RTI International
TEA of Model Fecal-Sludge Management and Sewer-Based Systems

Milestone #4:
Final Report
This study was funded by the Bill & Melinda Gates Foundation through RTI International – Sanitation Technology Platform (STeP). Funded by the Bill & Melinda Gates Foundation, STeP helps transformative technologies reach the 2.5 billion people worldwide who don’t have access to safe, affordable sanitation.

The overall study was carried out by Stantec Consulting Services Inc. On-site data collection in India was conducted by the Consortium for DEWATS Dissemination. Key technical inputs into the cost framework and review was provided by 30 Degrees LLC. Review was additionally provided by Global Development Services, LLC.
Executive summary

Background
Stantec conducted a *Techno-Economic Analysis (TEA) Study of Model Fecal-Sludge Management and Sewer-Based Systems in India* to help omniprocessor (OP) technology partners better understand the lifecycle costs of “incumbent” solutions, including fecal sludge management (FSM), sewer-based (SB), and co-treatment (CT) systems. Within this study, eight sanitation model systems are defined, a cost framework is developed to estimate costs for each model system, and capital and operational cost data were collected from existing systems to calibrate and validate this cost framework. The defined model systems include four FSM systems, three SB systems, and one CT system.

Key findings
Key findings for the modeled and existing systems include:

- **CapEx, OpEx and All-In costs are higher for SB and CT systems compared to FS systems.** This finding is consistent with available literature.
- **Cost drivers occur at different lifecycle phases** for FS and SB systems – i.e. a majority of costs are incurred during the capital infrastructure phase for SB systems and during operations for FS systems.
- **Solids treatment infrastructure** is primary cost driver for FS CapEx.

Key findings (cont.)

- **Collection (vacuum tanker operations) and labor costs are primary cost drivers for FS OpEx.**
- **Collection (sewer-network) infrastructure drives CapEx and All-In SB system costs.**
- **Electricity** is primary cost driver for SB OpEx.
- **Land** may be an important cost driver; however land was reportedly provided by local government at no cost for most existing FSTPs and STPs.
- **Solids disposal** may be an important cost driver if biosolids are landfilled (with an associated tipping fee). However, data collection from existing systems suggests that sufficient demand for biosolids for land application exists such that landfilling is not the current disposal practice in India.
- **Economies of scale exists for all SB, FS and CT systems** modeled (i.e. smaller per-capita costs for larger population served). However, a practical limit likely exists on the population served by FS systems due to limitations on the distance truck operators are willing to travel.
Executive Summary (cont.)

Key findings (cont.)

• Co-composting with municipal organic waste may potentially be a key source of revenue for FSTPs. However, investigation is needed to determine availability of bulking agent and demand for compost at a specific site.

• Biogas recovery may be a low to moderate source of revenue for FSTPs and STPs, with potential value dependent on the ability to convert biogas to an attractive product or transport it to a location at which there is demand for biogas.

Limitations

• The model system findings presented within this study are based on a particular set of assumptions. Results may vary by an order of magnitude depending on variations in input parameters.

• A key feature of the Excel Cost Framework developed within this study is the ability for the user to test how varying input parameters impacts model system results. However, the Cost Framework does not allow for changes to all input parameters. Additionally, there are several other parameters, site factors and costs not considered within the Framework. Moreover, the costs considered within this study are limited to costs borne by the municipality or service provider and exclude costs borne by the household for sanitation (e.g. household containment for FS systems; water supply for conveyance for SB systems). Thus this Cost Framework should be used in conjunction with additional planning tools and is NOT intended as a standalone tool.
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>annum</td>
</tr>
<tr>
<td>ABR</td>
<td>anaerobic baffled reactor</td>
</tr>
<tr>
<td>AD</td>
<td>anaerobic digester</td>
</tr>
<tr>
<td>Cap</td>
<td>capita</td>
</tr>
<tr>
<td>CapEx (or CX)</td>
<td>capital expenditure</td>
</tr>
<tr>
<td>CT</td>
<td>co-treatment</td>
</tr>
<tr>
<td>CPHEEO</td>
<td>Central Public Health and Environmental Engineering Organisation</td>
</tr>
<tr>
<td>D/R</td>
<td>disposal / reuse</td>
</tr>
<tr>
<td>EAC</td>
<td>equivalent annual cost</td>
</tr>
<tr>
<td>FS</td>
<td>fecal sludge</td>
</tr>
<tr>
<td>FSTP</td>
<td>fecal sludge treatment plant</td>
</tr>
<tr>
<td>FTE</td>
<td>fulltime employees</td>
</tr>
<tr>
<td>HPGF</td>
<td>Horizontal planted gravel filter</td>
</tr>
<tr>
<td>KLD</td>
<td>kiloliters per day (equal to cubic meters per day)</td>
</tr>
<tr>
<td>LPCD</td>
<td>liters per capita per day</td>
</tr>
<tr>
<td>MBBR</td>
<td>moving bed bioreactor</td>
</tr>
<tr>
<td>MLD</td>
<td>millions of liters per day</td>
</tr>
<tr>
<td>MSW</td>
<td>Municipal solid waste</td>
</tr>
<tr>
<td>OPCC</td>
<td>Opinion of Probable Construction Cost</td>
</tr>
<tr>
<td>OpEx (or OX)</td>
<td>operating expenditure</td>
</tr>
<tr>
<td>PPE</td>
<td>personal protection equipment</td>
</tr>
<tr>
<td>PSDB</td>
<td>planted sludge drying bed</td>
</tr>
<tr>
<td>SB</td>
<td>sewer-based</td>
</tr>
<tr>
<td>SDB</td>
<td>sludge drying bed</td>
</tr>
<tr>
<td>SLS</td>
<td>solids-liquid separation</td>
</tr>
<tr>
<td>STP</td>
<td>sewage treatment plant</td>
</tr>
<tr>
<td>ULB</td>
<td>Urban Local Bodies</td>
</tr>
<tr>
<td>VCWL</td>
<td>vertical constructed wetland</td>
</tr>
</tbody>
</table>
1. Introduction
2. Model Systems
3. Cost Framