers little pathogen removal	Cost and nutrient recovery

Note: Bright blue indicates the outcome is achieved; light blue, partially achieved. n.a. = not applicable.

Series 3: Innovative Waste Recycling Approaches and Technologies

Each case in the third series (chapters 19 to 24) explores a waste management innovation that could potentially be applied to FSM. Most of these innovations have reached a level of maturity in other waste streams in upper-middle-income economies and are financially sustainable, though subsidy might have been provided during the initial stages. See figure 6.13.

FIGURE 6.13. **Sanitation Features of Using Black Soldier Flies**



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	In situ black soldier fly degradation reduces waste volumes by up to 78.9%, which has haulage implications	Risks of pathogenic transmission and heavy metal accumulation need more research	Commercially viable protein and oil products sold for cost recovery of treatment

Note: Bright blue indicates the outcome is achieved; light blue, partially achieved. n.a. = not applicable.

Converting Organic Waste into High-Protein Animal Feed

Background. The larvae of the black soldier fly digest a wide range of organic wastes, including food waste, agricultural waste, animal manure, and human excreta. Breeding black soldier fly larvae is a rapidly emerging market for treatment of some organic waste streams.

What is the technology? Having fed on waste, the black soldier fly larvae are processed, producing protein and fat that can be used as animal feed. The residue can be used for fertilizer.

Why does it have potential? Markets include animal feed as a sustainable alternative to fishmeal and soymeal. While competing in global markets would require significant economies of scale, there is scope to serve local markets.

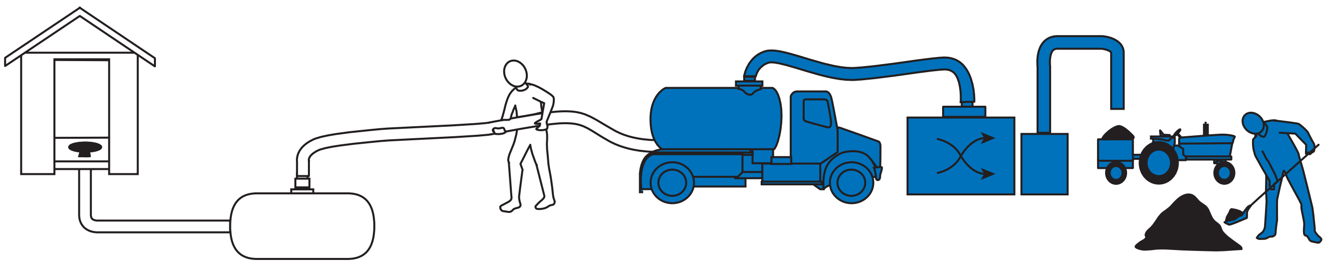
What is the potential? Organic waste including septage, fecal sludge with up to 80 percent water content.

What are the concerns? It is not yet proven at a very large scale that risks of pathogen transmission and heavy metal accumulation can be mitigated, so further research is needed. The regulatory situation is unclear in some countries due to restrictions on animal feed dating from the bovine spongiform encephalopathy (BSE) crisis of the 1990s.

Combined Natural and Engineered Media for Wastewater Treatment

Background. Wastewater gardens combine botanical garden aesthetics with conventional wastewater engineering. They look attractive and have almost no smell. See figure 6.14.

FIGURE 6.14. Sanitation Features of Wastewater Treatment Gardens



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	Aesthetics and odor-free mean it can be located in city	Improved efficiency compared to activated sludge wastewater treatment plants	Clean water recovery

Note: Bright blue indicates the outcome is achieved. n.a. = not applicable.

What is the technology? Integrated fixed film activated sludge places manmade, grid-like media into the treatment tanks, providing greater surface area for bacteria in a small space and reducing the footprint required for wastewater gardens.

Why does it have potential? Costs of transport are significant for FSM, and wastewater gardens can be located closer to residential areas than other treatment options. They are a viable option for new developments for which regulations mandate wastewater treatment at source.

What is the potential? Water-based organic waste including sewage; septage.

What are the concerns? Requires significant capital investment. So far proven for low-to-medium-strength effluent water, but for highly concentrated septage or fecal sludge, new technologies would need to be developed.

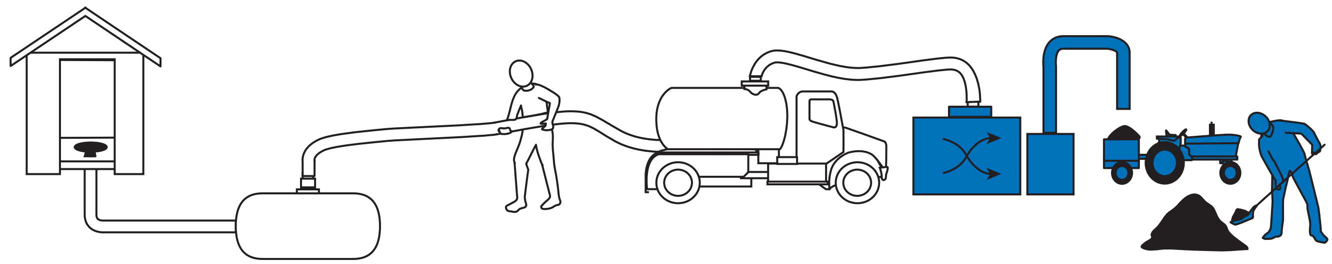
High-Energy Yield and Low Carbon Footprint Fuel of Torrefied Biomass

Background. Fecal waste does not typically have high energy yield, but it could be combined with other waste streams to convert into a clean fuel. Torrefaction converts biomass into dry pellets or briquettes—a greener alternative to coal—and inactivates pathogens. See figure 6.15.

What is the technology? Torrefaction is a process of heating at low temperatures to convert biomass into coal-like fuel. It optimizes the physical and chemical characteristics of raw biomass to a dry, homogenized product with increased energy yield.

Why does it have potential? The technology is already commercially mature and viable for woody biomass. It would be most applicable for drier fecal sludge, and for countries with high coal demand such as India, Bangladesh, or Uganda.

FIGURE 6.15. **Sanitation Features of Torrefied Biomass**



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	n.a.	Pathogens are inactivated when heated	Potentially for economic viability; energy recovery from waste

Note: Bright blue indicates the outcome is achieved. n.a. = not applicable.

What could it be used with? Dry organic waste, including fecal sludge up to 40 percent water content.

What are the concerns? The technology is not yet proven to be suitable for fecal sludge, though trials are underway. Further research is needed to optimize the parameters and value chain models: identifying the ideal torrefaction conditions for fecal sludge feedstock, optimized feedstock ratios, and products to suit market conditions. The low carbon dioxide emissions price is a hurdle when it comes to competing with coal.

GIS and Network Analysis to Reduce Haulage Costs

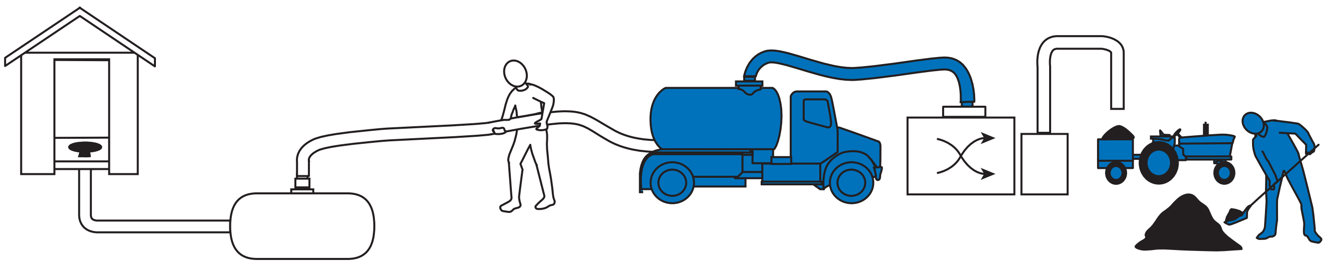
Background. Collection and transport accounts for up to 85 percent of waste management costs. Local conditions, the nature and volumes of waste, quality of roads, and institutional arrangements will influence how waste management services may or may not be viable in any given context. See figure 6.16.

What is the technology? Geographic Information Systems (GIS) modeling and network analysis software enables waste collection routes to be made more efficient.

What is the potential? Maximizing logistical efficiencies could have a significant impact on the viability of fecal sludge collection, especially outside of urban centers. Examples include vehicle collection systems and direct and transfer haulage models.

What are the concerns? Fleet management is relatively new to FSM, and there is a need to get the incentives and economies of scale right. Because this technology addresses only the logistical component of the chain, it would require pairing with other elements.

FIGURE 6.16. **Reducing Haulage Costs with GIS and Network Analysis**



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	Optimizing transport saves resources	n.a	Optimizing transport saves costs

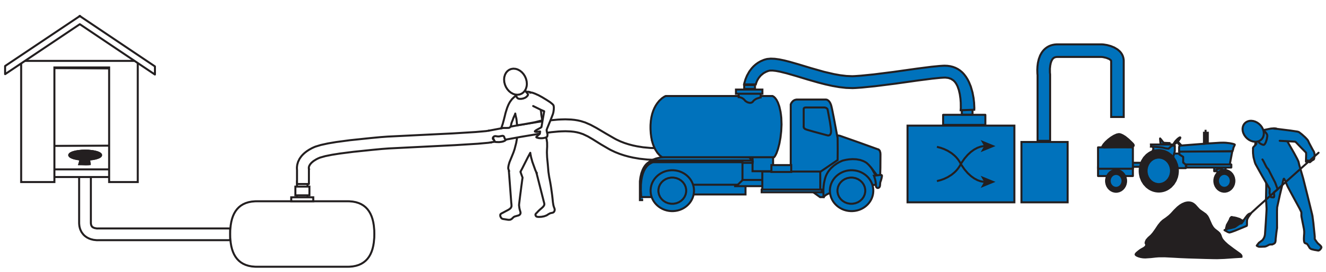
Note: Bright blue indicates the outcome is achieved. n.a. = not applicable.

Co-Production of Biofuel from Clustered Farms in Sweden

Background. Farmers in Sweden have joined forces to produce biogas, which is piped to a local slaughterhouse for use in heating, and then to an upgrading facility. The upgrading facility produces biomethane, which fuels public transport as well as being sold commercially. See figure 6.17.

What is the technology? Biogas plants on farms are fed manure, agricultural residues, and food industry waste from a cluster of local businesses.

FIGURE 6.17. **Sanitation Features of Co-Production of Biofuel from Clustered Farms in Sweden**



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	Waste from farms is treated locally; biogas is piped to upgrading facility	Anerobic digestion does not achieve full inactivation but is managed appropriately in a farm context	Cost and resource recovery is achieved

Note: Bright blue indicates the outcome is achieved. n.a. = not applicable.

What is the potential? When local conditions allow for sufficient economies of scale, investment can be viable in facilities to upgrade biogas to higher-value biofuel. Types of organic waste include septage and fecal sludge.

What are the concerns? Multiple stakeholders need to be organized. The regulatory and institutional environment needs to be conducive, and it is important to secure a long-term purchase agreement early on. The profit margin is too low for commercial investors, so the model relies on public sector support and social impact investors.

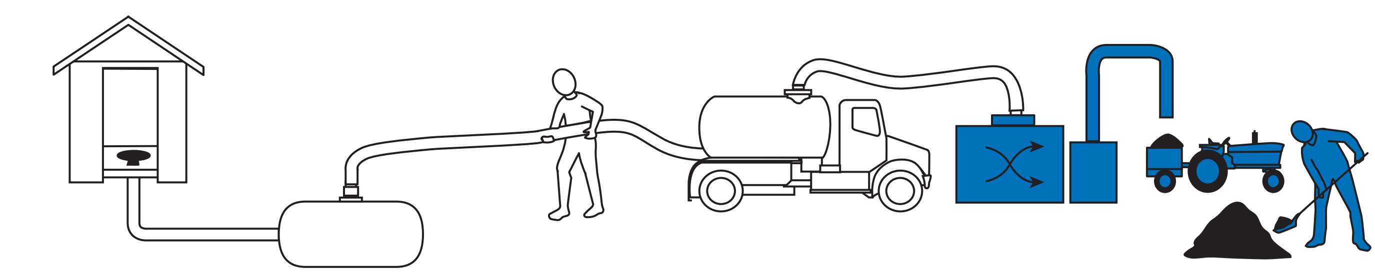
Reclaiming Phosphorus from Stabilized Sludge for Nutrient Recovery

Background. Phosphorus is an essential plant nutrient and a main ingredient in fertilizers. At current consumption levels, known reserves will be depleted in 80 years. Methods exist to recover phosphorus as part of wastewater treatment; however, their aim is usually to meet environmental standards for effluent discharge rather than to use the phosphorus. See figure 6.18.

What is the technology? Struvite crystallization technology recovers phosphorus from waste treatment plants, and it is then turned into a high-end commercial fertilizer.

What is the potential? The market for phosphorus is large. The plants are expensive, costing an estimated US$2 million to US$4 million, but return on investment is expected in three to five years. Examples of use include sewage, septage, and urine.

FIGURE 6.18. **Reclaiming Phosphorus from Stabilized Sludge for Nutrition Recovery**



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	n.a.	Crystallization is performed as additional treatment step	Nutrient recovery of a depleted resource

Note: Bright blue indicates the outcome is achieved. n.a. = not applicable.

What are the concerns? More data are needed on pathogen inactivation to inform regulations on fertilizer use. Regulatory reform will be required in some markets: for example, the European Union currently bans struvite recovered from wastewater or sewage sludge in organic farming.

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Part 2

Case Studies in Common Fecal Sludge Management Practices

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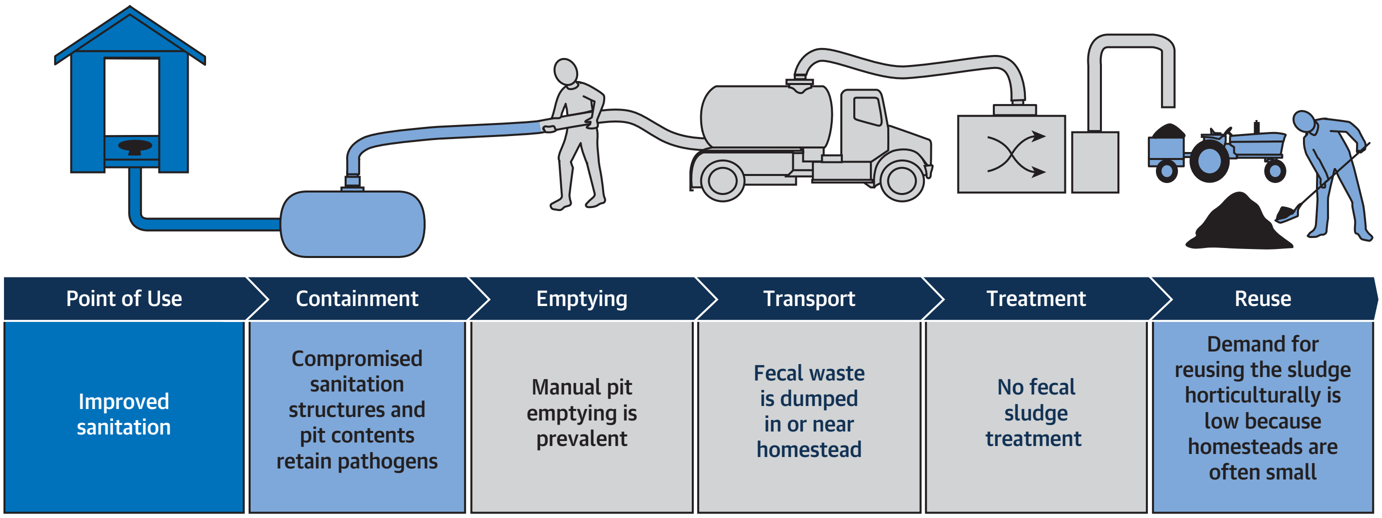
Chapter 7 The Fecal Sludge Management Challenge in Bangladesh



EMPTYING PIT LATRINES IN BHALUKA

Bangladesh is facing the next phase of its sanitation challenge, having brought open defecation down to 0.11 percent.[1] The biggest public health risks now relate to fecal pathogens not being safely managed due to compromised sanitation structures, sustained high pathogen levels inside pits, and the prevalence of manual emptying and localized dumping practices. Priorities include improving the quality of existing latrines, FSM, and hard-to-reach areas (BRAC 2016).

QUICK FACTS

- Bhakula is a subdistrict (Upazila) of the Northern Mymensingh District of Bangladesh.
- Regional typology: intermediate, close to a city.
- Population of district: 430,000.
- Population density of district: 969.1 residents per square kilometer
- Main economic activities: agriculture.
- Children under age three with diarrhea in Dhaka region: 7.5 percent (DHS 2014).
- Stunting rate of children under five in Bangladesh (2014): 36.1 percent (World Bank 2014).

Current Sanitation Practices

Bhaluka is a subdistrict of Mymensingh in central Bangladesh. As is typical of rural Bangladesh, pour-flush pit latrines are common: 93 percent of households use a latrine; 67 percent use the standard Bangladesh "hygienic latrine," consisting of a three-ring concrete single pit with a removable concrete slab and a latrine pan providing a water seal to reduce odors and fly contact with feces (BRAC 2008). Two or three liters of water are used to flush excreta into the pit, in which solids accumulate while liquids leach into the soil. Pits tend to be shallow (1–1.5 meters) due to the high water table.[2] Bhaluka's pits average 2.4 rings and a diameter of 0.83 meters, and the typical sludge accumulation rate is 0.11 liters per person per day with an average emptying frequency of once every 3.7 years (Balasubramanya et al. 2017).

Other common rural sanitation technologies include the SaTo pan (sanitary toilet pan), a low-cost pour-flush pan;[3] twin or double pits;[4] upgraded *duli* latrines (traditional woven bamboo basket liners combined with concrete rings); and septic tanks for the more affluent. Adding more bamboo or concrete rings is a common practice to extend the lifetime of the pit (Balasubramanya et al. 2017).

Fecal Sludge Management Practices

Bhaluka produces an estimated 15,000 cubic meters of sludge annually. The sludge has a high moisture content (around 90 percent), a carbon to nitrogen (C:N) ratio of 10:1, and a helminth presence of 41 eggs per gram (Balasubramanya et al. 2016). As is typical of rural Bangladesh, 90 percent of the pits are emptied manually using simple tools such as buckets, spades, and ropes (Balasubramanya et al. 2017). One emptier climbs into the pit to fill buckets while one or two others empty them nearby, often into a shallow trough, dug for this purpose, for infiltration into the soil. This "empty and dump" service costs Tk 400 (US$13), or about 14 percent of monthly household income. Fecal sludge may be removed short distances to a ditch using plastic barrels and a cart or truck, and there is evidence of honeysuckers depositing it on agricultural land for its nutrients, but no service exists in rural Bangladesh to collect and transport fecal sludge for treatment (Balasubramanya et al. 2017).

In many districts the poorest households were provided with single or double pit latrines at low or no cost by the union *parishad*, but those households may be unable to empty or maintain the latrines or repair them if they break. Manual emptying of single pits is not safe because the sludge at the top of the pit is relatively fresh and retains pathogens. Twin pit design in theory avoids this risk (Hussain et al. 2017); however, the high moisture content of sludge in Bangladesh (more than 80 percent) compromises in situ composting (Balasubramanya et al. 2016; Morgan 2007), so the lifetime of one pit may exceed the time required to render the other pit contents safe (Balasubramanya et al. 2017). Demand for reusing the sludge as soil conditioner is low because homesteads are often small, so there is a preference for taking the sludge off-site and dumping it indiscriminately in the environment (Balasubramanya et al. 2017). See summary in table 7.1.

TABLE 7.1. Public Health Issues and Scale of the Problem of FSM in Bangladesh

Public health issues	Scale of the problem
Single pits are not a safely managed sanitation system because the top layer of sludge retains fresh pathogens. In most cases, sludge is dumped indiscriminately in the environment.	67% of the 164 million residents of Bangladesh use a simple pit latrine.
	90% of the pit latrines are emptied manually.
Twin pit latrines may not be a safely managed sanitation system when the moisture content of sludge exceeds 80%, which it commonly does in Bangladesh, because this compromises in situ composting: the lifetime of one pit may exceed the time required to render the other pit contents safe (Balasubramanya et al. 2017).	Little technical capacity exists outside urban centers.
	Experience of managing complex service delivery arrangements and designing contracts, a key component of the rural FSM challenge, is weak.

Note: FSM = fecal sludge management.

Notes

1. WHO/UNICEF WASH Data website, accessed 30th May 2019, https://washdata.org.
2. The design stems from a standardized, low-cost hygienic latrine standard from the Department of Public Health and Engineering, Government of Bangladesh in the 1980s.
3. The SaTo pan is a low-cost, low-flush plastic toilet pan that uses a weighted flap instead of the water seal.
4. Users of the twin or double pit latrines, once the first pit is full, divert the waste to the second, allowing the contents of the first pit to decompose until the pathogen and helminth egg levels are theoretically sufficiently reduced for safer emptying and reuse for soil nutrients.

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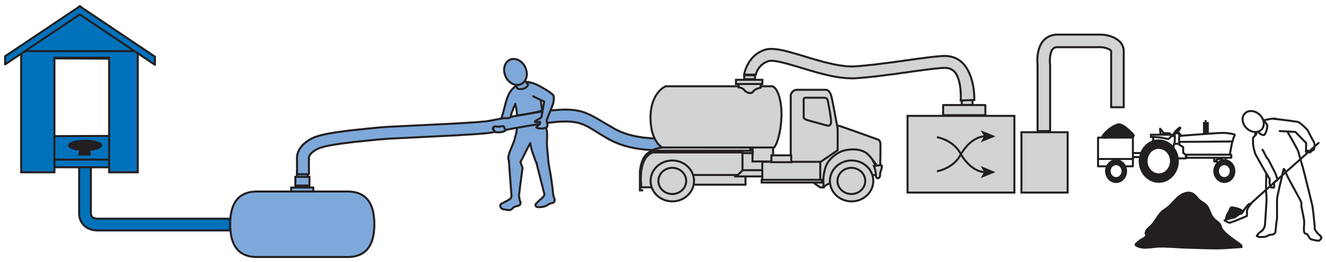
Chapter 8 Compromised Septic Tanks in India



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
Improved sanitation	Compromised construction	Manual emptying is prevalent; some mechanical emptying	Fecal waste is often dumped locally	No fecal sludge treatment	n.a.

COMPROMISED HIGHER END SANITATION TECHNOLOGIES

Single leach pits remain common in rural West Bengal, but the more affluent households are opting for septic tanks and mechanized emptying. These "aspirational technologies" are preferred to twin pit systems and are assumed to be "improved," but their public health benefits are questionable when construction does not adhere to design standards and emptying is not safely managed. Poorly constructed septic tanks and unsafe management of fecal sludge may present at least as high a risk to public health as open defecation.

QUICK FACTS

- Pathar Pratima is a village in South Twenty-Four Parganas District, West Bengal India
- Regional typology: intermediate remote
- Population of district: 8,161,961 (2011)
- Population density of district: 819.5 residents per km^2
- Main economic activities: agriculture and industry
- Children under age three with diarrhea in: 7.1% (West Bengal, DHS 2015-16)
- Prevalence of stunting under children under 5 (2015 DHS): 38.4%

Current Sanitation Practices

Single leach pits and manual emptying are common in rural West Bengal, though some more affluent households are opting for septic tanks. A study of households in 16 Indian districts, for instance, finds 21 percent of households have a septic tank (WaterAid India 2017b). Septic tanks are assumed to be "improved" sanitation, but their public health benefits are questionable when the construction does not adhere to design standards, and the emptying is not safely managed. Poorly constructed septic tanks and unsafe management of fecal sludge may present at least as high a risk to public health as open defecation.

In Pathar Pratima—a 100 percent open defecation free village in South Twenty-Four Parganas District, West Bengal—91 percent of households have single pit latrines; the other 9 percent, typically the more affluent, claim to have a septic tank (SRI 2015). Households are apprehensive of twin leach pit latrines, which they believe—perhaps on the advice of masons angling for more work—fill up faster than septic tanks (Ganesan 2017).

Septic Tank Components

A septic tank is a watertight structure with at least two chambers, allowing solids to settle in one tank while effluent flows into the second tank and eventually into a soak pit or leach field through an outlet pipe. The dividing wall of the two chambers retains the solids in the first tank and slows down the flow to provide greater opportunity for microorganisms to break down the organic material (known as anaerobic digestion, or the absence of oxygen). T-shaped inlet and outlet pipes prevent scum (floating on the surface) and solids (at the base) from escaping with the effluent.

Generally, a well-designed and well-maintained septic tank with more than 48 hours of retention time can achieve 50 percent removal of solids, a 30 percent to 40 percent decrease of biochemical oxygen demand (BOD), an indicator of the level of water pollution, and a 90 percent removal of *E. coli* (Tilley et al. 2014). This is not sufficient for the effluent to be discharged to the environment: it requires further treatment, such as infiltration through a leach field or soak away. Leaching from either septic tank soak pits or simpler pit latrines is effective only when the water table is below the depth of the structure. Appropriate septic tank design depends on the number of users, volumes of water per capita, the climate, and the desludging frequency. Wastewater characteristics and treatment efficiency vary greatly depending on operations and maintenance (O&M) and climatic conditions (Tilley et al. 2014).

In Pathar Pratima, septic tanks are typically made from brick and cement with an average size of 2.1 meters by 2.25 meters and with a ceramic flush toilet pan (WaterAid India 2017a). Masons typically build a septic tank to the space available and household requests rather than the Bureau of Indian Standards (BIS) specifications, so the size, number of chambers, and installation of a soak away are considered optional rather than necessary. Units sold as septic tanks are often in fact one large chamber with or without a solid base or walls.

Absence of the dividing wall and T-junction pipes, known as baffles, means the solids and scum will not be retained in the tank. This significantly reduces the system's treatment capacity: it risks clogging of the outlet and any downstream system, and creating other problems for the user household.

While the data are not definitive, there is a strong likelihood that this situation is replicated widely in the region, and many of the septic tanks built do not meet the BIS specifications and are not functioning or managed properly. This appears especially prevalent in Western Uttar Pradesh, Haryana, and Punjab. By some estimates, 67 percent of so-called "septic tanks" have unsealed walls and bases with no or poorly functioning soak away (WaterAid India 2017a), posing a public health risk similar to (or, in the case of open soak pipes in Pathar Pratima, worse than) leach pit latrines.

In Pathar Pratima, septic tank owners prefer to see the effluent outlet pipe discharging to a drain because they mistakenly believe this indicates it is working (Sugden 2015). This effluent will potentially have less suspended organic matter than raw fecal sludge, but will still have high levels of pathogens (Sugden 2015), which is not how septic tanks are designed to work.

Fecal Sludge Management Practices

In rural West Bengal, manual emptying of household latrines is prevalent (72.9 percent), although some mechanized private operators based in towns and cities serve predominantly the higher-income households with septic tanks.[1] The average cost of manual emptying is Re 724 (US$11); septic tank emptying costs are approximately double, and prices vary depending on socioeconomic class (SRI 2015).

In Pathar Pratima, emptiers are typically low-caste laborers who undertake any form of unskilled labor. Manual emptiers typically live locally and promote their availability on morning village rounds (Sugden 2015). The sludge has a high water content, and emptying is done using a bucket tied to a rope; emptiers do not necessarily enter the tank or lift the thicker sludge, but this may happen. Regardless of whether or not the emptier enters the tank, manual emptying is a dangerous and unpleasant job. Workers are exposed to pathogens and fumes and risk injury or death entering tanks. Sludge and effluent are discharged in the immediate environment. In higher density areas where such a practice is impossible, emptiers carry the waste a short distance to a more convenient and less controversial dumping location (Sugden 2015). The pathogenic and organic load of this waste depends on the conditions and length of time it has been contained.

The small number of private tanker operators use tractors with 4,000-liter trailers, dumping the waste locally into a pit or drain (SRI 2015; Sugden 2015). They typically serve the urban area—they will visit rural customers, but the higher costs associated with longer distances are passed on to the households (SRI 2015). There is a lack of private tanker operators in rural areas. See summary in table 8.1.

TABLE 8.1. Public Health Issues and Scale of the Problem of FSM in Bangladesh

Public Health Issues	Scale of the Problem
Increasingly, septic tanks are perceived as the aspirational sanitation technology for those who can afford one. However, septic tanks are often poorly constructed and do not adhere to BIS design standards.	A sample study in 16 districts found that 21 percent of households were found to have septic tanks (WaterAid India 2017b).
Poor construction will compromise the performance of the technology, leading potentially to both health risks (for example, effluent discharge) or higher costs to the household (in frequent emptying and maintaining costs). Households are often poorly informed about the maintenance costs, leaving them dissatisfied with their choice.	Many (by some estimates 67%) so-called septic tanks with unsealed walls and bases with no or poorly functioning soak away.
Manual emptiers fill the lack of mechanized emptying services using buckets and ropes tanks, which is an unhygienic, dangerous, and unpleasant job.	Indiscriminate dumping is likely to be widespread as there are few fecal sludge receiving or treatment plants adequately serving rural areas.
Fecal waste is commonly discharged in the immediate environment.	

Note: BIS = Bureau of Indian Standards; FSM = fecal sludge management.

Note

1. Bureau of Indian Standards IS 2470 (Part 1): Code of Practice for Installation of Septic Tanks, Part 2: Design Criteria and Construction.

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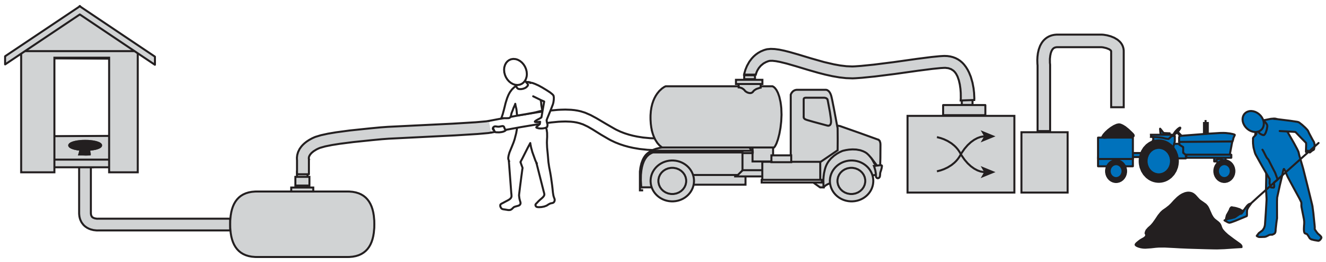
Chapter 9 Hanging Latrines and Fishpond Toilets in Vietnam



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
Unimproved sanitation technology	No containment	n.a.	Discharge to open rivers and canals	No adequate treatment of fecal waste	Cost and resource recovery in domestic pisciculture

FISHPOND TOILETS

Hanging latrines and fishpond latrines are common in rural Vietnam. The Mekong River Delta is home to one-fifth of the country's population, or approximately 17 million people (Arnold 2017). More than half of Vietnamese households without improved sanitation facilities live in this area (Nguyen et al. 2016). The biggest sanitation-related public health risks in the Mekong Delta come from the direct discharge of sewage, septage, and fecal waste into rivers and canals, often via hanging toilets. Thirty-seven percent of the Mekong Delta population use hanging latrines, with similar practices—albeit to a lesser extent—in rural Bangladesh, Indonesia, Cambodia, and the Lao People's Democratic Republic.

QUICK FACTS

- Can Tho Municipality is home to the largest city of the Mekong Delta, with five urban and four rural districts.
- Regional typology: intermediate and close to a city.
- Population of district: 1,272,800.
- Population density of district: 884.5 residents per square kilometer.
- Hub of agricultural and industrial activity in southern Vietnam.
- Children under age three with diarrhea in Mekong River Delta: 8.4 percent (DHS 2002).
- Stunting rate of children under five in Vietnam (2015): 24.6 percent (World Bank 2015).

Current Sanitation Practices

Access to basic sanitation in rural Vietnam is at 71.8 percent, with 19.1 percent using unimproved facilities.[1] Access increased rapidly from 30 percent to 67 percent between 1990 and 2011, and open defection is as low as 3 percent (UNICEF 2016). This progress, however, masks stark regional and socioeconomic disparities, including between urban and rural areas: only 34 percent of the lowest quintile in rural areas have access to improved sanitation (UNICEF 2016). Fecal sludge management (FSM) services are currently nonexistent in rural areas.

More than half of the households without improved sanitation facilities are in the Mekong River Delta (Nguyen et al. 2016). A hub of agricultural and industrial activity in southern Vietnam, it is home to one-fifth of the country's population, approximately 17 million people (Arnold 2017). The biggest sanitation-related public health risks in the Mekong Delta come from the direct discharge of sewage, septage, and fecal waste into rivers and canals, often via hanging toilets.

Sanitation Technologies

In the Mekong Delta, almost all the toilets are wet toilets. The most common improved system is a pour-flush to septic tank. Thirty-seven percent use hanging latrines (UNICEF 2015): either simple latrine structures suspended over a body of water or "field combat" latrines (a solid superstructure that flushes directly into the river or a fishpond). Latrines with a flush to a fishpond or other body of water are culturally accepted in rural areas. Pisciculture from the fishponds provide households with both a sanitation solution and a source of income or food (Nguyen et al. 2016).

Fishponds commonly farm tilapia, gouramis, and carp, and are fed by fishpond toilets, swine slurry, and chicken manure (Arnold 2009). The desire to retain the economic benefits of fishponds are a strong barrier for many rural households to replace fishpond toilets with hygienic latrines (Nguyen et al. 2016). Still, urbanization of rural areas—and the associated higher income—is likely to present growing market potential for improved sanitation.

There are primary risks associated with this form of domestic waste-fed pisciculture relate to workers, families, and communities being exposed to excreta-related hazards. For example, contaminated water may be used domestically, children may swim in the water, and there is increased vector breeding due to open wastewater-fed pools being in the immediate living environment (Kotsila 2017; WHO 2006). The risk of contamination is exacerbated by seasonal monsoon flooding, which affects large parts of the delta. The risk of infectious diseases from eating waste-fed aquaculture is significantly reduced if the foods are eaten after thorough cooking (WHO 2006).

Fecal Sludge Management Practices

FSM does not feature in the rural sanitation strategy for the Mekong River Delta Region (VIHEMA 2013). Even if households did not have economic reasons to prefer fishpond

TABLE 9.1. Public Health Issues and Scale of the Problem of FSM in the Mekong Delta

Public health issues	Scale of the problem
Health and environmental risks of fishpond latrines predominantly relate to people living near large bodies of contaminated water and contamination of drinking water sources.	**Scale of use.** Hanging latrines above water are common in many delta and other waterlogged areas in Southeast Asia. Fishpond toilets are very common in the Delta regions of Vietnam and elsewhere, including Cambodia, Lao PDR, and China. In the Mekong Delta approximately 6 million people are using hanging latrines.
Strong economic drivers to maintain the status quo. Many households are unwilling to build new or upgrade to hygienic latrines if it means destroying fishpond latrines and giving up economic benefits (Nguyen et al. 2016).	**No FSM treatment.** Upgrading rural households to more hygienic latrines does not provide a complete solution for safe excreta management. Further measures are needed to either safely contain excreta in situ or remove and treat it remotely.

Note: FSM = fecal sludge management.

toilets, currently there is no viable fecal sludge treatment solution. Even in Can Tho, the largest city of the Mekong Delta, fecal sludge—if collected—is dumped at the landfill (WHO 2006). Many urban households simply avoid the US$130 (3 million VND) emptying fee and connect their septic tanks to drains that discharge directly to the Mekong River (Arnold 2009). See table 9.1 for a summary.

Note

1. WHO/UNICEF WASH Data website, accessed May 30, 2019, https://washdata.org.

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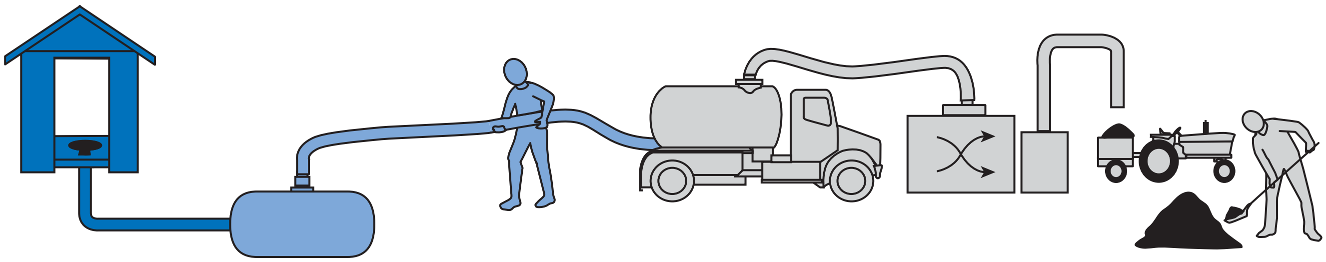
Chapter 10 Managing High Volumes of Septage in the Nile Delta, Egypt



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
Improved sanitation	Compromised construction	Mechanical emptying by vacuum tankers or by self-built, simplified sewers	Fecal waste is often dumped locally	No fecal sludge treatment	No cost and purposeful nutrient recovery

SEPTAGE MANAGEMENT IN THE NILE DELTA

Many high-density rural areas of the Nile Delta lie beyond the formalized sewer networks of cities and towns. The high water table limits ground infiltration and means on-site wet sanitation systems require frequent emptying, pushing their cost higher than networked systems. Several villages have installed rudimentary self-built sewers, which discharge to local drainage canals—as do vehicles that empty the on-site systems. The region is vulnerable to climate change: including sea rise, flooding, and water scarcity, which means untreated drainage canal water is increasingly used in crop irrigation.

QUICK FACTS

- Beheira Governorate is in the north Nile Delta.
- Regional typology: predominantly rural, close to a city.
- Population of governorate: 6,277,000.
- Population density of district: 1,000 residents per square kilometer.
- Primary economic activities: agriculture and industry.
- Children under age three with diarrhea in rural Upper Egypt: 22.9 percent (DHS 2014).
- Stunting rate of children under five in Egypt (2014): 22.3 percent (World Bank 2014).

Current Sanitation Practices

The Arab Republic of Egypt boasts 90.03 percent coverage of basic improved sanitation in rural areas.[1] The reported 26.28 percent of safely managed sanitation in the 2017 JMP report refers to sewers; no data were recorded for safely managed in situ or fecal sludge treated. The biggest sanitation-related public health risks in the Nile Delta come from the dumping of fecal waste in drainage channels and, with increasing water scarcity, the subsequent use of untreated wastewater in irrigation.

Sanitation Technologies

Kawm Azizah is a typical small village in the Nile Delta, densely populated with narrow lanes. Squatting pour-flush toilets are most common, with a small proportion of sitting flush toilets. The village water supply has low pressure. Villages with rehabilitated water supply are witnessing more frequent emptying due to their increased water consumption.[1] Approximately half of the 1,500 residents use *bayaras,* or simple vaults (cesspits), 9–15 cubic meters, which receive all blackwater, some greywater, and sometimes liquid manure. They are typically bricked with a ground (unsealed) or concrete floor, depending on the perceived groundwater level (approximately 1 meter deep in Kawm Aziah). Bayaras cost LE 3,000 (US$168) to build and require emptying every 10–30 days (the average is 20).

The other half of the residents use self-built, self-funded sewer networks that discharge to a nearby drainage channel. There are five such networks. Several households discharge directly to stormwater drains. Pipes are approximately 10 inches wide. Small, informal sewers are common, and often designed by a private contractor. A study of 40 villages in the Beheira Governorate identifies multiple informal sewer networks, ranging from recently constructed up to 30 years old (Reymond et al. 2014). Typically, they are problematic, and one person is tasked with their frequent maintenance.

Both on-site and off-site systems discharge untreated waste to the drainage channels, which poses public health and environmental risks. The bayara septage is five to 10 times more concentrated than the sewage from the same village, because bayara owners do not discharge their greywater to the on-site systems to minimize emptying costs (Reymond et al. 2014).

Fecal Sludge Management Practices

Estimates of total fecal sludge production are 70–110 liters per capita per day. Table 10.1 shows the average fecal sludge characteristics of bayara septage, though samples show a high variability—some comparable to sewage, others with up to four times the normal septage levels of concentrations of biochemical oxygen demand (BOD) and pathogenic load. This is mainly affected by (a) water consumption, primarily driven by water supply quality; and (b) the number of animals and how households manage animal excreta.[1]

Emptying of bayaras is typically mechanized: a truck aspirates the septage and transports and discharges it to the nearest drain. This practice is technically illegal, but in a survey covering 12 villages, emptiers reported encountering no enforcement or punitive action (Reymond et al. 2014). Village councils may have a truck, but mainly bayara emptying is informal and private. Emptying vehicles are typically simple, such as a tractor with tanker trailer with a capacity of 4 cubic meters. Emptiers typically make several (one to eight) trips to empty a bayara (Reymond et al. 2014). Public trucks, when available, are typically cheaper (LE 8 per trip US$0.45]]) than private (LE 25, or US$1.40, per trip).

Wastewater reuse in Egypt is illegal, but farmers report using drain water for irrigation when the canal water is too low. Direct application of fecal sludge to fields is rare because the septage is too concentrated to be applied directly.

Capacity

There is well-established technical water management knowledge in Egypt, but it tends to be biased toward centralized wastewater management systems for larger towns. Rural areas and smaller towns lack technical and institutional support for sanitation services. The clandestine sewer networks run, often poorly, independently from any utility, and there is little to no fecal sludge management capacity or interest in decentralized, smaller scale systems.

TABLE 10.1. Typical Septage Characteristics in 12 Sample Villages

		Average (Std.)	Max.	Number
pH	-	7.8 (0.3)	8.2	12
DO	mg/l	0.14 (0.02)	0.18	7
Cond.	mS/cm	4.56 (2.43)	8.62	8
BOD	mg/l	2,017 (1,864)	5,800	9
COD	mg/l	5,703 (5,556)	15,225	10
TS	mg/l	7,278 (9,778)	28,400	12
TSS	mg/l	1,252 (1,336)	3,900	12
NO2-N	mg/l	0.03 (0.05)	0.13	8
NO3-N	mg/l	2.11 (1.57)	4.07	8
NH4-N	mg/l	262 (214)	735	12
TN	mg/l	415 (343)	1,290	12
PO4-P	mg/l	11.6 (7.4)	20.9	8
TP	mg/l	41 (43.7)	159	12

Source: Reymond et al. 2014.

Note: BOD = biochemical oxygen demand; COD = chemical oxygen demand ; DO = dissolved oxygen; NO2-N = nitrate-nitrogen; NO3-N =nitrite-nitrogen ; NO4-N = oxio-nitrate; PO4-P = phosphate; TN = total nitrogen; TP = total phosphorus; TS = total solids; TSS = total suspended solids.

TABLE 10.2. Public Health Issues and Scale of the Problem of FSM in the Nile Delta

Public Health Issues	Scale of the Problem
Untreated fecal waste is disposed of into open drainage channels because there is typically no primary treatment of rural septage across Egypt (Reymond et al. 2014). With unsealed on-site systems in areas of high water table, depending on the soil and groundwater conditions and construction of the bayara, groundwater either seeps into the bayara, increasing the emptying frequency, or septage seeps into the ground, which may pollute the groundwater.	The use of untreated wastewater in irrigation. This practice is illegal but used when the well-established canal system irrigation is low. In water-scarce climates, this becomes more frequent. Centralized approach to wastewater treatment. Egypt is institutionally geared toward centralized, large-scale wastewater systems; there is little to no capacity for nonnetworked FSM systems. FSM activities remain largely informal and underdeveloped.

Note: FSM = fecal sludge management.

Note

1. Communication April 26, 2018, Philippe Reymond, Eawag.

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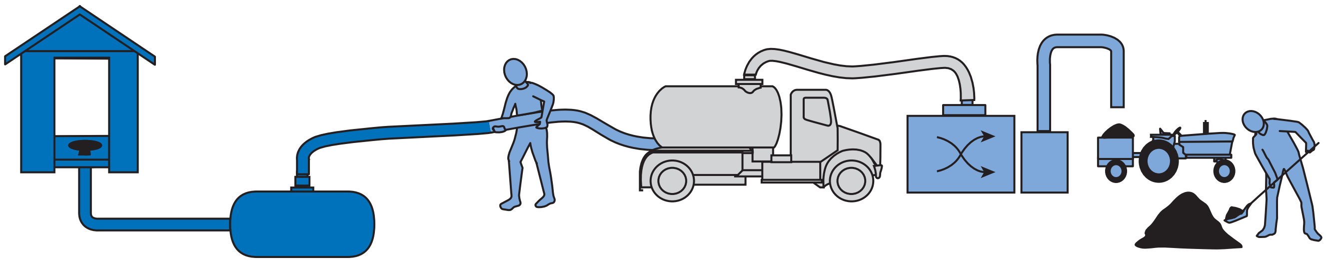
Chapter 11 The Challenges of Sustained Fecal Sludge Management for Ecosan Units in Bolivia



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
Improved sanitation	Safely contained	Emptying in context of inconsistent pathogen inactivation presents a risk	Lack of sustained emptying and transport services implemented	Inconsistent pathogen innactivation in situ	Questionable demand for household horticultural reuse

LEGACY OF SUPPLY-LED AND AD HOC INTERVENTIONS IN BOLIVIA

In Bolivia, rural towns may have better water supply and sanitation (WSS) infrastructure than peri-urban zones of larger cities. Generally, in areas outside the formal sewer systems, sanitation provision and uptake of latrines have been low. Water scarcity, minimal governmental support for sanitation, and critical conditions of hygiene and disease have led several nongovernmental organizations (NGOs) to focus on sanitation (Allen et al. 2016; Eelderink et al. 2017). Tens of thousands of urine diverting dry toilets (UDDTs) have been built in rural Bolivia, but the ad hoc, supply-led nature of the programs has resulted in varying quality.

QUICK FACTS

- This chapter draws on peri-urban Cochabamba and peri-urban el Alto, a city in La Paz district.
- Regional typology: predominantly urban area
- Population of urban area: Cochabamba: 1,971,500 / La Paz: 2,883,500
- Population density: 33,182/km^2 peri-urban
- Cochabamba; 846/km^2 in El Alto
- Economic activities: service, agribusiness for export and small-scale farm holding
- Children under age three with diarrhea: 35.6 % (Cochabamba, DHS 2008) and 31.0% (La Paz, DHS 2008); Under five stunting prevalence (Colombia, 2010): 12.7% (World Bank)

Current Sanitation Practices

In urban Bolivia, 42.4 percent of people have improved sanitation—half of which are sewers—compared to 26.8 percent in rural areas.[1] In 2015, 46 percent of the 3.5 million people living in rural Bolivia still practiced open defecation (WHO/UNICEF 2012). The rural-urban divide is complex, however, because rural towns may have better WSS infrastructure than peri-urban zones of larger cities. For example, in the informal Zona Sur of Cochabamba, there is no piped water, 75 percent lack improved sanitation, and open defecation remains common (Bjersing, Krusich, and Simeone 2015), whereas a rural town of 1,900 residents in the same region has almost full sewerage coverage and wastewater treatment (Cafolla et al. 2012).

Generally, in areas outside the formal networked systems, sanitation provision and uptake of latrines is low. NGOs have targeted rural and peri-urban sanitation, particularly ecological sanitation, given the context of water scarcity, minimal governmental support for sanitation, and critical conditions of hygiene and disease (Allen et al. 2016; Eelderink et al. 2017).

Sanitation Technologies

Beyond the sewage networks in rural areas, ad hoc sanitation projects from a range of organizations have provided various forms of latrines, often fully subsidized. There is typically a range of sanitation solutions ranging from pit latrines, flush toilets to septic tanks, UDDTs, and open defecation. Despite the support of NGOs, limited understanding of the cultural values of indigenous communities—and insufficient attention to demand creation, hygiene awareness and behavior change—mean supply-led sanitation interventions have achieved a low latrine uptake—typically around 50 percent (Dicken 2016; World Bank 2012).

The numbers of ecological sanitation ("ecosan") systems are growing in rural Bolivia, and tens of thousands of these toilets have been built. The most common type is the double chamber UDDT (McKinley 2012). Urine is diverted to holding tanks to keep the feces chamber dry. One to two cups of lime or ash are added after defecation to lower the moisture content and pH, creating less favorable conditions for pathogens and reducing odor and flies (Jenkins 2005). Cellulose or sawdust can also be used as a less efficient but highly compostable desiccant. When one chamber is full, the user leaves it to decompose and switches to the other. Theoretically, once the second chamber is full, the first can be emptied and the compost can be used to condition horticultural soil.

Fecal Sludge Management Practices

Ecosan, when properly managed, can be a viable decentralized option for rural areas. However, it is socioculturally sensitive and vulnerable to improper maintenance, leading to adverse effects on health (Eelderink et al. 2017). It is difficult to draw a

TABLE 11.1. Public Health Issues and Scale of Problem of FSM in Bolivia

Public health issues	Scale of the problem
Inconsistent pathogen in activation of UDDTs. **Toilets provided by projects and programs but no FSM measures in place**. Ecosan toilets are often provided with an expectation that households will manage the waste themselves; there is no institutional mandate for the municipality to take any FSM role so even in cases when NGOs have attempted to generate emptying services, there are challenges to initiate and sustain them.	**Legacy of unused toilets.** A history of supply-led sanitation provision and limited role of government has contributed to a legacy of ad hoc supply, unused, or misused toilets. There is a lack of awareness and behavior change to create the demand needed to sustain toilet uptake and hygienic use. **Ad hoc on-site sanitation provision.** Because there is no institutional ownership in areas beyond networked sanitation systems, provision is mostly left to NGOs, on an ad hoc basis which presents challenges for sustained quality and universal approaches.

Note: FSM = fecal sludge management; NGO = nongovernmental organization; UDDT = urine diverting dry toilet.

comprehensive picture in Bolivia: the project-based implementation of on-site UDDT systems by multiple NGOs has led to variable quality; some projects focus on technology, others on behavior and hygiene. Documentation and comparative analysis is weak. This review identified the following challenges with UDDT interventions in rural Bolivia (see also table 11.1):

- **Lack of sustained emptying and treatment services for the ecosan units.** NGO interventions have provided tens of thousands of households with ecosan units. In many cases households are expected to manage the waste themselves (Suntura and Sandoval 2012). Not all the NGO ecosan project designs include postconstruction support. Some intend to collect, safely compost and commercialize the end product for local markets; there is evidence that when these services were not introduced or failed, households returned to open defecation or dumping of the waste in the immediate environment (Dicken 2016; Rayneart 2016).
- **Inconsistent pathogen inactivation in UDDTs.** Tests have shown that even when properly used, some UDDTs do not consistently achieve pathogen inactivation as a result of inconsistencies in pH, moisture content, or temperature (McKinley 2012). This is a significant public health concern if households are encouraged to compost the solids for personal horticultural use.
- **Lack of fecal sludge treatment.** Even in areas with established enterprises to empty septic tanks and other on-site systems, households or others discharge the waste untreated into local river basins.[2]

Notes

1. WHO/UNICEF WASH Data website, accessed 30th May 2019, https://washdata.org.
2. Personal communication with Humberto Caracas May 7, 2018, Latin American and Caribbean WASH expert.

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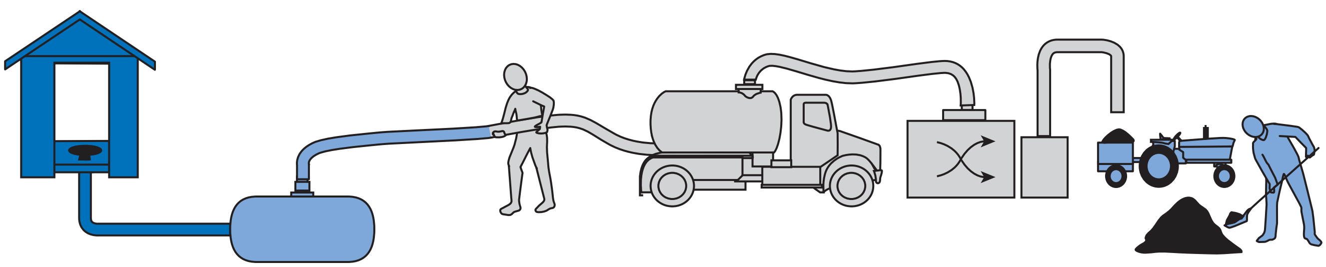
Chapter 12 Poorly Constructed and Managed Toilets in India



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
Improved sanitation	Compromised sanitation structures and pit contents retain pathogens	Manual pit emptying is prevalent	Fecal waste is dumped in or near homestead	No fecal sludge treatment	Demand for reusing the sludge horticulturally is low because homesteads are often small

POORLY CONSTRUCTED TWIN PITS

Over 80 million household toilets have been built in India since 2014 (http://swachhbharatmission.gov.in). The twin leach pit latrine is the dominant technology promoted for rural areas in India. Indeed, over half of all the toilets constructed under the most recent Swachh Bharat Mission-Gramin (SBM-G) are twin leach pit toilets (WaterAid India 2017). 2017 figures from India indicate a sharp increase in numbers and usage of latrines (QCI 2017; WaterAid India 2017). There are however some concerns regarding quality of construction of the latrines.

QUICK FACTS

- The basic twin leach pit design is the primary household technology of the Swachh Bharat India Campaign, and recent figures indicate a sharp increase in numbers and the usage of latrines (QCI 2017; WaterAid India 2017). Good functionality is a key predictor of latrine use. Chapter 16 considers well-constructed systems; this case study considers some known quality issues around construction across India.
- Children under age three with diarrhea (rural India): 12.4 percent (DHS 2015–2016).
- Stunting of children under five in India (2014): 38.4 percent (World Bank 2014).

Current Sanitation Practices

The basic twin leach pit design (see photograph 12.1), which is promoted by the SBM-G, consists of two pits, typically 1 meter in diameter and 1-1.5 meters deep, for alternate use. The pits are connected to the latrine via a junction chamber: once one is filled, the other is put into use. Honeycomb walls or perforated concrete rings allow the effluent to leach into the soil. In areas with a high water table, the pit should be surrounded by a soil or sand envelope for improved filtration, with a sealed base. The latrines are typically connected to a pour-flush pan. It takes an estimated three years to fill one pit, by which time—under the right conditions—the contents of the other pit should have degraded sufficiently to be handled safely (Bejjanki 2017). Well-constructed twin pits are technically suitable for 60 percent to 70 percent of India's rural population, outside of areas that are rocky, hilly, flood-prone, or with a high water table.

The key predicators of latrine use include their functionality and the quality of the superstructure (Sinha 2017). In the Puri District of Odisha, the primary causes for dysfunctional toilets are pit collapse, soil infiltration, and junction box malfunction (Roy 2012). Poor construction is a widespread problem: 31 percent of toilets across eight states do not safely prevent human contact with fecal matter (WaterAid India 2017). The effectiveness

PHOTOGRAPH 12.1. Twin Pit Latrine Construction

Source: World Bank.

of fecal sludge management (FSM) is mostly dependent on the quality of the substructure, which is difficult to inspect while the latrine is in use. However, the following technology failures have been observed in the field:[1]

- **Nonadherence to design, preventing leaching of effluent or desiccation of pit contents.** This includes both pipes from the junction box leading to one large pit, with a separating wall; only one pit being dug, with an expectation that the second will be constructed when needed; and use of unperforated ferro-cement rings instead of the honeycomb structure to line the pits, preventing leaching and reducing the lifetime of the pit.
- **Faulty, missing, or wrongly operated junction box.** This includes when the junction is missing, so both pits fill simultaneously; or when the junction box is easily clogged or broken, which presents problems when switching to the alternate pit and often causes continued seepage of fecal matter to both pits.
- **Construction in unsuitable areas**, including areas with high groundwater tables and flood-prone or rocky areas.

The underlying reasons for these technology failures include the following:

- **Households lack awareness of the technological options,** and are therefore not equipped to make informed decisions, monitor what is being built for them, or maintain the systems as required.
- **Twin pit leach toilets are perceived as the low-cost technology option**; families who can afford to often opt for an septic tank, which—though larger—often lacks baffles or soak away, so may not necessarily offer reduced emptying frequency.
- **Masons attempts to maximize their economic return by cutting corners in toilet construction.** The government flat rate incentive of Re 12,000 (US$170), depending on local conditions, often does not cover the full cost of a twin leach pit latrine. Contractors may therefore seek to reduce costs and opt to build a single pit or a nonstandard substructure using cheaper and fewer materials or doing less labor.
- **Lack of monitoring of what is being built underground**; there are no policy measures or implementation mechanisms to monitor the quality of the substructure during construction.
- **Current behavioral change communications focuses on social status**, **convenience, privacy, and safety,** which are met by a sound and high-quality super structure.
- **Householders are not always provided with an informed choice of technology.** In some districts the technology is selected for an entire area, and households get little supporting information, communication, or education on the selected sanitation technology and the O&M thereof.
- **Insufficient awareness and technological options for flood-prone or rocky land.** There is a lack of adequate knowledge of technical options for different terrains (WaterAid India 2017).

TABLE 12.1. Public Health Issues and Scale of the FSM Problem in India

Public health issues	Scale of the problem
Poor latrine construction will lead to technology becoming unusable, with public health implications if users revert to unimproved alternatives or open defecation.	Over 40 million twin pit latrines have been built in India since 2014. There is concern that significant numbers of the underground structures do not adhere to minimum technical standards.
Compromised functionality of on-site systems. Poorly constructed twin pits compromise the ability to provide conditions to render fecal sludge safe for emptying.	There is an expectation that the sludge is managed autonomously by the household, but household awareness, education, and institutional support to monitor and ensure those practices are done safely is not yet a central focus.
Safely managing the fecal waste of India is a significant challenge, following the already significant task of ending open defecation. Eleven states incorporate FSM into their sanitation strategy, but mostly for cities rather than rural areas, and most strategies are not yet operationalized.	One study across eight states finds 31% of toilets do not safely prevent human contact with fecal matter (WaterAid India 2017).

Note: FSM = fecal sludge management.
a. WaterAid India 2017.

Fecal Sludge Management Practices

Information on FSM for high-density rural areas in India is limited. Some evidence comes from Cuttack, a city of 610,189 people, 60 percent of whom rely on on-site sanitation. Municipal and private vacuum tank operators exist in the city, and the municipal trucks charge Re 750 (US$11.29) (Rohilla 2015). Fecal sludge is dumped on wasteland outside the city, because there is no dedicated fecal sludge treatment or deposit site. The tankers will sometimes visit households further outside the city with septic tanks and dump the waste locally. This is likely practiced in other urban and high-density rural agglomerations with no dedicated fecal sludge treatment site (see chapters 7 and 9). See also table 12.1 for a summary.

Note

1. Personal communications with Joep Verhagen July 16, 2018, Water Global Practice of the World Bank, and V. K. Madhavan August 1, 2019, WaterAid India.

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Part 3

Case Studies in Organically Emerged Fecal Sludge Management Services

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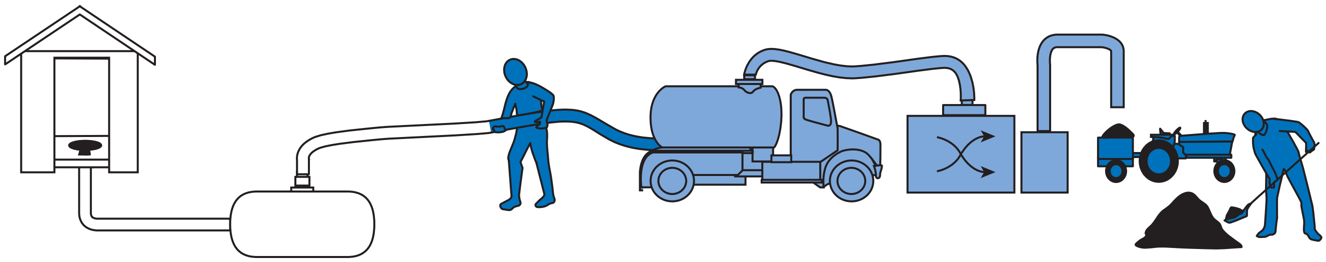
Chapter 13 Irrigation by Septage, India



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	Fecal waste is hygenically emptied mechanically	Fecal waste is removed from living environment, some	Basic trench infiltration unlikely to achieve full pathogenic inactivation	Cost and nutrient recovery

IRRIGATION BY SEPTAGE

Reuse of untreated wastewater and septage in irrigated agriculture is documented in more than 60 countries. Because it is predominantly an informal activity, the true scale is likely larger. In the absence of infrastructure to treat or simply receive the thousands of cubic meters of septage and fecal sludge collected, emptiers of on-site sanitation must find suitable locations to discharge it. In Bengaluru, India's third most populous city, farmers and pit emptiers have become allies to tackle this problem (BBC 2018; Kvarnström et al. 2012).

CASE QUICK FACTS

This case documents a common, informal practice of irrigation of agriculture with septage and fecal sludge. The case presents a organic relationship between emptiers and farmers offering cost and nutrient recovery, but poor pathogen control is a health hazard to farm workers, farmers, and consumers.

Demand for Wastewater

The reuse of untreated wastewater and septage in irrigated agriculture is documented in more than 60 countries (Thebo et al. 2017) and more than an estimated 30 million hectares

(Strauss and Blumenthal 1990). Because it is predominantly an informal activity, the true scale is likely larger (Thebo et al. 2017). Eighty-six percent of wastewater-irrigated croplands are found in China, India, Mexico, Pakistan, and the Islamic Republic of Iran. The practice is common in downstream of urbanized and densely populated rural areas (Thebo et al. 2017).

In the absence of infrastructure to treat or simply receive the growing volume of black and greywater from the world's cities, emptiers of on-site sanitation must find suitable locations to discharge the thousands of cubic meters of septage and fecal sludge they collect. This case study draws predominantly from a case study in Bengaluru, India's third most populous city, where farmers and pit emptiers have become partners to deliver this fecal sludge management service (BBC 2018; Kvarnström et al. 2012). See table 13.1 for a summary of this case study's assessment of fecal sludge management outcomes; see table 13.2 for a summary of limitations and enabling factors.

Technical Aspects

In Bengaluru, 60 percent of residents rely on on-site sanitation systems. These are typically septic tanks or simple holding tanks receiving wastewater from toilets, kitchens, and showers. These tanks are periodically emptied by informal private operators, dubbed "honeysuckers." Households are charged Re 500 to Re 3,000 (US$7.50 to US$45) for the emptying service at a frequency ranging from daily to once a year (Kvarnström et al. 2012). At the time of the Bengaluru study, the emptiers had been granted permission to dump in designated sewage treatment plants managed by Bengaluru Water Supply and Sewerage Board for a fee of Re 20 (US$0.30) per cubic meter of sludge deposited. Fecal sludge typically has a higher solids content than sewage wastewater and can overload wastewater treatment plants (WWTPs) (Lopez-Vazquez et al. 2014). However, tanker operators more commonly dumped in vacant plots or in farms adjacent to the city (Kvarnström et al. 2012). This practice emerged organically between the farmers and tanker operators, without any external brokering.

The honeysucker drivers seek farmers who are willing to accept fecal sludge deposited on their land in one of three ways. In one option, the farmer digs a large pit adjacent to the farmland to receive fecal sludge. It is left to settle for two to three months for infiltration or evaporation of the liquid. Once dry, the fecal matter is dug out and applied to crops, or in the case of one farmer, sold as soil conditioner. In another, trenches are dug between the plants and fresh sludge fills the trench network and infiltrates to the soil (Kvarnström et al. 2012). This happens mainly on banana plantations or vineyards. This practice is also reported 70 kilometers away in Tumkur (Rohilla et al. 2015). In the third option, fecal sludge effluent is applied directly to vacant land that will be farmed later in the season. The handling of fresh sludge carries a higher health risk for the farm laborers and consumers of the produce, though the risk can be mitigated by using trenches and growing crops that are not customarily eaten raw.

TABLE 13.1. The Fecal Sludge Management Model

Objective	Description
Removing Waste from the Environment	In Bengaluru, the honeysuckers provide a service of removing fecal sludge from the immediate environment using mechanical emptying. However, we cannot confirm that all the fecal sludge collected is processed in this way and must assume some fecal sludge is dumped in other locations (e.g., canals, wastelands). The system emerged as a response from middle- and upper-income groups that are not connected to the city's sewer network and needed a solution to empty their septic or holding tanks.
Pathogen Inactivation	The techniques applied in the Bengaluru case (i.e., dewatering and infiltration) would likely achieve partial pathogen removal; however, this is not controlled and presents a risk to the farm laborers because there is likely to be high variation in the pathogenic load of different batches. In addition, the informal practices do not adhere to the World Health Organization (WHO) guidelines on wastewater use in agriculture, which suggest a combination of measures are required for health risk mitigation (WHO 2006) to mitigate the risk for consumers.
Waste to Resource	In Bengaluru, farmers report an increased yield with the use of fecal sludge as a fertilizer. It is especially common to use dried sludge as compost in banana gardens and grape orchards (BBC 2018; Kvarnström et al. 2012).
Scale	In Bengaluru, this system is operating at scale and the use of fecal sludge in agriculture has been practiced for decades. Similar practices are in operation in nearby towns. Wastewater use in agriculture is a worldwide phenomenon, and similar practices are likely to exist elsewhere (Thebo et al. 2017).
Self-Sufficiency	In Bengaluru, this system of collection, disposal, and reuse of fecal sludge developed entirely outside formal systems and institutions, without any financial or technical assistance (Kvarnström et al. 2012).
Financial Arrangements	Financial arrangements depend on local dynamics. In Bengaluru, households are charged for their pits to be emptied; the sludge is then dumped on nearby farms, most commonly with no money exchanged between the emptier and farmer, although sometimes the farmer may pay a small fee (e.g., Re 100 [US$ 1.50]) to "buy" the waste. Emptiers are also permitted to dump fecal sludge at a WWTP for a fee of Re 20 (US$0.30) per kiloliter of sludge (Kvarnström et al. 2012). In Tumkur (70 kilometers away), the emptiers pay local farmers a tipping charge of Re 10,000 (US$150) per year (Rohilla et al. 2015). The financial gains for farmers in Bengaluru from reduced need for fertilizer range from Re 8,000 to Re 170,000 per year (US$120 to US$2,550). One farmer who sold dried sludge to other farmers had an additional yearly income of Re 450,000 (US$6,750) (Kvarnström et al. 2012). The financial viability for the farmer is reliant on the fact that he does not assume any transport or treatment costs.
Business and Client Partnerships	In Bengaluru, arrangements between the emptiers and farmers are opportunistic and informal. Most often truck drivers take their waste to farms in a network of locations known to them, minimizing haulage costs (Kvarnström et al. 2012). In Tumkur, there is a more formal relationship, in which the emptier pays the farmer (Rohilla et al. 2015).
Robustness	As the contrast between Bengaluru and Tumkur shows, contextual dynamics and the direction of incentives can be quite localized. This robust example emerged without subsidy or external support. The system is viable because the negative effects of the dumping of untreated sludge are not born by the polluters but by the farmers and consumers.

TABLE 13.2. Limitations and Enabling Factors

	Limitations	Enabling factors
Policy, regulation, and enforcement	Regulatory and policy frameworks that do not allow any use of wastewater in agriculture limit the growth of these informal enterprises. They may force a widespread practice to remain under the regulatory radar and informal, which reinforces the risks of limited awareness and poor practices. The informal character of the enterprises hampers scaling up and technical innovation.	Acknowledgement of the practice in an appropriate policy and regulatory framework may provide the right incentives to promote safer wastewater use practices. The WHO guidelines suggest health protection may be achieved through a combination of measures, including (a) crop restriction to nonfood crops, (b) food crops that are processed before consumption, or (c) cooked foods (potatoes, rice) (WHO 2006).
Risk mitigation	Farmers are applying some measures to control for pathogens, such as settling prior to application and the use of irrigation trenches; however, their effectiveness in terms of health or environmental risk mitigation is not quantified or controlled. Further controls need to be in place on risks around chemicals and heavy metals.	Safer practices can be reinforced at the farm site through awareness of the hazards and mitigation points and upgrading the wastewater storage, handling, and distribution.
Nutrient recovery	Fecal sludge is a relatively poor soil conditioner.	There is scope to work with farmers to produce higher-quality compost, with market value.

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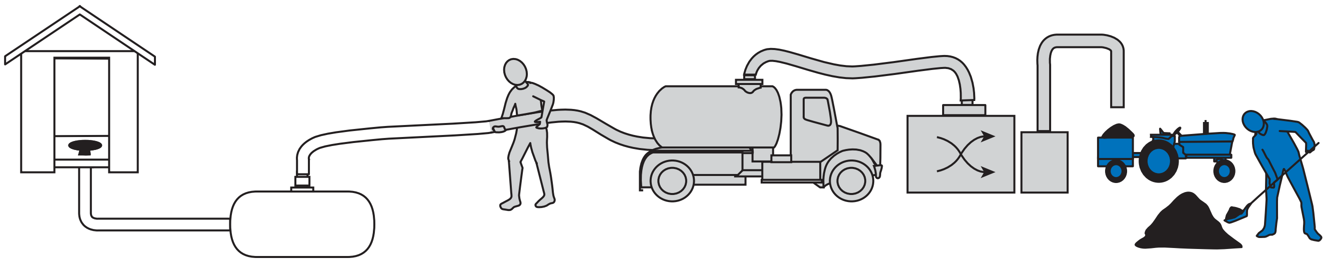
Chapter 14 Looking Back at the Traditional Dry Vault Systems of Afghanistan



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	Likely direct pathogen exposure during manual emptying	Fecal matter is removed by donkey cart, presenting risks	Likely poorly controlled pathogen removal	Nutrient recovery for farmer

HISTORICAL ECOLOGICAL SANITATION

A traditional eco-sanitation service had been operating in Kabul for decades. Fecal sludge was being collected from individual households and used by farmers in the vicinity of Kabul.

CASE QUICK FACTS

This case documents a self-sufficient ecological sanitation system that was in place several decades ago in Kabul, in which demand for soil conditioner by farmers maintained a household emptying service of their dry vault systems. The system was imperfect, but has lessons in terms of sustained incentives and scale.

Although imperfect, the dry vault toilet system in Kabul operated for several decades, and its collapse has resulted in a very poor sanitation situation. Enabled by dry sanitation technology and demand for organic material in a semi-rural area, this system was an example of sustained and mutually beneficial reuse. The system collapsed when the supply exceeded demand from farmers: urbanization, drought, and the fertilizer market combined to weaken the chain. Unsafe manual handling was a key risk, and the breakdown of the system led to fecal sludge contamination of a highly populated area. See table 14.1 for a summary of this case study's assessment of fecal sludge management outcomes; see table 14.2 for a summary of limitations and enabling factors.

TABLE 14.1. Assessing Fecal Sludge Management Outcomes

Objective	Description
Removing waste from environment	At regular intervals, dry sludge was manually removed from the vaults. It was then taken by contractors by cart to farms surrounding the city for application to soil. The collection was irregular and informal. It worked better in some areas than others, likely due to variations in supply and demand.
Pathogen inactivation	With limited data it is difficult to reliably assess decomposition rates in Kabul. However, it can be assumed that the fecal matter would likely not have reached 100 percent safe pathogen levels when handled. The data available on Kabul suggest that once the fecal matter reached the farms, it was either spread directly on the land or co-composted. Thus, pathogen contamination could occur potentially not only at the point of emptying the household vaults but also at application to the farmland and at the point of consumption of farm outputs. Thermophilic composting involves piling the sludge and co-composting with other organic wastes. By raising the temperature it can eliminate pathogens in weeks. It was identified as a potential intervention to improve the system in the 1975 Kabul Water Supply and Sanitation World Bank project (World Bank 2019).
Waste to resource	This system was maintained by farmer demand and collapsed in its absence. Adding organic matter to soil offers dual benefits: (a) it provides nutrients and improves the soil structure and aggregation; and (b) it improves aeration, water infiltration, and resistance to erosion and crusting (Bot and Benites 2005). The NPK nutritional values are relatively low for dry feces (Rose et al. 2015; Werner et al. 2000), because the largest proportion of NPK nutrients in excreta is found in urine. However, because the carbon content of feces is 44 percent to 55 percent of dried solids, there is benefit in returning the bulk organic matter to the soil (Rose et al. 2015).
Scale	In 1972 there were an estimated 29,000 dry vault toilets in Kabul (World Bank 2019). Although some concerns were raised about the safety of the system, it was still operating (albeit with the same public health concerns) in parts of the city in 2003.
Self-sufficiency	The system operated informally as a mutually beneficial arrangement between householders, contractors, and farmers. The emptiers were either small-scale informal contractors or farmers.
Financial arrangements	The contractors negotiated a small fee for night soil removal and sold fecal waste to farmers. There is no clear record of how this process started (Etemadi 2015; World Bank 2019).
Business and client partnerships	The 1975 World Bank Kabul Water Supply and Sanitation project supplied vehicles and trailers to collect night soil, improved 8,000 latrines, and installed a co-composting site (World Bank 2019).
Robustness	The system, while imperfect, operated largely self-sufficiently at a significant scale for decades. It collapsed when the supply of vaults to be emptied exceeded the demand from farmers for the end product, leading to unsafe disposal in the street in a highly populated area.

Note: NPK = nitrogen, phosphorus, and potassium.

TABLE 14.2. Limitations and Enabling Factors

	Limitations	Enabling factors
Market distortion	The direct and indirect consequences of the war and urbanization contributed to the collapse of the water facilities and sanitation systems. Kabul is resource-constrained and lacks institutional capacity for WSS. Various ad hoc and NGO efforts have attempted to rehabilitate the night soil system in Kabul: ICRC and ACF have been most active (Patinet 2012), but in both cases the collection and composting were not sustained.	While ecological sanitation is not well suited to dense urban areas, upgraded ecological sanitation systems that avoid unsafe emptying and handing may be appropriate in rural centers where they are already established technologies, because they build on existing knowledge, practice, and systems.
Financing	The system was entirely financed through private sources of the households and farmers, making it very vulnerable to fluctuations in demand. Once such a system breaks down it is hard to reinstate. The breakdown in demand for fecal sludge reuse brought about an acute public health risk when the FSM chain failed.	Ecological sanitation requires robust downstream pathogen removal technologies and logistical arrangements to enable them to capitalize on the waste-to-resource opportunities. In resource-constrained locations that are unattractive for the private sector, public financing is likely needed to underpin and establish these capital investments and operational services.

Note: ACF = Administration for Children and Families; FSM = fecal sludge management; ICRC = International Committee of the Red Cross; NGO = nongovernmental organization; WSS = water supply and sanitation.

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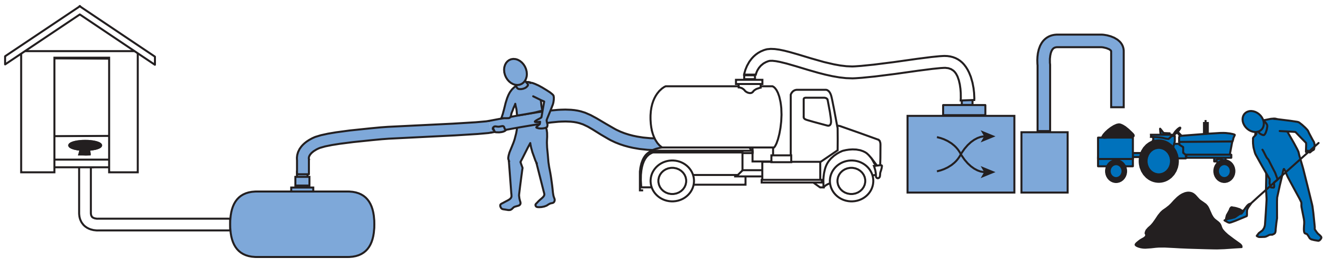
Chapter 15 The Cost-Recovery Potential of Domestic Biogas



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	Waste streams are combined on-site	Slurry needs to be emptied from digestor	n.a.	Reduces but does not eliminate viruses, bacteria, and parasites	Cost and nutrient recovery in gas and slurry

SMALL-SCALE BIOGAS DIGESTORS

Technology to produce biogas from anaerobic digestion is applied globally on a small or large scale. China has more than 30 million household digesters; India, 3.8 million; Vietnam, more than 0.5 million; Nepal, 0.2 million; and Bangladesh, 60,000 (Anwar et al. 2018). In both upper-middle-income economies and low-income economies, biogas is considered a significant contributor to rural development, but potentially a source of greenhouse gases if released unused. Its uptake has been due to the cost saving potential of energy and fertilizer costs, not as a waste disposal solution (Vögeli et al. 2014). This brief draws on experience of small-scale biogas digesters from Kerala (India), Nepal, and Vietnam.

CASE QUICK FACTS

Small-scale biogas digestors have been promoted widely in Asia to reduce health hazards from domestic waste and animal and human excrement. Uptake is often not self-initiated, but there are valuable insights in terms of working with parallel sectors in which rural development—not waste management—was the driver of uptake.

Small-Scale Biogas Digestors

Small-scale and community biodigesters apply an established technology to stimulate the economic development of rural areas in many countries across Asia. Biogas digestors create an airtight environment (anaerobic digestion) in which the organic matter of waste and wastewater breaks down to methane (CH_4) and carbon dioxide (CO_2), which can be transformed into heat or power and a nutrient-rich digestate.

The components of a biodigester are (a) a digester dome tank, ideally with a baffle to improve flow and retention of solid particles; (b) a gas holder drum; (c) waste inlets; (d) an effluent outlet; and (e) biogas outlets (Bruun et al. 2014). Maintaining good bacterial health of the biodigester is essential and requires careful management. Human excrement needs to be balanced carefully with other biowaste (agricultural or food waste), which varies by season. When too much waste means supply of gas exceeds demand, surplus gas is often leaked. Small-scale biodigesters may account for 1 percent of global methane emissions (Bruun et al. 2014).

In Kerala, a local nongovernmental organization (NGO) pioneered the installation of digesters to manage food and toilet waste. Toilet waste is flushed directly to the pit; food waste is first cut into small pieces (Müllegger, Langergraber, and Lechner 2011). The generated biogas is used directly by the household for cooking or heating. The digestate can be used as garden fertilizer, but most often is directly discharged into backwaters without any further treatment. It often exceeds 1,000 milligrams per liter of COD (chemical oxygen demand), at which level it will contribute to surface water pollution. These digesters measure 142 centimeters in diameter and were initially made from prefabricated reinforced cement concrete and fiberglass-reinforced plastic. Since 2010, they have been made fully from fiberglass-reinforced plastic, but this has increased the cost from US$600 to US$800—even with a partial subsidy, which is unaffordable for most families (Müllegger, Langergraber, and Lechner 2011). See table 15.1 for a summary of this case study's assessment of fecal sludge management outcomes; see table 15.2 for a summary of limitations and enabling factors.

TABLE 15.1. Assessing Fecal Sludge Management Outcomes

Objective	Description
Removing waste from environment	Small-scale biogas digestors have been promoted in Asia to reduce environmental pollution and health hazards from kitchen waste, animal manure, and human excrement. In Vietnam, for example, it is used to manage manure from smallholding farms (El Solh 2010), and in Kerala, to reduce pollution of villages and backwaters (Vögeli et al. 2014).
Pathogen inactivation	The anaerobic digestion process reduces but does not eliminate viruses, bacteria, and parasites. Biodigester effluent COD values often exceed 1,000 milligrams per liter, contributing to surface water pollution (Vögeli et al. 2014). Post-treatment of fecal biodigester effluent is required. Although nutritionally rich, it can be difficult to transport in large volumes to fields (Vu et al. 2015).
Waste to resource	The products of a biogas digester are biogas, slurry, and effluent. These are all valuable, but not always fully utilized—the effluent, for example, is bulky to transport (El Solh 2010). One cubic meter of biogas contains the equivalent of 6 kilowatt-hours of heating energy (i.e., 300–400 liters of biogas are needed to cook for one hour), so a 7.2-cubic-meter biogas reactor could provide sufficient fuel for 16 hours of cooking (Vögeli et al. 2014).
Scale	Anaerobic digestion is a well-established treatment technology suited for wastewater or wastes containing high levels of organic matter. It is proven at industrial-scale and in multiple household-scale units. With more than 300,000 units installed in the last 22 years, household-scale biogas is one of the success stories of rural development in Nepal (NBPA 2015).

table continues next page

TABLE 15.1. continued

Objective	Description
Self-sufficiency	Household biogas uptake has typically been driven by governmental rural development programs. The Nepal Biogas Support Program established more than 37,000 biogas plants from 1992–98, serving over 200,000 people (NBPA 2015). The Kumbalangi Island Tourism Development Project aimed to improve sanitary conditions of Kerala backwaters as a tourist destination (Vögeli et al. 2014). In Vietnam, agricultural and environmental development programs have built approximately 200,000 biogas digesters (Vu et al. 2015). Germany recognizes biogas as contributor to the economic development of rural communities (El Solh 2010).
Financial arrangements	Financial viability depends on the cost and benefit of the products (self-production of fuel or fertilizer) (Vögeli et al. 2014) and what energy or nutrient source can be replaced by the biogas and digestate. For rural households the capital expenditure on a biogas digester is likely to be unaffordable without a partial subsidy, though small-scale farmers can break even within a few years (NBPA 2015).
Business and client partnerships	Once the biogas systems are installed, they become largely self-sufficient. They are suitable for institutions such as schools, prisons, hospitals, hotels, and abattoirs that have large volumes of organic waste to manage and interest in offsetting their energy costs, and for rural commercial businesses looking for manure or fertilizer solutions.
Robustness	Anaerobic digestion can be applied on a small or large scale and is appropriate globally. It is a proven technology with robust commercial availability. A wide variety of low-cost organic waste can be treated for biogas production, typically manure and slurry, sewage and septage sludge, and municipal solid waste. (NBPA 2015).

Note: COD = chemical oxygen demand.

TABLE 15.2. Limitations and Enabling Factors

	Limitations	Enabling factors
Greenhouse gases	Greenhouse gases leak or are released if a surplus is produced, with climate change implications (Lohri 2012).	Well-built and well-managed digestors, with adequate awareness and support.
Capital expenses	The initial capital outlay can be prohibitively high for poor households and small enterprises.	Financing and subsidy mechanisms may be required to make the technology accessible.
Regulatory, policy, and fiscal environments	n.a.	In Europe, growth in the biogas sector over the last decade is driven by incentives such as feed-in tariffs (Germany), obligatory certification for energy renewability (United Kingdom), and a favorable fiscal environment (Sweden) (NBPA 2015).
Technology	The anaerobic digestion process reduces but does not eliminate viruses, bacteria, and parasites. A disadvantage of biogas is the relatively small energy density compared to fuel oil; 1 cubic meter of biogas contains only as much energy as 0.6 to 0.7 liters of fuel oil (Vögeli et al. 2014).	Need for low-tech effluent nutrient recycling options, including reducing the water discharged into digestors or pumping systems to distribute effluent to fields for farmers (Lohri 2012). If not compressed, biogas needs a big storage volume that is UV, temperature, and weather resistant (Vögeli et al. 2014).
Awareness and behavior	In low-income countries, many small-scale digesters are not fed properly, and subsequent inefficiencies reduce cost-effectiveness.	Optimizing the combination of parameters through awareness and technical expertise is the key to cost-effective biogas production (NBPA 2015). Complexity increases with scale.
Partnerships	Human fecal waste is not rich feedstock, and although users may be enticed by the prospect of better waste management, it is the cost saving that is the decision factor.	There is a need to work with other sectors and waste streams, and to seek opportunities for fecal waste to be managed under rural development programs. Potential partnerships are with those working in climate change, clean development, and agriculture interventions.

Note: n.a. = not applicable.

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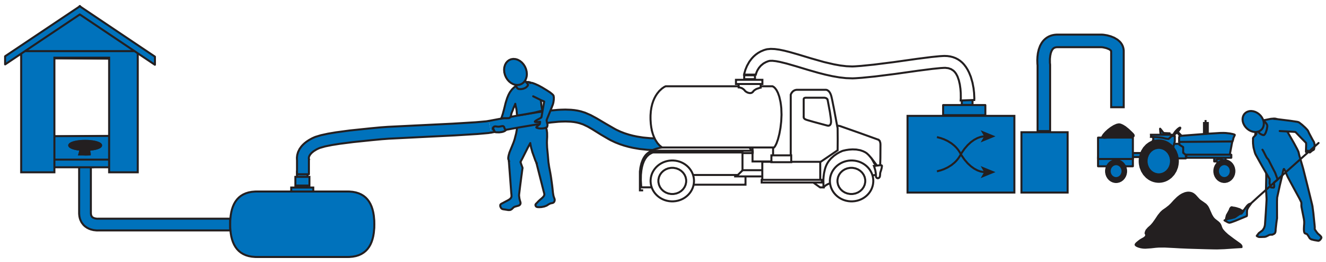
Chapter 16 Improved Product Design of an Established Technology



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
Improved sanitation	Waste is safely contained in situ	Alternating pits allow for the pit to be emptied once safe	n.a.	In situ	Nutrient recovery

IMPROVED TWIN PIT TECHNOLOGIES

Double pit pour-flush latrine technology provides an autonomous sanitation and excreta management unit for households. If the latrines are solidly designed, constructed, and maintained, they can be a viable, long-term improved sanitation option. This brief describes how the introduction of purpose-designed sanitaryware is modernizing the twin pit latrine to improve both functionality and user experience.

CASE QUICK FACTS

This case demonstrates how the introduction of purpose-designed, modern, low-cost, and locally manufactured sanitaryware for an established latrine technology can improve both functionality and user experience. There is scope for user-focused design and modern manufacturing processes to improve existing sanitation technology. This case assumes the latrines are solidly designed, constructed, and maintained, unlike those assessed in chapter 12.

PHOTOGRAPH 16.1. Emptying a Toilet Pit

Source: Uzi Films/World Bank.

Technical Aspects

Double pit pour-flush latrines are an autonomous sanitation and excreta management technology for households, and can be a viable long-term option for improved sanitation. The introduction of low-cost plastic sanitaryware further improves this technology.

The basic twin leach pit design consists of two pits, typically 1 meter in diameter and 1–1.5 meters deep. When the first pit is full, the household begins to use the second pit. Under the right conditions, there should be enough time for the contents of the first pit to have degraded sufficiently to be managed safely by the household before the second pit is full. Safely desiccated and dry feces can be emptied manually by the household or by professional pit emptiers (see photograph 16.1) and added to soil.

Conventionally, a brick and concrete Y-junction box arrangement connects each pit to the latrine via a junction chamber. However, switching the flow is an unhygienic and time-consuming job, which is often not done correctly. These junction boxes are prone to block, leak, or break, allowing waste to flow into both pits at the same time. This compromises the functionality of the system and the safety of the pit contents. Pits that are too shallow or too close to each other are also common problems in India, Bangladesh, and elsewhere.

A qualitative study of double pit pour-flush latrines in Bangladesh noted a reduction in flies, mosquitos, and bad odors in the household environment; latrines were kept clean and provided users with greater privacy, convenience, and comfort compared to individuals' former practice of open defecation. In addition, the latrines improved social standing; and households welcomed the perceived lack of emptying costs (Hussain et al. 2017). See table 16.1 for a summary of this case study's assessment of fecal sludge management outcomes; see table 16.2 for a summary of limitations and enabling factors.

TABLE 16.1. The Fecal Sludge Management Model

Objective	Description
Removing waste from environment	Well-functioning alternating pit pour-flush latrine technology provides a long-term, improved, safely managed sanitation option. Chapter 12 presents an overview of the issues around compromised systems.
Pathogen inactivation	Constructed in suitable areas (e.g., not waterlogged), this technology provides conditions to render fecal sludge safe for emptying if left to desiccate for one year or more.
Waste to resource	Decentralized household waste-to-resource potential: desiccated feces can be added to soil, although the nutritional values are relatively low for dry feces.
Scale	Widespread: in India alone, tens of millions alternating twin pit latrines have been built.[a]
Self-sufficiency	Twin pit alternating latrines are more expensive than single units and are often implemented with a government subsidy. Donor funding and project support have catalyzed product development of affordable sanitaryware with a view to encouraging private sector investment: at least one global private sector sanitaryware producer is now producing and marketing these products.
Financial arrangements	Although the capital costs are higher than for single pits, the operational costs should be lower if households are able to empty the pit themselves.
Business and client partnerships	There are some clear private sector opportunities to deliver improved sanitation technologies. However, due to the bulky raw material and the simple technologies, twin pit latrines are mainly constructed by small enterprises of individual masons. Despite many efforts little has happened beyond this.
Robustness	While the design may be sound, the implementation of these technologies is vulnerable to compromised quality. Reasons include (a) a more complex design; (b) higher labor and material requirements than a single pit; (c) suitable only for certain soil types; and (d) many are built by individual masons. Poor construction of twin pit latrines is widespread.

a. http://swachhbharatmission.gov.in.

TABLE 16.2. Limitations and Enabling Factors

	Limitations	Enabling factors
Poor installation	Poorly built or installed toilets compromise the safe management and use of excreta. Construction problems—such as pits being too close together, too shallow, or in unsuitable soil—are widespread.	Improved M&E of construction, improved payment incentives in toilet contractor models, improved household education on proper design, and adequate O&M.
Appropriate designs for user	Technologies suited to one context may not work in as well in another (e.g., areas with high groundwater tables or that are flood-prone).	Iterative product design and local adaptation. Space and soil conditions are determining factors.
Reaching the poorest households	Cost remains a limiting factor.	Targeted financial incentives.
Scale	Achieving scale without compromising quality.	Complementary interventions of education, product marketing and distribution, financing for all, and subsidies or financial incentives for the poorest households.

Note: M&E = monitoring and evaluation; O&M = operations and maintenance.

Improved Sanitaryware

Many sanitation efforts focus on the superstructure of the latrine, which is associated with social status, convenience, privacy, and safety. However, the technical functionality of the substructure is fundamental to the ongoing operation and use of the units. The introduction of low-cost, purposefully designed, and locally manufactured plastic sanitaryware offers marked improvements on the alternating pit pour-flush latrine technology (LIXIL India 2018):

- **Low-cost pour-flush sealed pan.** There are various pour-flush pan designs, including a recent innovation: plastic with a counterweight flap door. This design provides a water seal to safely contain human excreta and minimize flies and smells. It can flush with as little as 0.5 liters of water. Originally developed in Bangladesh, since 2012 more than 1.2 million pans have been installed in 14 countries, including Uganda, Haiti, Malawi, Nigeria, and India.
- **Low-cost plastic V-junction box.** Launched in India in 2017, this alternating twin pit diverter is made of plastic and uses a V- rather than Y-shaped arrangement. It is located directly under the toilet pan, and is compatible with plastic and ceramic toilet pans. It diverts the flow immediately into one or the other waste pipes. The design reduces blockage risk and requires less water to flush. Initial take-up has been mainly in the upscaling market, with 8,000 units sold between the October 2017 launch and April 2018 (Lixil India, 2018).
- **Low-cost plastic slab.** Various low-cost plastic slabs (see photograph 16.2) have been developed with local private sector players, notably in Kenya and Tanzania, where a plastic latrine slab with a foot-operated lid was introduced (see photograph 16.3).

PHOTOGRAPH 16.2. Plastic Latrine Slab over Pit Latrine

Source: World Bank.

PHOTOGRAPH 16.3. **Rendering of a Plastic Latrine Slab with Lid Prototype**

Source: International Finance Corporation.

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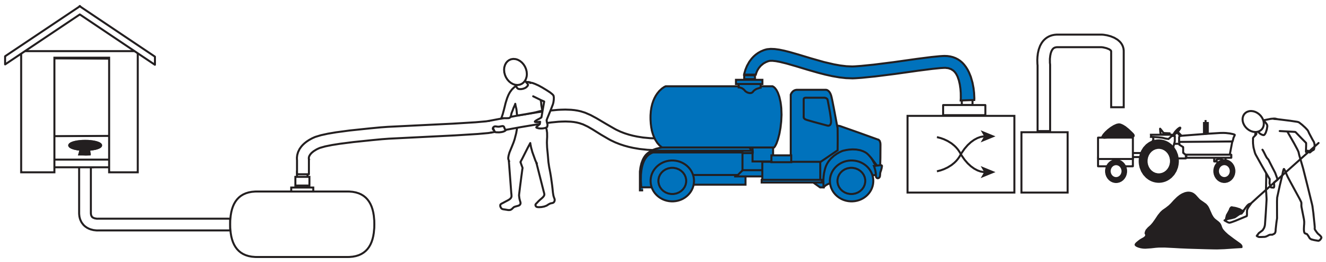
Chapter 17 Reducing Haulage Costs through Dewatering and Transfer



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	Systems that safely transport the fecal waste away	n.a.	n.a.

DEWATERING AND TRANSFER

Haulage is a significant part of waste management costs. Potential ways to reduce haulage costs fall into two categories: (a) reducing conveyance distances; and (b) reducing volumes that require transportation. In solid waste management, optimizing haulage costs through vehicle fleets, transfer stations, and decentralized processing are well-known techniques. This case documents examples of how these approaches have emerged or been applied in FSM, sometimes on an ad hoc basis.

CASE QUICK FACTS

The case demonstrates examples of interventions—including transfer haulage and dewatering—to reduce transport costs compared to the more conventional direct haulage model of fecal sludge management (FSM). While some of the interventions are promising, key elements are missed in their implementation, compromising their viability.

Reducing Haulage Costs

The costs of removing and transporting fecal sludge from emptying to disposal sites can be significant. Often disposal sites are on the outskirts of urbanized areas, requiring several trips on heavily congested roads. Costs of time and fuel are often passed on to the end customer. Prior to a market intervention to bring costs down, in Dakar in 2008 the annual cost of mechanical emptying was on average US$55, compared to US$26 for manual emptying (Scott, Cotton, and Sohail 2013). For nonmechanized emptiers, transporting the sludge any distance is difficult, so it tends to be dumped or buried locally. See table 17.1 for a summary of this case study's assessment of fecal sludge management outcomes; see table 17.2 for a summary of limitations and enabling factors.

Technical Aspects

Direct and Transfer Haulage

There are two main models for haulage of waste: direct and transfer haulage. FSM is typically *direct haulage:* the same vehicle that empties a household system transports the waste to a disposal site. In *transfer haulage*, a fleet of vehicles is used: a smaller, more efficient vehicle will collect waste, transferring it to a larger vehicle for conveyancing to a processing

TABLE 17.1. Assessing Fecal Sludge Management Outcomes

Objective	Description
Removing waste from environment	Optimized haulage and transfer can improve coverage of emptying services, as smaller vehicles can access narrower areas; reduce haulage costs; and improve public and environmental health if localized dumping is avoided.
Pathogen inactivation	n.a.
Waste to resource	Sorting and processing at transfer stations offer the potential to manage different waste streams or optimize for reuse.
Scale	Such systems operate at scale for solid waste management, and there are some ad hoc applications in FSM. A more comprehensive approach with clear governance, improved modeling for suitable locations, and optimized fleet management would enable scale-up. However, because fecal sludge is messy and smelly, there would likely be resistance from those living near to proposed locations.
Self-sufficiency	Transfer stations often operate at the interface between different scales of operations and the public and private sector. These relationships are complex and may need external support. Typically, these activities are unfamiliar to FSM actors, and the institutional capacity to coordinate them is often weak.
Financial arrangements	Even the most basic fleet or transfer stations incur capital and operational expenditure. Any associated costs for land, equipment, site maintenance, and staffing of the transfer point need to be considered in the fixed overhead costs. It is likely that some public funding will be required to sustain part of the chain. The optimal direct haul distance for each type of vehicle depends on size, speed, and staff numbers; economic analysis can identify when transfer or direct haul is most appropriate.
Business and client partnerships	Transfer stations can act as a clear interface between public and private elements of FSM.
Robustness	Examples of transfer haulage in FSM have operated imperfectly, hampered by technical and institutional inconsistencies and incomplete solutions—but they are potentially a missing link in FSM service provision (UMA Engineering, n.d.).

Note: FSM = fecal sludge management; n.a. = not applicable.

TABLE 17.2. Limitations and Enabling Factors

	Limitations	Enabling factors
Cost modeling	Getting the incentives and resource allocation right across the multiple stages of the FSM service chain (e.g., dumping fees, volumes and capacities required, identifying break-even points).	Using optimized GIS models and direct vs. transfer haul calculations to test options prior to resource commitment (see chapter 22).
Regulation and enforcement	A weak regulatory and enforcement environment makes it easier and cheaper to dump fecal sludge in the environment despite the negative externalities.	Rebalance the positive and negative incentives around fecal sludge transport and treatment.
Fleet management	FSM is often hampered by poor operational management. Fuel, maintenance, and spare parts are continuous expenses to manage a fleet of vehicles, and a budget and planning is required to sustain operations. This is true for almost any service delivery system in a low-income economy, but traditionally sanitation is seen as an infrastructure rather than service focused.	As with all fleet-based services, the best way to control and budget for downtime is through preventative and planned maintenance by skilled technicians and experienced fleet managers and systems.

Note: FSM = fecal sludge management; GIS= geographic information system.

or disposal site. In solid waste management, transfer haulage systems commonly operate in formal and informal markets.

The Vacutug is a well-known example of a purpose-built FSM vehicle that can access narrow roads. It was, however, rarely implemented as part of a transfer haulage system, and was completely impractical for direct haulage due to its limited volume capacity, slow speed, and inability to cover difficult terrain. There are examples of FSM transfer haulage fleets: in Haiphong, North Vietnam, the public utility Sewer and Drainage Company locates a 5-cubic-meter storage tank on the back of a truck on the nearest access road, while mini-vacuum tugs, or "quang-tanks" (350-liter capacity and 0.7 meters wide; US$4,000 per unit), access narrow streets to empty household septic tanks. They can empty 500 septic tanks per year, at an operational cost of US$3,300. The system achieves almost 100 percent coverage of the city's population of 400,000 (Klingel 2001; Strauss and Montangero 2004).

Holding and Transfer Tanks

In solid waste management, transfer stations provide the interface between the fleet of smaller vehicles and larger conveyance vehicles. They can range from a simple transfer area to dedicated sorting and compacting facilities. They are financially viable if their costs are outweighed by savings on haulage (UMA Engineering, n.d.). The analog for FSM is holding and transfer tanks (see photograph 17.1). Prior to the ban of bucket latrines in Ghana, the municipal government in Accra built 60 underground fecal sludge holding tanks to provide a hygienic disposal solution; however, unauthorized dumping caused the tanks to fill faster

PHOTOGRAPH 17.1. Underground Fecal Sludge Holding Tanks

Source: fn.artworks/Shutterstock.

than anticipated, and the system eventually collapsed (Boot and Scott 2008). As recent as 2018, in Nakuru, Kenya, Sanergy has installed a 30-cubic-meter underground tank to provide an alternative to illegal dumping of sludge in rivers and drains. Manual emptiers pay a small fee to use the tank.[1] See box 17.1 for an equation to help determine costs of transfer hauls and direct hauls.

Decentralized Dewatering Technologies

Fecal sludge haulage costs can be reduced if the volume of fecal sludge to be transported is reduced, which effectively means reducing its water content. Mobile dewatering vehicles, which are a similar size to the larger vacuum tankers used for FSM, separate solids and liquids (often using a flocculant to promote clumping of solids) and discharge the excess liquid on-site. The dewatered sludge is transported by tanker to a disposal site. This can reduce the volume to be transported by 60 percent to 90 percent, but requires an effective way to safely discharge effluent.

In South America, the first company to adopt mobile dewatering units for septic tank emptying was in Los Lagos Region, Chile. The effluent is pumped back into the septic tanks and dispersed through the leach field. The region's largely rural context and large haulage distances make it particularly suited to on-site dewatering.[2] In 2010, the Malaysian water utility Indah Water trialed a dewatering technology called Geotubes. There was a 35 percent increase in revenues for emptiers, because they could make more trips per day, and a 37 percent decrease in operational expenses. However, the capacity of the Geotube dewatering process was limited by the slow speed of dewatering (Ho et al. 2012).

BOX 17.1. Costs of Transfer Hauls and Direct Hauls

Transfer haul cost **T = ax + b**

Direct haul cost **D = cx**

Where T = transfer haul cost; D = Direct haul cost; a = unit transfer haul cost / m^3; b = fixed base transfer cost / m^3; c = unit direct haul cost / m^3; x = roundtrip haul distance /km.

Unit costs can be estimated based on annual quantities of fecal sludge collected and the local operational and capital costs associated with each option, including labor, technical equipment, consumables, and land costs. Other factors, such as crew size and number and lengths of shifts, can also be factored into the comparative analysis. The above equations enable the break-even point between transfer and direct haul to be identified.

Source: Adapted from Ho et al. 2012.

Notes

1. Personal Communication with Dr. Nicola Greene December 5, 2018, FSM expert.

2. Personal communication with Constructoro Najar, Chile, February 6, 2013.

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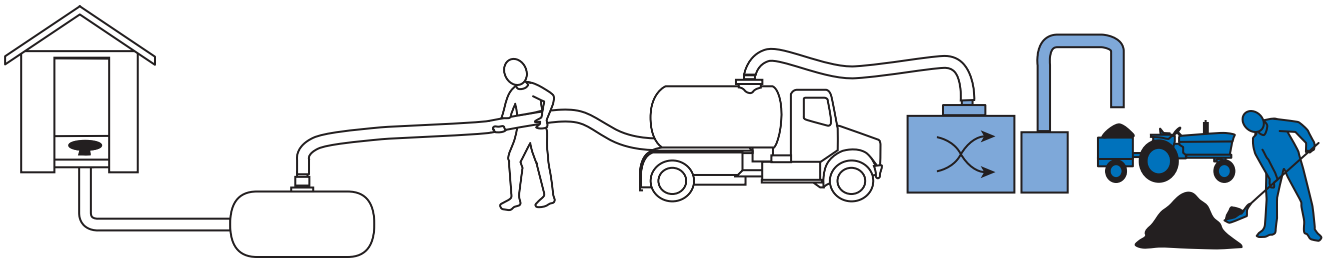
Chapter 18 Fishpond and Duckweed Aquaculture



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	n.a.	Process offers little pathogen removal	Cost and nutrient recovery

COMMUNITY AQUACULTURE

Aquaculture, the farming of fish, plants, algae, and other organisms, is widely practiced across parts of Asia, on both domestic and larger scales. Wastewater containing organic matter can be used to feed the systems. The process offers little benefit in terms of pathogen removal, but if those risks can be managed, aquaculture offers a reliable income source for rural families or commercial enterprises, and can offset costs for larger-scale production and wastewater or fecal waste treatment.

CASE QUICK FACTS

This case documents promising examples of aquaculture from managed excreta-fed fishponds. Aquaculture is a widespread practice in several countries, though the inherent risks of hazard exposure means that systems have to be well managed. This case presents examples of community- or larger-scale systems that may be suitable for public-private partnerships.

Aquaculture

Excreta- or wastewater-fed aquaculture is practiced extensively in China; Taiwan, Indonesia; the Philippines; Vietnam; Thailand; Malaysia; West Bengal (India); and Vietnam. The practice also exists in Bangladesh and Pakistan (Cross and Strauss 1985; Nguyen et al. 2016). In Bangladesh, 75 percent of rural households practice some form of aquaculture, covering 10 million ponds, most of which measure less than 400 square meters (Sarwer et al. 2016). This brief draws on examples of household (Vietnam) (Nguyen et al. 2016) and commercial (Bangladesh, India) aquaculture practices (Journey, Skillicorn, and Spira 1993; Kumar, Hiremath, and Asolekar 2014; Otoo and Drechsel 2017). See table 18.1 for a summary of this case study's assessment of fecal sludge management outcomes; see table 18.2 for a summary of limitations and enabling factors.

Technical Aspects

There are four main kinds of aquaculture design: (a) effluent-fed fishponds; (b) excreta or sludge-fed fishponds (e.g., fishpond toilets; see photograph 18.1); (c) fish grown in wastewater treatment system maturation ponds (Tilley et al. 2014); and (d) duckweed fishponds (Journey, Skillicorn, and Spira 1993). Under ideal operating conditions, up to 10,000 kilograms per hectare of fish can be harvested per annum (Tilley et al. 2014).

PHOTOGRAPH 18.1. Fishpond Toilet

Source: LeQuangNhut/Shutterstock.

TABLE 18.1. Assessing Fecal Sludge Management Outcomes

Objective	Description
Removing waste from environment	Waste removal is slow and requires the right equilibrium between bacterial degradation and organic load. In Bangladesh, many families grow pumpkins in a wooden rack over their small fishpond to prevent water evaporation, but they can be exposed to excreta-related hazards through contaminated water being used domestically, children swimming in the water, and increased vector breeding (Otoo and Drechsel 2017). These risks are reduced when ponds are managed away from the immediate domestic environment, such as in the East Kolkata wetlands (a complex, manmade system, covering 125 square kilometers), which treats sewage and sustains fish farms and agriculture.
Pathogen inactivation	The fish do little to improve the water quality. There are health risks for workers and consumers (Otoo and Drechsel 2017), though the latter can be significantly reduced by thorough cooking.
Waste to resource	If the fish are not acceptable for human consumption, they can be a valuable source of protein for other high-value carnivores, such as shrimp, or converted into fishmeal for pigs and chickens.
Scale	Excreta- or wastewater-fed aquaculture is practiced extensively in many countries across Asia. In Bangladesh, 75 percent of rural households practice some form aquaculture (Sarwer et al. 2016). It is appropriate for warm or tropical climates with no freezing temperatures, and preferably with high rainfall and minimal evaporation (Tilley et al. 2014). The technology is replicable where space is available, but the land requirements are significant (Otoo and Drechsel 2017).
Self-sufficiency	In Mirzapur, Bangladesh, a duckweed aquaculture plant was profitable without public funding. However, because duckweed and aquaculture farming require different expertise, it is unlikely that farmers will start such combined ventures on their own volition (Journey, Skillicorn, and Spira 1993). The extent of small-scale, informal household aquaculture ponds that have emerged without external assistance suggests that there are economic incentives.
Financial arrangements	Aquaculture shows strong profitability potential. On a small scale, fish provide income for families; and on a larger scale, fish sales can offset the costs of wastewater treatment (Nguyen et al. 2016). The larger-scale case studies demonstrate financial viability with an estimated payback period of less than 10 years, 26 percent rate of return, and a gross margin of 20 percent (Journey, Skillicorn, and Spira 1993; Kumar, Hiremath, and Asolekar 2014; Otoo and Drechsel 2017).
Business and client partnerships	Suitable for private-private partnerships in which the public entity provides wastewater and infrastructure for treatment and disposal; and the private sector offers treatment and fish farming expertise, invests in additional fishponds or fingerlings, and assures the O&M costs of the overall treatment system (Otoo and Drechsel 2017).
Robustness	Significant informal replication suggests it is a robust solution, with a strong revenue stream when there is a market for fish, and socioenvironmental impacts that include reduced water pollution and food security (Otoo and Drechsel 2017). However, expertise is required to run commercial wastewater-fed aquaculture safely.

Note: O&M = operations and maintenance.

Wastewater- and excreta-fed fishponds need to maintain aerobic conditions: biological oxygen demand (BOD) should not exceed 1 gram per square meter per day, and oxygen content should be at least 4 milligrams per liter (Tilley et al. 2014). Fish species need to be tolerant of low oxygen conditions (Tilley et al. 2014). Varieties of carp, milkfish, and tilapia have been successfully used.

TABLE 18.2. Limitations and Enabling Factors

	Limitations	Enabling factors
Land requirements	The land requirement for fishponds is substantial, which may make domestic aquaculture prohibitive in higher-density rural environments. It may also exclude women. Informal activities may come under pressure from urban development.	In areas where aquaculture is appropriate, ensure inclusive actions for women. Formal acknowledgement of the practice may protect informal encroachment on land.
Risk mitigation	Waste and pathogen removal is low in simple fishponds and can cause a risk to those living in the immediate environment.	Awareness of risks and safer practices for consumption, including: (a) moving fish to a clearwater pond for several weeks before consumption; (b) cooking prior to consumption; (c) requiring workers to wear appropriate clothes and educating them about the risks. (WHO 2006)
Spontaneous partnerships	It is unlikely that farmers will unite in a coordinated duckweed or fish venture without an external broker or catalyst.	Brokering these partnerships will require coordinating the interests of different groups and ensuring working capital and technical assistance (Journey, Skillicorn, and Spira 1993). It can take different institutional forms: government extension services, private voluntary agencies, producer cooperatives, or agribusiness (Journey, Skillicorn, and Spira 1993).

In the Mekong River Delta (chapter 9), 55 percent of households use unimproved latrines that typically flush or are located directly over fishponds or other bodies of water. Fishponds serve as both latrines and a source of income or food (Nguyen et al. 2016).

In Karnal, India, a wastewater treatment plant (WWTP) with a capacity of 8 million liters of sewage per day introduced fish into its facultative and maturation ponds (Kumar, Hiremath, and Asolekar 2014). Fish sales yield US$9,000 to US$12,000 annually (Kumar, Hiremath, and Asolekar 2014). Using fish in the aerobic pond of a WWTP can also be useful to control algae and mosquitos.

In Mirzapur, Bangladesh, the Agriquatics duckweed-aquaculture site treated local wastewater for fish production and crop cultivation. Duckweed was grown in a pond fed by wastewater from a hospital. Fish were reared on the harvested duckweed in adjacent tanks. Sale of the fish and perennial crops planted around the ponds not only covered the operating costs of the plant but also recovered the original capital expenditure. The site operated at a profit for two decades before being replaced (Journey, Skillicorn, and Spira; Otoo and Drechsel 2017).

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Part 4

Case Studies in Innovative Waste Recycling Approaches and Technologies

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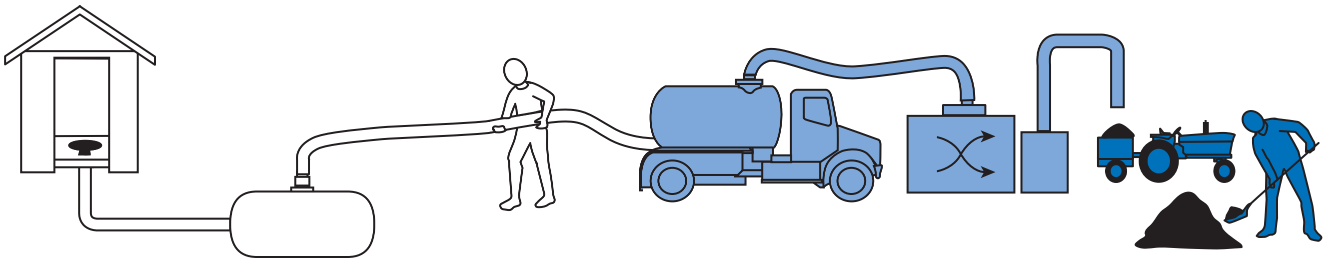
Chapter 19 Converting Organic Waste into High-Protein Animal Feed



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	In situ black soldier fly degradation reduces waste volumes by up to 78.9%, which has haulage implications	Risks of pathogenic transmission and heavy metal accumulation need more research	Commercially viable protein and oil products sold for cost recovery of treatment

BLACK SOLDIER FLY

The larvae of the black soldier fly digest a wide range of organic wastes such as food waste, agricultural waste, animal manure, and human excreta. They produce protein and fat for animal feed, and soil conditioner as a by-product. This is a rapidly emerging market for organic waste treatment, but further research on the risks and appropriate mitigation measures would support its application to fecal waste treatment.

APPLICABILITY FOR FECAL SLUDGE MANAGEMENT

Black soldier flies convert organic waste into edible animal protein. For commercial application, the process requires a preprocessing stage for optimal food stock and careful control. Business models range from low-grade animal feed to capital-intensive biodiesel production.

Black Soldier Fly

The larvae of the black soldier fly (BSF), or *Hermetia illucens L. (Diptera: Stratiomyidae),* digest a wide range of organic wastes, such as food waste, agricultural waste, animal manure, and human excreta. They generate protein as an animal feed; bio-oil (for industrial use or as a food supplement); and substrate (for soil conditioner). In recent years, the private sector has shown interest in BSF larvae (BSFL), with companies such as Protix (The Netherlands), AgriProtein (South Africa), and Ynsect (France) establishing commercial operations. The Worldwide Insect Feed Market analysis lists 23 BSF companies, and projects revenue to exceed US$1 billion by 2022 (Research and Markets 2017). See table 19.1 for a summary of waste process typology; see table 19.2 for a description of limitations and enabling factors.

TABLE 19.1. Waste Process Typology

Objective	Description
Removing waste from environment	BSF are vociferous eaters of all organic wastes and will reduce the volumes of waste they feed on by 55 percent. They also reduce foul odors in general and the common housefly populations (*Musca domestica*) by 94 percent to 100 percent (FAO 2013; Sheppard et al. 1994).
Pathogen inactivation	Pathogen risk reduction is achieved mainly through the reduction of waste quantities in a controlled space, rather than pathogen inactivation, although there is ongoing research into the antibiotic properties of BSF. Reductions have been noted in E. coli and salmonella (Liu et al. 2008), but more research is required.
Waste to resource	On a dry weight basis, the average bioconversion rate of BSFL from food waste is 10 percent to 25 percent, and from manure, 12 percent to 15 percent (Wang and Shelomi 2017).[a] Fresh human feces have produced 23 percent (Agrawal et al. 2011). BSF production can be unstable, and maintaining optimal conditions and high production volumes remains a challenge. Commercial prices for BSF larvae are around US$200 to US$530 per ton, dry weight; US$466 per ton, oil; and US$13 per ton, residue compost (FAO 2013; Wang and Shelomi 2017).[a, b] Fishmeal typically costs US$1,200 to US$1,600 per ton.[c]
Scale	At present, several small-scale operations are reporting profitability, but several companies are attempting to scale to much larger commercial operations. AgriProtein, for example, is establishing nine BSF factories, including in Saudi Arabia, the United Arab Emirates, the Republic of Korea, and Johannesburg (South Africa), with a capacity of 250 tons of organic waste per site. These plants are expected to run as commercially viable businesses,[a] though this is yet to be proven. Operations on this scale present significant logistics and waste management challenges.
Self-sufficiency	Commercialization has grown from research and several rounds of venture capital and equity financing. The best-funded companies are Protix, which operates in 12 countries and raised US$50.5 million in equity and debt funding in 2017; AgriProtein, which raised US$17.5 million in 2016; and Ynsect, which raised US$15.2 million in 2016. The International Platform of Insects for Food and Feed is a 42-member NGO lobby group representing the insect production sector toward the EU.
Financial arrangements	The details of commercial viability are closely guarded as companies race to operationalize large-scale sites. It depends on capital and operating costs, quantities and types of organic waste, the market price of alternative animal feed, the costs of pre-processing and processing, whether concentrated or dispersed, the weather, and revenue from product sales and tipping fees (Dortmans et al. 2017).[d] The most significant costs are labor and waste transport. Biocycle, a subsidiary of AgriProtein, operates a proof-of-concept BSF treatment plant for fecal sludge from UDDTs in South Africa. A viable business model was agreed between eThekwini municipality and the BSFL plant operator for a 5-year period with a 6-month start up, where eThekwini municipality guaranteed a fixed fee based on tons delivered to the plant. At present only soil conditioner is being generated.
Business and client partnerships	Growth of BSF is predominantly in the private sector.
Robustness	BSF require a climate of 24 degrees Celsius to 30 degrees Celsius. BSF processing can deal only with organic wastes, and pretreatment of waste inputs is required. Inorganic waste will need to be removed, while dissolved chemicals (such as acids, solvents, pesticides, detergents, and heavy metals) are unsuitable and can contaminate an entire waste batch.

Note: BSF = black soldier fly; BSFL = black soldier fly larvae; EU = European Union; NGO = nongovernmental organization; UDDT = urine diverting dry toilet.

a. AgriProtein website, agriprotein.com; personal interview, Ian John Banks, April 24, 2018.

b. FSM3 website, https://www.susana.org/en/knowledge-hub/trainings-conference-and-events-materials/conferences/97-2015/259-fsm3.

c. Figures taken from indexmundi. Accessed May 5, 2018 https://www.indexmundi.com/commodities/?commodity=fish-meal.

d. Jeffery K Tomberlin. personal interview May 2, 2018.

TABLE 19.2. Limitations and Enabling Factors

	Limitations	Enabling factors
Validation of safety for fecal waste	BSF is a proven but sensitive technology, but there is insufficient research on pathogenic transmission risks and heavy metal accumulation. Additional processing steps, such as additional composting of organic residue or processing of larvae to remove heavy metals, are expected to be able to mitigate any such risks. However, as yet, this has not been proven at an industrial scale.	Develop the evidence base around risks and mitigation measures. Though more work is needed, those in the sector do not consider the challenges insurmountable.
Regulation	BSF applications are limited by two types of regulatory restrictions in the EU, the United States, and Australia: (a) around what is permitted as animal feed,[a] in part a legacy of the BSE crisis of the 1990s; and (b) if insects are a licensed food.[b] Some larger private companies have worked toward regulatory approval for BSF in aquaculture in the United States and the EU. Other countries with well-established regulatory frameworks (China, the Republic of Korea) or lack of restrictive legislation (Middle East economies) are more welcoming.	Clear and open regulations will attract the private sector. The regulatory environment is changing: in May 2017, the EU lifted the "feed ban" for aquaculture for seven insect species, including BSF. As new R&D emerges on, for example, feeding insects to other livestock, regulatory frameworks will need to be updated regarding chemical accumulations, allergic reactions, and infectious diseases.
Market share, competition, and scale	The BSF industry is dwarfed by fishmeal and soymeal in the global animal feed sector, estimated in 2011 at 870 million tons and US$350 billion (FAO 2013). FAO estimates a 70 percent increase in demand for animal feed by 2050. Fishmeal is becoming more expensive, and there is a need to develop more sustainable alternatives.[c] BSF companies are attempting to scale quickly to become competitive. The yield rate of organic waste to BSF is 10 percent to 25 percent dry weight, so the logistics of waste management and space requirements are significant.	Different business models exist on the spectrum of waste management compared to animal feed production. There is scope to consider scaling operations in less competitive animal feed markets than the global fishmeal market, or for local markets in which fishmeal import is prohibitively expensive. There is also potential to develop partnerships and diversification opportunities with established markets and players rather than compete with them. Insect animal feed offers sustainability and efficiency gains compared to fish or soymeal. The growing BSF industry would be helped by market incentives for more sustainable animal protein sources by developing (a) evidence to inform a more attractive policy and regulatory environment, and (b) appropriate concession or partnership agreements with local governments.
Quality of waste	Variability of inputs of organic matter can reduce the efficiency of BSF production. FSM contaminated with inorganic wastes, such as plastics, requires more preprocessing; sand reduces the nutritional value of the waste; and heavy metals could interfere with larval growth (Cai et al. 2016).	Considering fecal sludge as a resource requires actions to safeguard its quality through improved infrastructure and better awareness.
Potential matchmaking	Except for Biocycle, and to a lesser scale Sanergy, few BSF companies[d] in Europe or the United States are focusing on FSM. Biocycle targets receiving 20 tons of pit latrine waste per day and producing 0.84 tons of MagMeal, 0.3 tons of MagOil, and 3.6 tons of soil residue.	With appropriate R&D on the risks and applicability of fecal sludge, the higher-end BSF producers could target top aquaculture markets (i.e., China, India, Vietnam, Indonesia, Thailand) in countries with less restrictive legislation around insect-based protein.

Note: BSE = bovine spongiform encephalopathy; BSF = black soldier fly; EU = European Union; FSM = fecal sludge management; R&D = research and development.

a. The prohibition of animal derived protein to be used in feed for farmed animals.

b. That farmed insects are fed only "feed grade" substrates, that is, insects cannot be fed slurry or manure, catering waste, or former foodstuffs containing meat or fish.

c. International Platform of Insects for Food and Feed, ipiff.org.

d. Protix; Jagran (the Netherlands); Blacksoldierfly.nl (the Netherlands); Hermetia (Germany); Ynsect (France); Víur (Iceland); BioFlyTech (Spain); R&D and production, Entomotech S.L. (Spain); AgriProtein and side venture, Biocycle (South Africa); Enviroflight (Ohio); Organic Value Recovery Solutions (Georgia); Enterra Feed (British Columbia); Co-Prot (Phnom Pen); Terracycle (Singapore); Xinfeng County Soaring Roc Specialist Mealworm Raising Cooperative Freshrooms Lifesciences (India).

Process

BSFL feed on a wide range of organic wastes with a water content of 70 percent to 80 percent (Diener et al. 2011). Under ideal conditions, after two weeks the prepupa (the last larval stage) migrate away from the waste to a dry location to become adult BSF—hence, in purpose-designed BSF farms, prepupa effectively "self-harvest." Adult BSF are not considered as risk vectors for disease transmission: they lack mouth parts, so they cannot bite; they cannot fly long distances; and they no longer seek food, avoiding cross-contamination from visiting waste sources (Diener et al. 2011).

In situ BSF degradation reduces waste volumes by up to 78.9 percent (Diener et al. 2011), reducing transport cost—though there are costs in getting the waste to a BSFL farm. BSFL food stock from organic wastes typically requires preprocessing, including removal of non-organic wastes (plastics and other contaminants); shredding to a uniform particle size of 1–2 centimeters in diameter; and balancing of water content to 70 percent to 80 percent (Dortmans et al. 2017).

Products and Market

Animals and fish farmed for food need protein and fat, which are traditionally sourced through fishmeal—but diminishing fish supplies and rising prices have opened the market to alternatives. Averaging 44 percent protein and 33 percent fat, BSFL can substitute for fishmeal (Diener et al. 2011). Business models range from offsetting organic waste processing costs through sales of low-grade BSFL and soil conditioner, which analysis suggests does not break even; to capital-intensive commercial production of high-grade feed with optimized nutrient content, or biodiesel. In this model a return on investment is anticipated in 2.51 years, although the risks are higher (Agrawal et al. 2011).

One South African-based company produces two animal feed products: (a) a feed with 55 percent protein and less than 10 percent fat, targeted at poultry, fish, and shrimp farming; and (b) a purified oil sold as an animal feed supplement. The company blends the larval residue soil with compost to produce a richer soil conditioning product with a nitrogen, phosphorus, and potassium (NPK) value of 4:2:2.[1] Research is underway to confirm any risks of pathogen transfer to feed of BSF reared on human or animal excreta, and additional decontamination procedures such as pasteurization, cooking, or UV treatment (Wang and Shelomi 2017).

Note

1. AgriProtein website, agriprotein.com, and personal interview Ian John Banks April 24, 2018.

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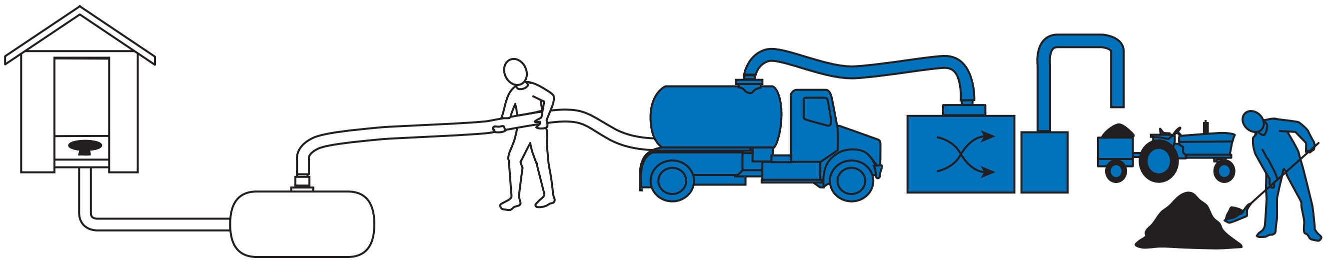
Chapter 20 Combined Natural and Engineered Media for Wastewater Treatment



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	Aesthetics and odor-free mean it can be located in city	Improved efficiency compared to activated sludge wastewater treatment plants	Clean water recovery

WASTEWATER GARDENS

Wastewater gardens combine botanical garden aesthetics with conventional wastewater engineering such that treatment plants can be located closer to residential or commercial areas. This case presents an example of aesthetically pleasing botanical gardens combining conventional aerobic wastewater treatment engineering with a technological innovation and greater treatment efficiency on a reduced footprint.

APPLICABILITY FOR FECAL SLUDGE MANAGEMENT

Costs of transport are significant for fecal sludge management (FSM). This case presents potential improvements, in terms of efficiency and aesthetics, in wastewater treatment that could be transferable—in concept if not in detail—to more localized FSM treatment facilities

Wastewater Treatment

Conventional wastewater treatment plants (WWTPs) are typically built on the outskirts of urban areas and have a significant footprint. They are often unsightly (and smelly) and located away from, or at least hidden from, residential areas. They can be expensive to build and operate and require long distances of sewer network to reach.

Wastewater gardens combine botanical garden aesthetics with conventional wastewater engineering such that treatment plants can be located closer to residential or commercial areas.[1] This brief presents an example of a wastewater garden that combines conventional engineering with technological innovation and architectural aesthetics and draws inspiration from forms of natural treatment including constructed wetlands, tree farms, and other phytoremediation mechanisms (i.e., the use of plants to remove contaminants). See table 20.1 for a description of waste process typology; see table 20.2 for a summary of limitations and enabling factors.

TABLE 20.1. Waste Process Typology

Objective	Description
Removing waste from environment	Combining IFAS technology with plants improves the efficiency of the reactor tanks compared to activated sludge.
Pathogen inactivation	The influent tolerances range from weak to medium-strong wastewater (but not fecal sludge), and output can achieve tertiary treatment standards.
Waste to resource	The main resource is gaining clean water in the immediate environment, in case there are market value for reclaimed water there would be potential cost efficiencies.
Scale	Use of plants for wastewater treatment is widespread, with innovations in phytoremediation increasing the efficiency. One company that combines the use of plants, IFAS, and activated sludge has 90 IFAS botanical WWTPs under commission, with 50 operating sites in Europe and Asia. New installations of IFAS systems will generally require less volume and therefore have less capital cost than a conventional activated sludge system.
Self-sufficiency	All the innovations studied have involved some degree of R&D: in the case studied, the company originated as a conventional wastewater design-build company, and it self-funded R&D in this new model. The various mechanisms of phytoremediation are the focus of several R&D efforts.
Financial arrangements	Wastewater gardens require significant capex—one case studied had a return on investment of six years. Constructed wetlands require much lower investment but more space and land availability.
Business and client partnerships	In the case studied, the company offers design and some specialized equipment (bio modules and control equipment, training and commissioning support), while the implementing partner builds and operates the plant. To date 88 out of 99 of their plants have been designed for municipal customers.
Robustness	IFAS wastewater garden treatment plants provide greater stability in the face of variations in wastewater treatment concentration. IFAS can be retrofitted to existing sites, but requires professional O&M to ensure longevity. It is resistant to organic and hydraulic shock loads, but fails in case of power failures.[a]

Note: capex = capital expenditure; IFAS = integrated fixed film activated sludge; O&M = operations and maintenance; R&D = research and development; WTTP = wastewater treatment plant.

a. SSWM website, https://sswm.info/water-nutrient-cycle/wastewater-treatment/hardwares/semi-centralised-wastewater-treatments/fixed-film-activated-sludge.

TABLE 20.2. Limitations and Enabling Factors

	Limitations	Enabling factors
Strength of effluent	Currently IFAS WWTPs are appropriate for low- to medium-strength effluent water; it would not be appropriate for highly concentrated septage or fecal sludge.	Application of the principles of design (state-of-the-art wastewater engineering, including phytoremediation—that is, the use of plants to remove contaminants—with architecture) to find alternative, but similar phytoremediation solutions for fecal waste treatment.
Regulations	n.a.	For contexts in which there is impetus to treat wastewater locally, such as when new commercial and domestic buildings of a certain size are mandated to include wastewater treatment at source. (One example is in Bengaluru, India.) IFAS WWTPs would provide a viable solution for this.

Note: IFAS = integrated fixed film activated sludge; n.a. = not applicable; WTTP = wastewater treatment plant.

Technical Innovations: Plants with Engineered Media

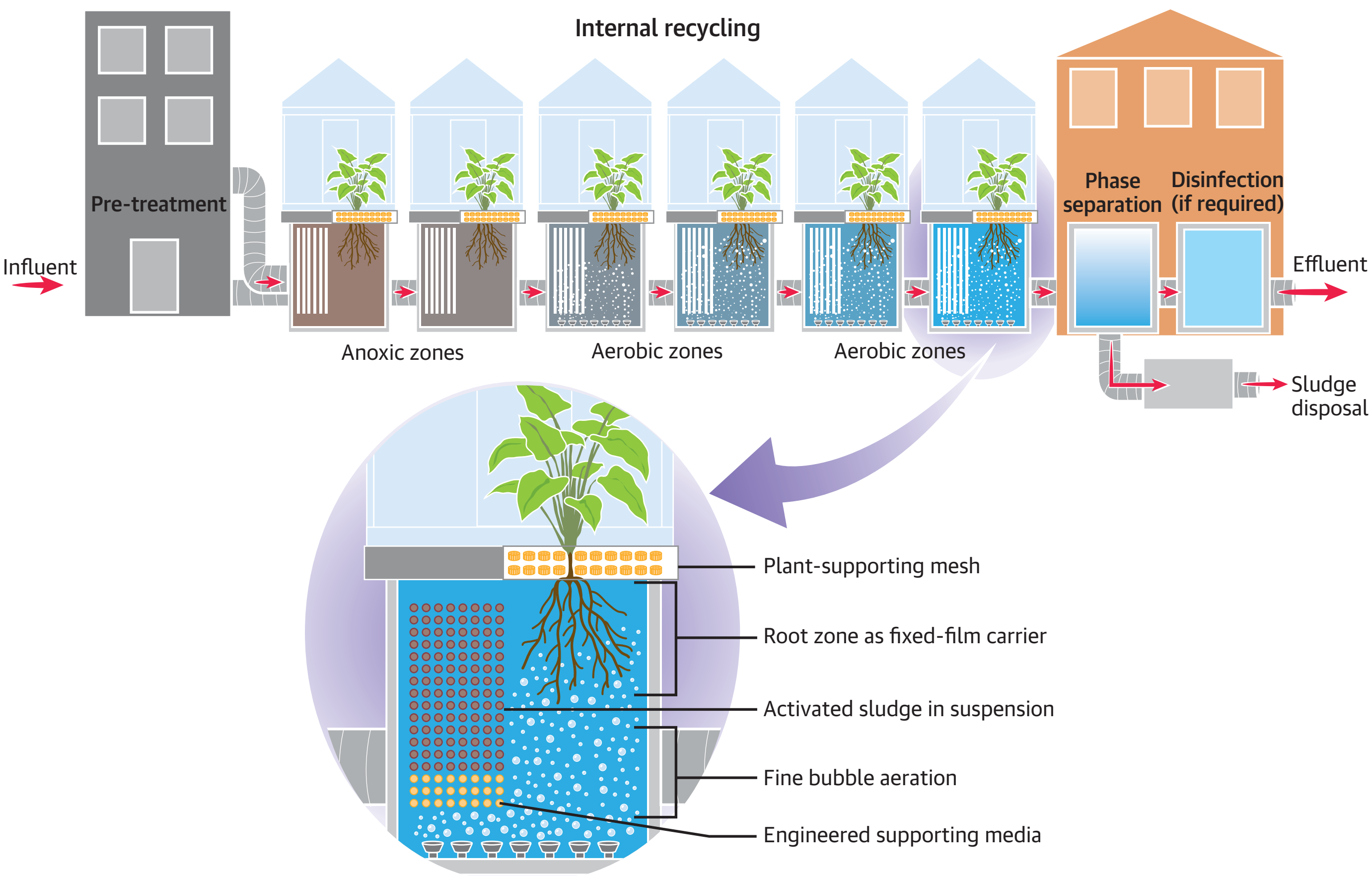
A conventional activated sludge WWTP requires bacteria to decompose waste. Increasing the surface area available to the bacteria increases the efficiency of the plant; however, aerobic WWTPs—as well as constructed wetlands, tree farms, and the like—often require large areas of land away from residential areas. One technological development that increases surface area in a more efficient way is integrated fixed film activated sludge (IFAS). IFAS technology places manmade, grid-like media into the treatment tanks, providing greater surface area for bacteria in a small space.[2] In a wastewater garden, a botanical garden is planted on top of the treatment tanks: the plant roots, which penetrate up to 2 meters into the tanks, offer additional surface area for the biomass growth needed to clean the water. See figure 20.1 for a depiction of an IFAS botanical WWTP.

The combined use of botanical and manmade media in aerobic WWTPs can increase the biomass per cubic meter by three to four times, hence requiring a smaller footprint compared to that of conventional activated sludge plants. In Bekasi Fajar, Indonesia, a WWTP occupying a 2-hectare plot (capacity of 27 millions of liters per day) required upgrading to achieve capacity of 45 millions of liters per day. The land requirement for a conventional activated sludge system would have been 4–4.5 hectares, whereas an IFAS system needed 1.5 hectares, which allowed the treatment plant to stay at the same location.[3]

The composition of the biofilm culture and ecosystem changes along a series of reactors adapted to decreasing nutrient concentrations. The number and size of the reactor tanks required depend on a variety of factors including influent wastewater characteristics, effluent requirements, temperature, and the capacity of the WWTP, which can be controlled with intelligent software.[4]

Similar to constructed wetlands, properly designed wastewater gardens are practically odorless and aesthetically pleasing (Koumoukelis 2015). They have the look and feel of a

FIGURE 20.1. IFAS Botanical Wastewater Treatment Plant



Source: Adapted from https://www.organicawater.com/facility/.

botanical garden because the reactors are hidden from view and a greenhouse is typically added (or an open shaded structure in warmer climates). The aesthetics and smaller footprint mean wastewater gardens can be built in urban environments, with buffer zones reduced from 350 meters to 50 meters (Koumoukelis 2015).

Products and Market

Wastewater garden and IFAS technologies can be retrofitted to existing aerobic treatment plants, as well as being new builds, and retrofitting can be cost-effective compared to extending sewage networks. For example, a new urban development for 4,000 residents in California would cost a private housing developer US$6.9 million to connect to the public sewer network, while households would be charged around the national average of US$435 for their sewage connection (Organica, n.d.). An IFAS botanical system would cost US$3.4 million to build and US$75,000 annually to run (or US$49 per household per year).

The projected cash flow would more than offset the cost of owning and operating a decentralized facility, providing an anticipated full return on investment within six years (Organica, n.d.).

Notes

1. See the Organica Food Chain Reactor website, www.organicawater.com.
2. See the SSWM website, "Fixed Film Activated Sludge Factsheet." https://sswm.info/water-nutrient-cycle/wastewater-treatment/hardwares/semi-centralised-wastewater-treatments/fixed-film-activated-sludge.
3. See the Organica Food Chain Reactor website, www.organicawater.com.
4. See the Organica Food Chain Reactor website, www.organicawater.com.

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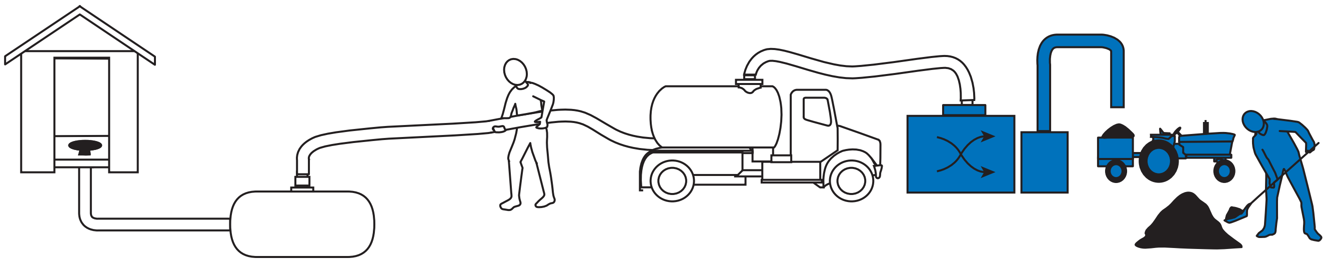
Chapter 21 High-Energy Yield and Low Carbon Footprint Fuel of Torrefied Biomass



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	n.a.	Pathogens are inactivated when heated	Potentially for economic viability; energy recovery from waste

BIOCHAR FROM BIOMASS

Torrefaction is a thermal process that converts biomass into coal-like fuel: it optimizes the physical and chemical characteristics of raw biomass to a dry, homogenized product with increased energy yield. The volatile gases produced as part of the process are captured and repurposed, avoiding greenhouse gas emissions, and the torrefied biomass can be easily processed into briquettes to be sold as a greener alternative to coal.

APPLICABILITY FOR FECAL SLUDGE MANAGEMENT

Fecal waste does not typically have high energy yield, but could be combined with other waste streams to inactivate pathogens and convert into a clean fuel. Optimal moisture content of the feedstock is less than 35 percent to 45 percent, so this process is most applicable for drier fecal sludge and for countries with high coal demand.

Producing Fuel

Raw biomass has all the components of a renewable fuel, but its heterogeneity and likelihood to putrefy and release monoxide gases pose problems. Torrefied biomass is homogenized, has an increased energy yield, and can be easily processed into briquettes to be sold as a coal alternative. Torrefaction is a mild pyrolysis (thermal) process, derived from traditional coffee roasting (Coalition for Sustainable Rail 2018) and designed to maximize the product's fuel and physical characteristics. The volatile gases are captured and repurposed, avoiding greenhouse gas emissions.

Torrefaction of woody biomass has been proven as a commercially viable coal substitute at industrial scale (Thrän et al. 2016).[1] Although not commercially viable yet for other feedstocks, torrefaction is suitable for a range of biomass including horse manure[2] and sewage sludge, and it is being trialed through NASA's waste system for human fecal waste (Serio et al. 2017). See table 21.1 for a description of waste process typology; see table 21.2 for a summary of limitations and enabling factors. See map 21.1 for global locations.

TABLE 21.1. Waste Process Typology

Objective	Description
Removing waste from environment	Torrefaction treatment offers a bulk mass (dry) reduction of 20 percent to 30 percent. As a dry product it can reduce transport and storage costs.
Pathogen inactivation	Excellent, because pathogens are inactivated when heated for more than 7 minutes at 70°C; 30 minutes at 65°C; 2 hours at 60°C; 15 hours at 55°C; or 3 days at 50°C (Carrington 2001).
Waste to resource	A wide range of organic materials (including fecal matter) shows an increase in energy density after torrefaction (Dhungana 2011; Fuad et al. 2018)[a] and can be used as biofuel.
Scale	Technical development of torrefaction has intensified in the past decade (see map 21.1) with one plant achieving production rates up 60,000 tons per year.[b]
Self-sufficiency	Research by the ECN catalyzed the development and commercialization of Europe's largest demonstration plant.[b]
Financial arrangements	To make a biomass torrefaction plant economically viable, it is crucial to capture and use the energy of the volatile gases the process produces. Burning these gases can provide heat for drying the input feed or for the torrefaction process. When the input feedstock has a moisture content of less than 35 percent to 45 percent, the torrefaction process can be autothermal.[b] When the moisture content is higher, additional energy sources are needed: for example, combining anaerobic digestion of agricultural waste (85 percent to 90 percent) and fecal sludge (10 percent to 15 percent) to produce biogas and heat, which in turn is used to run the torrefaction process with municipal waste (including plastics) to generate fuel.[a]
Business and client partnerships	Demonstration plants have typically built on a combination of government grants and private financing. The primary market for torrefied biochar is seen by many producers as co-firing with large power producers.[b] In 2016, Blackwood Technology signed a licensing agreement for a plant with the South African public utility Eskom.[b]
Robustness	A strong R&D partner is essential to determine the optimized process parameters for the desired product; this can take trial and error, but would be feasible in locations with good engineering capacity. Topell Energy experimented with 800 samples to arrive at an optimum pellet size.[b]

Note: ECN = Energy Centre for The Netherlands; R&D = research and development.

a. Personal communication Antonie de Wilde, May 2, 2018.

b. See the Blackwood Technology website on co-firing, http://www.blackwood-technology.com/applications/co-firing/.

TABLE 21.2. Limitations and Enabling Factors

	Limitations	Enabling factors
Research	The technology is commercially mature and viable for woody biomass. Nonwoody biomass has been investigated but needs further development (Thrän et al. 2016).	Further research is needed to optimize the parameters and value chain models: identifying the ideal torrefaction conditions for fecal sludge feedstock, optimized feedstock ratios, and products to suit market conditions.
Combining technologies	The commercial viability of torrefaction depends on whether the costs of heating the biomass can be compensated, either through burning off the volatiles gases or through a separate energy source such as solar or biogas.	Examples to build on include: • A biogas and torrefaction combined municipal waste management model.[a] • Solar pyrolysis by Sanivation to produce fuel from fecal sludge.[b] • Harnessing large-scale solar furnace technology to offset the drying required for higher moisture input wastes such as fecal sludge.[c]
Political and regulatory framework	The relatively low carbon dioxide emission price is a major hurdle for any coal substitute. Price parity with coal is essential to enable commercial co-firing of torrefied biomass (Cremers et al. 2015).	Fiscal subsidy schemes for torrefied biomass; articulation of torrefied biomass within regulatory frameworks; standardization, trade registration, and legal permissions.
	Matchmaking potential with countries that have a minimum technical capacity and a coal market deficit (e.g., India, Bangladesh, Uganda).	

a. Personal communication Antonie de Wilde April 2, 2018.
b. See the Sanivation website, http://www.sanivation.com/. At the site, feces is transferred into repurposed metal paint drums, which are attached to large parabolic mirrors that act as solar energy concentrators. As the sun beams down, it heats the waste to a high enough temperature to deactivate pathogens. The exact amount of time Sanivation leaves the waste in the concentrator depends on how bright the sun is. If the temperature in the metal drums reaches 85 degrees Celsius, one hour is sufficient. If the drums reach only 65 degrees Celsius, the waste stays for six hours. Sanivation's process of carbonizing fecal sludge finds that the high lignin content acts as a binder.
c. The Odeillo solar furnace in France can reach temperatures of 3,500 degrees Celsius; torrefaction requires 200 degrees Celsius to 300 degrees Celsius.

Process

When heated at high temperatures, biomass undergoes thermal decomposition and turns into solids (char or carbon), liquids (tar, hydrocarbons, and water), and gas. The torrefaction process heats raw biomass to 200–300 degrees Celsius in a low-oxygen atmosphere to produce torrefied material and combustible gas. Limiting the oxygen and hydrogen content increases the carbon content of the product. During pyrolysis, combustible gases (volatile organic compounds) are emitted, but these can be recaptured to provide the energy needed for the torrefaction process or the process of predrying to less than 20 percent moisture content. The higher the moisture content of the biomass, the lower the yield because more gas will be required to dry the product. After torrefaction, the product is cooled and compacted into briquettes or other appropriate forms for sale as biofuel.

Experiments on chicken litter, horse manure, and dried sewage sludge show an increase in energy density after torrefaction (Dhungana 2011). High-density polyethylene (HDPE) can also be processed, if mixed with organic waste, which improves the physical and combustion properties of the final product (Fuad et al. 2018). Fecal chars made at 300 degrees Celsius are similar in energy content to wood chars and bituminous coal.[3]

Products

The products obtained depend on the process conditions—speed of heating, temperature, length of time heated—which can be varied to produce products of different qualities.[4] Typically, the torrefaction process results in a mass loss (dry basis) of 20 percent to 30 percent and an energy loss of 10 percent to 15 percent.[5] Chemical attributes of the torrefied pellets include no biological activity, a higher calorific value, and a higher bulk density, and they are more homogenous than raw biomass. Physically they are hydrophobic (water-resistant), durable, and burn like coal but with a lower sulfur and ash content. Benefits include lower transport and handling costs and higher energy yield compared to coal, making it a potentially ideal coal replacement (Thrän et al. 2016). Torrefaction recaptures carbon dioxide emitted during the combustion process to co-fire the boiler. Substituting 100 percent of coal for torrefied biomass in a typical 900 kilograms of carbon dioxide per megawatt-hour coal-fired utility plant emitting 915 kilograms per megawatt-hour would see a net reduction of carbon dioxide emissions of more than half compared to the pure coal case (403 kilograms per megawatt-hour) (Li et al. 2013). Aside from fuel, char has potential applications as a soil nutrient and a filtration medium to absorb pollutants or as a building material (Draper 2016).

Notes

1. See the Blackwood Technology website on co-firing, http://www.blackwood-technology.com/applications/co-firing/.
2. See the Biomass Technology Group (BTG) website on torrefaction. http://www.btgworld.com/en/rtd/technologies/torrefaction.
3. Have a heating value of 25.6 ± 0.08 megajoule per kilogram, while fecal chars made at 750 degrees Celsius have an energy content of 13.8 ± 0.48 megajoule per kilogram (Ward et al. 2014).
4. See the Biomass Technology Group (BTG) website on torrefaction. http://www.btgworld.com/en/rtd/technologies/torrefaction.
5. See the Blackwood Technology website on co-firing, http://www.blackwood-technology.com/applications/co-firing/.

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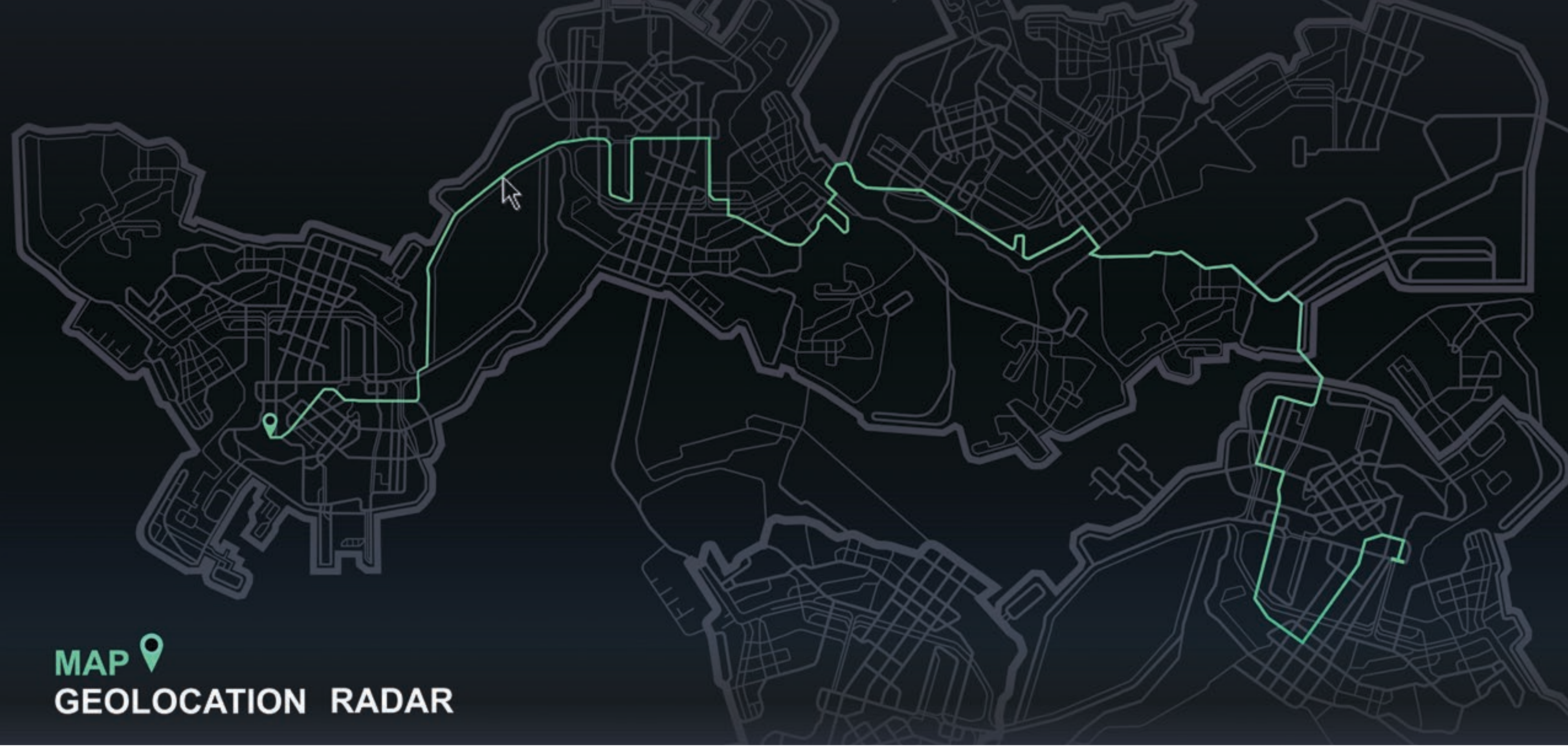

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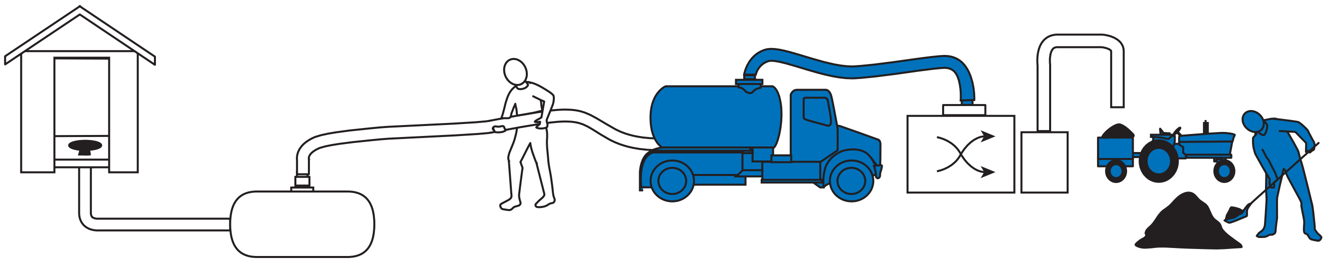
Chapter 22 GIS and Network Analysis to Reduce Haulage Costs



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	Optimizing transport saves resources	n.a	Optimizing transport saves costs

WASTE COLLECTION OPTIMIZATION

Collection and transport accounts for up to 85 percent of waste management costs. There is no universal set of rules to determine which waste management collection arrangements are optimal for any given environment. Local conditions, the nature and volumes of waste, quality of roads, and institutional arrangements will influence how waste management services may or may not be viable. GIS modelling can link data to geographic locations to optimize logistical management and resource allocation.

APPLICABILITY FOR FECAL SLUDGE MANAGEMENT

The cost of haulage is significant for fecal sludge management, and increasingly so outside urban centers. Geographic information system (GIS) and network analysis could determine the size, nature, and network routes of cluster or decentralized business models in local contexts.

Treating the estimated 6.8 billion tons of organic domestic waste across the globe through anaerobic or aerobic processes could reduce carbon monoxide emissions by 1.4 billion tons (Anwar et al. 2018). However, optimizing the scale and logistics is a major challenge.

Planning and operating a successful waste management strategy require collecting large amounts of data and mapping static or dynamic assets. Software using GIS and network analysis has proved useful in gathering and analyzing multivariate information to output optional routines and models for solid waste management. See table 22.1 for a description of waste process typology; see table 22.2 for a summary of limitations and enabling factors.

TABLE 22.1. Waste Process Typology

Objective	Description
Removing waste from environment	Technology optimizes removal of waste from the environment by identifying the best places to locate service areas and treatment and processing sites, mapping facilities, and ways of factoring in traffic and routing problems.
Pathogen inactivation	n.a. GIS models can be combined with pollution risk maps to capture the impact of hazards.
Waste to resource	Software can incorporate waste-to-resource technologies and processes in optimization scenarios.
Scale	GIS technologies are heavily relied on in high-income economies for mapping complex systems. Although a few cases exist, their uptake is lower in low-income economies. There is scope for GIS and network analysis to be scaled to any location to determine optimum waste management models (Apaydin and Gonullu 2008).
Self-sufficiency	Complex waste management systems have been a field of GIS application from the early days of the technology (Mihai and Taherzadeh 2017).
Financial arrangements	Accurate mapping of systems and the technology license will incur costs, which may be recouped through the potential savings.
Business and client partnerships	Well-defined and clear partnership opportunities.
Robustness	Robust and transferable to FSM optimization, integrated waste management, and waste management in the circular economy. Some FSM networks have been mapped in Kampala (Ulrich et al. 2016).

Note: FSM = fecal sludge management; GIS = geographic information system; n.a. = not applicable.

TABLE 22.2. Limitations and Enabling Factors

	Limitations	Enabling factors
Fleet management	Fleet management is relatively new to FSM.	Modeling can be an effective way of testing multiple solutions and establishing the optimal resource locations prior to any construction.
Systems management	Informal and independent operations with a disincentive to reveal exact locations of waste dumping.	Getting the incentives and economies of scale right.

Note: FSM = fecal sludge management.

Process

In major cities, collection and transportation accounts for more than 66 percent of total solid waste management expenditure in low-income countries and more than 50 percent in upper-middle-income economies (Malakahmad et al. 2014; Sanjeevi and Shahabudeen 2016). Rural areas are usually the most neglected, with few incentives for private operators and rarely any public financial support (Mihai and Taherzadeh 2017). In many rural areas of low-income countries, waste management systems are simple and informal, if they exist at all. Waste is typically disposed on open dumps or riverbanks or burnt, often causing ground, water, and air pollution and associated health hazards (Mihai and Taherzadeh 2017).

When high-density rural areas (i.e., with a concentrated population or close to an urban center) are clustered, economies of scale may make collection and transportation feasible (Balasubramanya et al. 2017). Solid waste management often uses the transfer haulage model, by which smaller vehicles work locally and travel smaller distances, sometimes via transfer stations, and larger vehicles travel longer distances.

GIS and network analysis have been widely applied in urban utilities planning, transportation, natural resources protection and management, health sciences, forestry, geology, natural disaster prevention and relief, and aspects of environmental modeling and engineering (Mihai and Taherzadeh 2017). GIS and network analysis lend themselves to decisions about siting waste management and disposal facilities. GIS applications have been used since their onset to optimize waste collection and transport (Mihai and Taherzadeh 2017).

GIS analysis of waste management systems allows the user to map and analyze configurations, for example: (a) a centralized system that gathers all the waste in one location to treat; (b) a clustered system that identifies zones to locate waste treatment centers; or (c) a decentralized system, in which waste is treated at the village or household level (Anwar et al. 2018). Within each of these configurations, weighting criteria and restrictions can be introduced into the model to optimize for fuel costs, carbon dioxide emissions, or distance; and map to the context and intended objectives.

Products

GIS analysis simply means overlaying layers of data on geographic maps. Dedicated environmental and waste management packages are available to improve efficiency though routing optimization and resource reallocation.

In Tunisia, optimized waste collection scenarios were developed using GIS to improve the efficiency of waste collection and transportation in the district of Cité El Habib, Sfax (Kallel, Serbaji, and Zairi 2016). The baseline scenario was mapped, then other scenarios were generated and analyzed to identify how different routing options, vehicle fleets, and combinations of routes and collection methods would impact costs. The scenarios generated cost

TABLE 22.3. Benefits of Waste Collection Optimization

Location and population	Benefit	Ref.
Ipoh city, Malaysia (pop. 536,000)	22% reduction in length of solid waste collection routes	Malakahmad, A. et al. (2014)
Area of Elgin, Illinois (pop. 108,000)	10% reduction in number of collection trips	Sahoo S., Kim S., Kim B.I., Kraas B., Popov J. (2005)
Municipality of Nikea, Athens, Greece	3% to 17% improvement in collection time; 5.5% to 12.5% reduction in travel distance	Chalkias, C. and Lasaridi, K. (2009)
City of Ansasol, India (pop. 1 million)	Minimized distance and cost of waste transportation to landfill	Ghose M.K., et al. (2006)
Santo Antao, Cape Verde (pop. 45, 000)	52% fuel savings, despite traveling 34% longer distances	Tavares G., et al. (2008).
City of Trabzon, Turkey (pop. 300,000)	24.6% reduction in distance; 44.3% in total time traveled	Apaydin, O. and Gonullu, M T. (2008)

savings ranging from 14 percent to 57 percent and reduced travel distances by 13.5 percent to 40.5 percent compared to the original situation, enabling savings on fuel and wider benefits of reduced carbon dioxide emissions, work hours, and vehicle maintenance (Kallel, Serbaji, and Zairi 2016). Further examples are in table 22.3.

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Ulrich, L. et al. 2016. *Assessing the Costs of on-Site Sanitation Facilities*. Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (Eawag).

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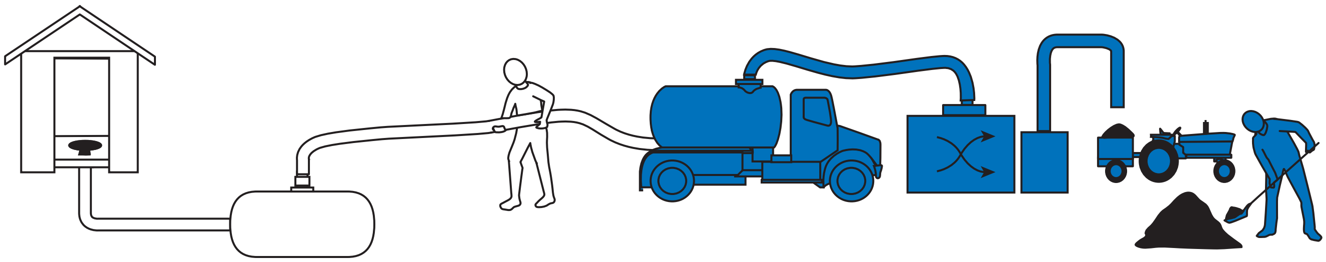
Chapter 23 Co-Production of Biofuel from Clustered Farms in Sweden



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	Waste from farms is treated locally; biogas is piped to upgrading facility	Anerobic digestion does not achieve full inactivation but is managed appropriately in a farm context	Cost and resource recovery is achieved

LOCAL GAS GRID PARTNERSHIP

This case documents a local gas grid partnership in Sweden, in which four biogas plants located on farms are fed manure, agricultural residues, and food industry waste from a cluster of businesses. The generated biogas is piped to a local slaughterhouse and used for heating and to an upgrading facility to produce biomethane. The fuel supplies a commercial fuel station used by the general public and to fuel public transport in urban centers 30 kilometers away.

APPLICABILITY FOR FECAL SLUDGE MANAGEMENT

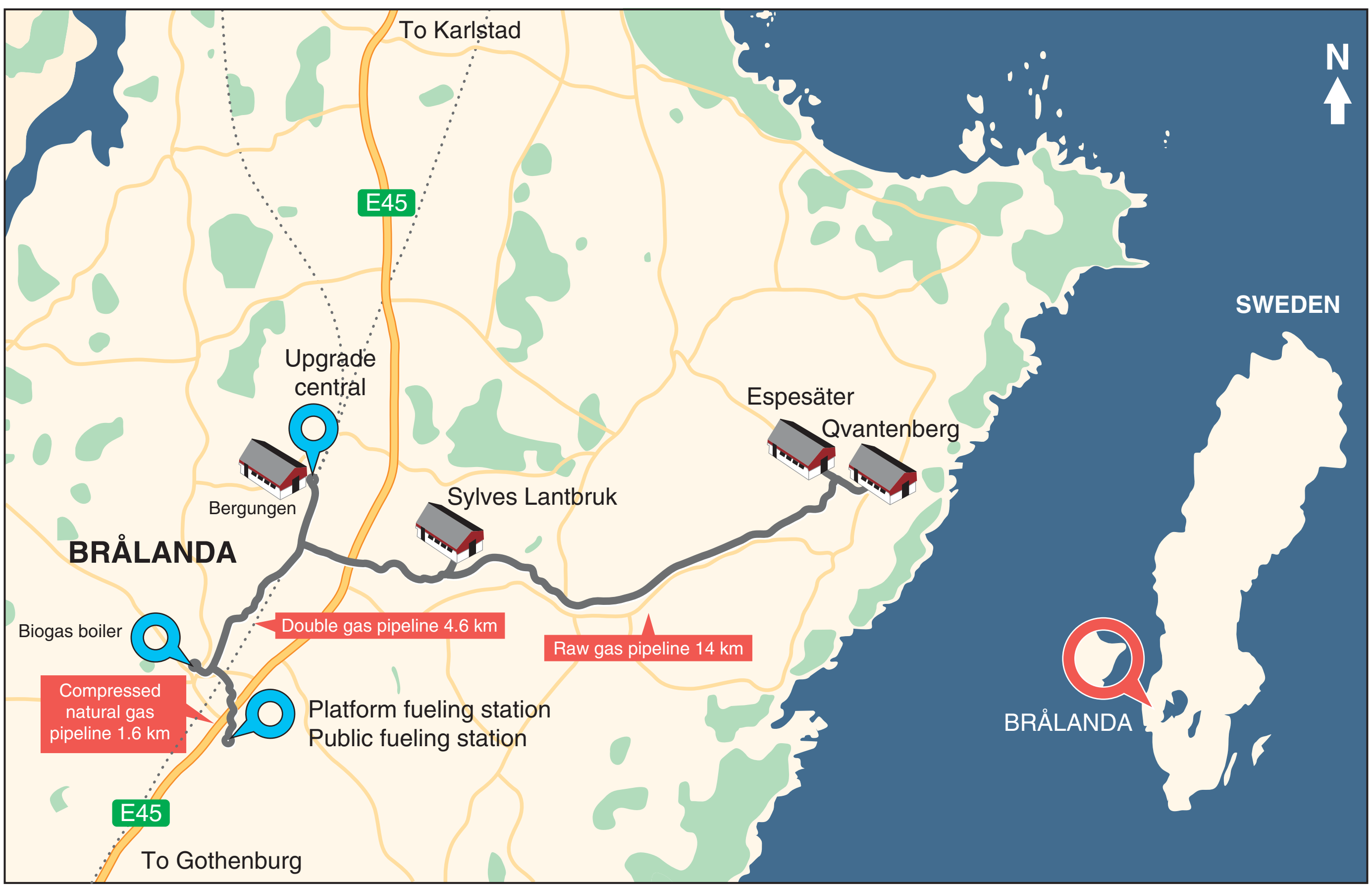
This case presents a commercially viable model of clustering farms to produce biogas and biomethane. Key lessons for fecal sludge management are on the regulatory and institutional environment that underpin this partnership, the roles and partnership arrangements, the scale of clustering to justify the upgrading to a higher-end product, and the importance of securing a long-term customer and purchase agreement with the municipality. In addition, a well-established renewable energy market with clear institutional and regulatory arrangements lowers risks on investment, and securing a long-term customer and purchase agreement is key to success.

Local Gas Grid Biogas Partnership

Sweden is a leader in waste recycling and waste-to-resource production, with a target of at least 50 percent renewable energy by 2020 (Thorin et al. 2011). In 2016, biomass supplied 24.6 percent of the total energy production. Biofuels (biomethane), which can be made by upgrading biogas, has served 19.5 percent of the national transport fuel market.[1]

Local gas grids are gaining more attention in Sweden (Persson and Svensson 2014), and examples exist in Brazil (Bley and Amon 2013). Farm-based biogas plants offer primary energy savings by replacing fossil fuels and reductions in greenhouse gas emissions by capturing methane that would otherwise be released into the atmosphere. This case documents one such example: in Dalsland County in western Sweden, clustered small-scale farms are producing biogas from farm and food waste (no fecal sludge). The biogas is

MAP 23.1. Localized Gas Grid: Brålanda Biogas Network



Source: Adapted from Biogas Dalsland Economic Association.

distributed through a local gas grid pipe network and used as a heating fuel by local industry and upgraded to biofuel for vehicles. Farmers have installed biogas units and have broken even financially after five years of operation.[2] See table 23.1 for a description of waste process typology; see table 23.2 for a summary of limitations and enabling factors.

TABLE 23.1. Waste Process Typology

Objective	Description
Removing waste from environment	Farm waste is processed and reused on-site as fertilizer (digestate) or transported off-site as biogas through a dedicated pipe network.
Pathogen inactivation	The anaerobic digestion process to produce biogas reduces, but does not eliminate, viruses, bacteria, and parasites: biodigester effluent COD values often exceed 1,000 milligrams per liter of COD, which can pollute surface water (Vögeli et al. 2014). Post-treatment of fecal biodigester effluent is required, such as sedimentation or composting; in the rural farm context, this is quite feasible. In Europe, regulations govern the application of digestate to land: for example, in Sweden, farmers must have a minimum storage capacity for digestate of six to 10 months and must apply the fertilizer during growing season in a controlled way, minimizing run-off and environmental pollution and health risks (Lukehurst, Frost, and Al Seadi 2014).
Waste to resource	Biogas, biomethane, and fertilizer achieve 100 percent use in the Brålanda example through committed stakeholders, careful site selection, and securing a committed and long-term customer.
Scale	Biogas Brålanda is operating at 7 gigawatt-hours per year, but is designed to accommodate more farms up to 30 gigawatt-hours (Persson and Svensson 2014). Similar local gas grids exist in Brazil (Bley and Amon 2013). More generally, anaerobic digestion is a well-established treatment technology suited for wastewater or wastes containing high levels of organic matter.
Self-sufficiency	The project was partly supported by investment funding from EU's KLIMP. The EU supported investments in production facilities, while KLIMP supported the pipelines, upgrading facility, and filling station (Biogas XPOSE 2015).
Financial arrangements	Established in 2009, it took six years to be profitable and currently operates at a narrow profit margin of 7.24 percent.[a] Achieving end-to-end, waste-to-resource partnerships was an added complexity in this model. The operating company is 66.7 percent owned by the private sector arm of the municipality and 33.3 percent by the Biogas Dalsland Economic Association (comprising farmers, producers, and the general public). The infrastructure company is owned by two adjacent municipalities (73 percent and 18 percent) and 9 percent by the operating company.[b]
Business and client partnerships	Brålanda has clear and well-defined partnership opportunities. The farmers build and operate their biogas plants individually or in groups. Two private entities manage the distribution: one owns, manages, and maintains the pipeline network, and the other manages the biogas and upgrading process to bioethanol. The operating company rents the use of the pipeline. The key to sustainability is the long-term agreement with the municipal energy company, which already had established access to existing markets and use of fuel for public transport.
Robustness	The technology is robust, and the arrangements are upheld due to the favorable enabling environment that Sweden and the EU provide for renewable energy.

Note: COD = chemical oxygen demand; EU = European Union; KLIMP = Rural Development Programme and Swedish Climate Investment Programme.

a. See the Allabolag website page "Biogas Brålanda AB Company Information," https://www.allabolag.se/5567839450/bokslut.

b. Biogas Dalsland Economic Association, http://biogasdalsland.se/index.php/bralanda-biogas/.

TABLE 23.2. Limitations and Enabling Factors

	Limitations	Enabling factors
Enabling environment	Multiple stakeholders were needed to operationalize the Biogas Brålanda process.	A very favorable enabling environment included (a) a robust regulatory and policy framework; (b) clearly articulated roles and responsibilities; (c) good existing capacity, skills, and technology in biogas; (d) committed stakeholders; (e) an established biogas market and customers; (f) securing a long-term customer purchase agreement at a satisfactory price early on; and (g) finance from climate change funds. All these factors significantly de-risk private sector investment. In Sweden, these factors have come about through large-scale and long-term sector reform.
Margins of profitability	Ensuring an optimized and stable feed of the biodigester and establishing the maximum transport distances that are feasible are key to the system's profitability.	The Biogas Brålanda model works because of adequate technical support in designing the scale of the grid network and balancing the digestor. The waste sources and customers are within a reasonably short distance, and the ground conditions were favorable to justify investments in pipeline distribution (Biogas XPOSE 2015). As with all waste-to-resource activities, locating waste customer hotspots is crucial for achieving commercial viability (Thorin et al. 2011).
Profitability	Current profit margin is just enough for a social impact investor, but not for a commercial investor.	Favorable enabling environment reduces risks of investments.
Potential matchmaking	Sweden's renewable energy model is mature and is attracting private investment after decades of investment and sector reform. There may be useful lessons for countries (such as China, India, Brazil, Latvia, the Czech Republic, Greece, Turkey, Poland, Chile, and Argentina) that have some experience of biogas to increase uptake from public institutions and infrastructure as a means of leading the way for private sector interest in renewable energy. Identifying hotspots for waste-to-resource clusters has high potential for FSM.	

Note: FSM = fecal sludge management.

Biogas Cooperative Concept

Biogas Brålanda is an association of approximately 30 farmers. They feed manure, agricultural residue, and food industry waste into four biogas plants, located on the farms. The biogas is captured and transported through a 19-kilometer pipeline to the local slaughterhouse, where it is used for heat, and to a joint upgrading facility that produces vehicle fuel. The latter is piped a further 6 kilometers to a commercial fuel station for cars. At the fuel station, tankers are filled with biogas, which they transport to filling stations in the nearby cities of Vänersborg (24 kilometers) and Trollhättan (35 kilometers), where most buses run on biogas. Clustering the farms provides the economies of scale to justify the joint upgrading facility.

The main feedstock of the biogas plants is farm manure. The slaughterhouse waste is used in the biogas plants (Biogas XPOSE 2015). Getting the balance of waste right took a few months: a premixing tank combines the different substrates and agricultural residues. Because it uses electricity, achieving stable and optimized operation is key to profitability. Similar models exist in other areas of Sweden, where grain and pig farmers bring agricultural waste and manure to a centralized biogas plant and recoup biofertilizer for their land (Biogas XPOSE 2015). The farmers use the digestate as fertilizer: under Swedish law, its application is controlled by season, and biogas farm sites must have a minimum storage capacity for digestate of six to 10 months.

Products and Market

Chemically, biomethane is identical to natural gas and can be fed into the natural gas grid or used in adapted vehicles as fuel. The process of upgrading biogas to biomethane involves removing carbon dioxide and various other impurities (Hoyer et al. 2016). Securing a long-term customer and purchase agreement has been key (Biogas XPOSE 2015): most of Brålanda's biogas is upgraded to biomethane, which supplies the filling station, the municipal energy company Trollhättan Energi, and municipal public transport buses.

Notes

1. See the Swedish Energy Agency website page "Energy in Sweden Facts and Figures 2018," http://www.energimyndigheten.se/en/news/2018/energy-in-sweden---facts-and-figures-2018-available-now/.
2. See the Allabolag website page "Biogas Brålanda AB Company Information," accessed June 1, 2018, https://www.allabolag.se/5567839450/bokslut.

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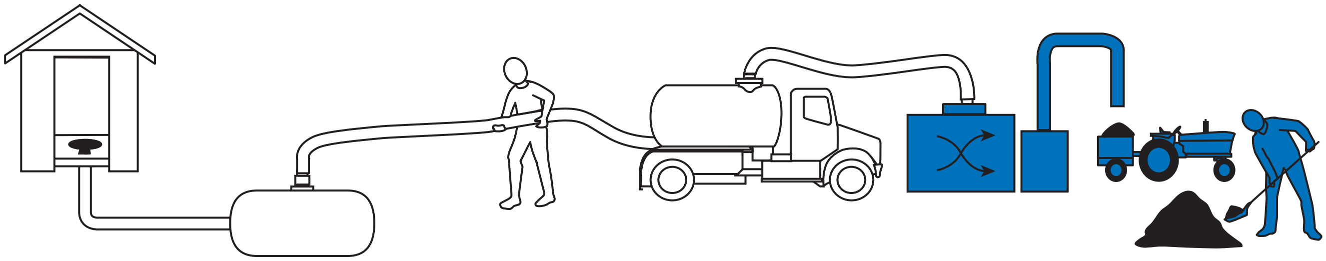
Chapter 24 Reclaiming Phosphorus from Stabilized Sludge for Nutrient Recovery



Point of Use	Containment	Emptying	Transport	Treatment	Reuse
n.a.	n.a.	n.a.	n.a.	Crystallization is performed as additional treatment step	Nutrient recovery of a depleted resource

RECLAIMING PHOSPHORUS

Phosphorus is an essential plant nutrient and ingredient in fertilizers. At current consumption levels, known reserves will be depleted in 80 years. Methods exist to recover phosphorus as part of wastewater treatment; however, their aim is usually to meet environmental standards for effluent discharge. This case considers a technology that recovers phosphorus through a struvite crystallization process with the aim of marketing the material as a high-end commercial fertilizer.

APPLICABILITY FOR FECAL SLUDGE MANAGEMENT

Urine-diverting toilets facilitate the collection of urine, and there is proven research into phosphorus recovery from human urine and pilots of relatively low-cost and low-tech solutions. However, financial viability depends on high volumes of urine, which incur more complex and costly logistics. There may be efficiency gains in terms of product and process to be learned from the higher-tech operations.

Global Supply of and Demand for a Depleting Resource

Phosphorus is an essential nutrient for plants and ingredient in fertilizers. Reserves are finite and highly concentrated: four countries (Morocco, Algeria, China, and the Syrian Arab Republic) hold the bulk of untapped rock. At current consumption levels, known phosphorus reserves will be depleted in 80 years. Demand for phosphorus will increase as a growing global population consumes more food.

Several methods have been commercialized to recover phosphorus from wastewater, biosolids, fecal sludge, and urine (Otoo Drechsel, and Hanjra 2015; Wollmann and Moller 2015). However, their aim is usually to take phosphorus out of the water that will be discharged from treatment plants to prevent algal blooms. This brief considers a high-tech process based on crystallization of struvite (magnesium ammonium phosphate), which can produce a high-value fertilizer product (Nieminen 2010). See table 24.1 for a description of waste process typology; see table 24.2 for a summary of limitations and enabling factors.

TABLE 24.1. Waste Process Typology

Objective	Description
Removing waste from environment	n.a. This is a treatment technology.
Pathogen inactivation	The crystallizing happens once the sludge is stabilized. Little data are available on the behavior of pathogens during precipitation and drying of struvite from wastewater. Pathogen inactivation depends on temperature and humidity during drying and the length of the drying period, which varies. The product is, however, licensed in the United States and not classified as a biosolid waste (Wollmann and Moller 2015).
Waste to resource	The aim is to produce a high-value product, avoiding the common problem with biosolids-as-fertilizers that the amount of nutrients is often too low for commercial viability (Otoo, Drechsel, and Hanjra 2015).
Scale	One company has 17 commercial plants worldwide, each with a struvite production rate of 500 kilograms per day.[a]
Self-sufficiency	The process was developed at the University of British Columbia, Canada, and patented in the United States. The company commercializing it has guaranteed price purchase agreements in its three main countries of operation—Canada, the United States, and the United Kingdom.[a]
Financial arrangements	Private and sector-led, the plants cost an estimated US$2 million to US$4 million with return on investment estimated in three to five years (Nieminen 2010).
Business and client partnerships	The model is being popularized by a private sector player that specializes in private-public partnerships with WWTPs (Otoo, Drechsel, and Hanjra 2015). For example, Thames Water UK is paying a monthly fee, for 20 years, which is less than its former maintenance costs for struvite removal from pipes and valves (Otoo, Drechsel, and Hanjra 2015). Public sector WWTPs are not necessarily interested in marketing fertilizer, so private sector partners with specialized knowledge of agricultural markets are needed to broker between the sanitation and agricultural actors (Otoo, Drechsel, and Hanjra 2015).
Robustness	Phosphorus recovery needs high investment but offers a high return.

Note: n.a. = not applicable; WWTP = wastewater treatment plant.
a. Ostara website, www.ostara.com.

TABLE 24.2. Limitations and Enabling Factors

	Limitations	Enabling factors and actions
Research and development	Little data are available on the behavior of human pathogens during precipitation and drying of struvite.	Further research on optimizing parameters and value chain models.
Partnerships	WWTPs are not necessarily interested in developing and marketing fertilizer products.	Identifying and brokering partnerships with actors that have expertise in the commercial fertilizer market.
Market competition	The market for phosphorus is large, but currently dominated by rock phosphate and commercial fertilizers.	Fiscal, policy, and regulatory incentives: for example, the EU could reconsider the current prohibition on using struvite recovered from wastewater or sewage sludge in organic farming (Wollmann and Moller 2015).
Matchmaking	China, India, and the United States account for half of the global consumption of fertilizer (Zhou 2017). China has abundant phosphate deposits and some capacity in recovering phosphorus, but at a lower grade and efficiency than the process described here.	

Note: EU = European Union; WWTP = wastewater treatment plant.

Struvite Crystallization Process

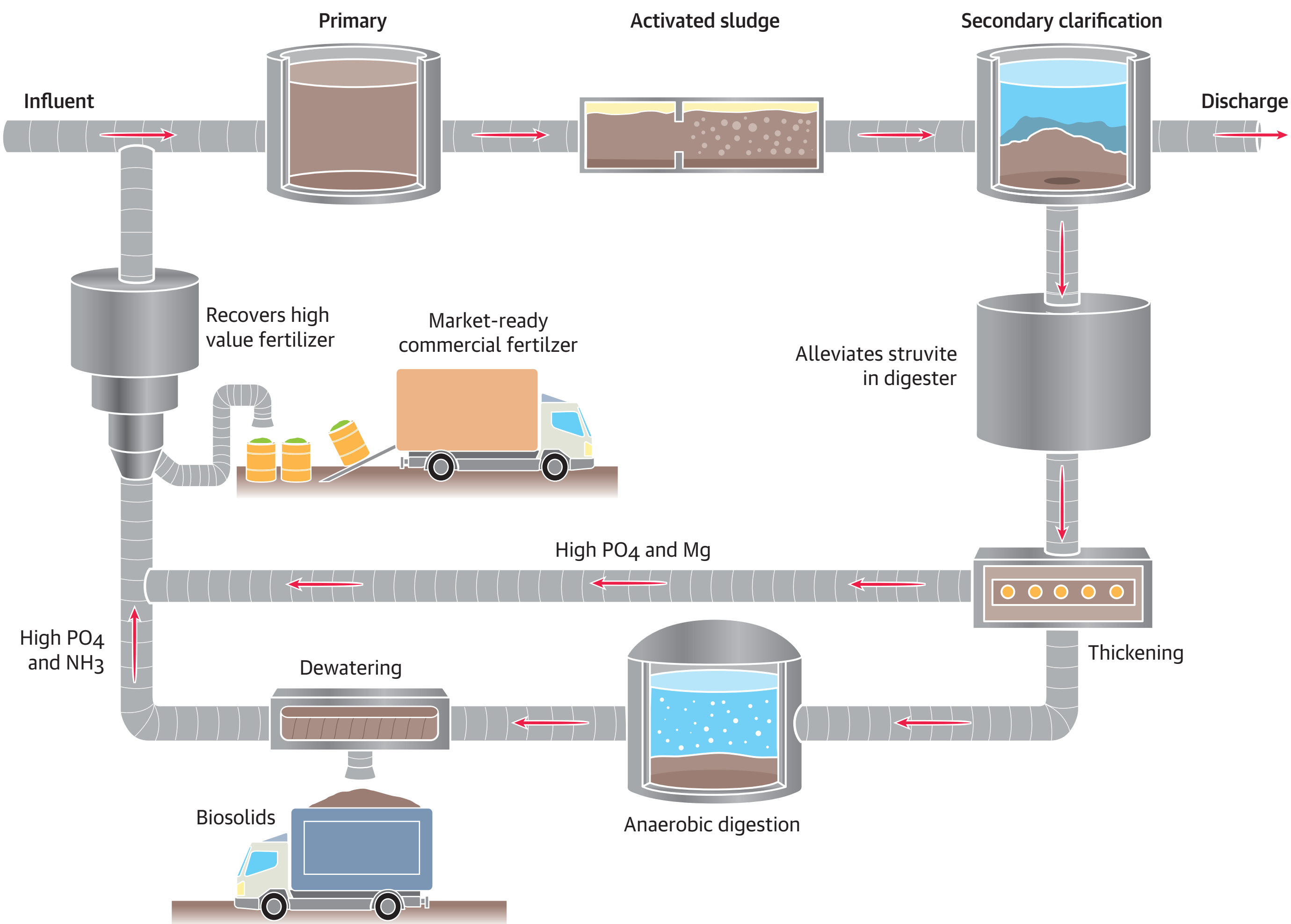
Struvite is a cement-like deposit that that often clogs wastewater treatment plant (WTTP) equipment, incurring maintenance and part replacement costs. The struvite crystallization process involves carefully dosing sludge liquor with magnesium, which controls the levels of struvite formation, within a fluidized bed reactor. The struvite crystallizes as pellets, which are dried, sorted, and bagged for distribution as high-value fertilizer.

The process recovers 75 percent to 90 percent of phosphorus and 10 percent to 40 percent of the ammonia from the wastewater (Nieminen 2010; Otoo, Drechsel, and Hanjra 2015).[1] An influent flow of 500 cubic meters per day with suspended solids content of less than 1,000 milligrams per liter has an energy demand of 7.2–13 kilowatts for drying and generates 500 kilograms of struvite per day. The pH range of the effluent remains constant at 7.2–8.0 (Nieminen 2010). The benefits of introducing the crystallization in WWTPs is twofold. First, that process minimizes the need, typical in other phosphate recovery processes, for heavy chemical dosing to modify the pH for precipitation (Nieminen 2010); second, it prevents the struvite deposits that clog the machinery. See figure 24.1 for a description of the process.

Products

The struvite pellets produced by this method have a nitrogen, phosphorus, and potassium (NPK) value of 5-28-0, with 10 percent magnesium.[1] They are marketed as a premium fertilizer for municipal lawns and golf courses, offering slow release of nutrients (six to nine months on the surface, or three months in soil), guaranteed purity, and consistent quality and size.

FIGURE 24.1. Process of Reclaiming Phosphorus Process



Source: Adapted from www.ostara.com.

Note

1. See the Ostara website, www.ostara.com.

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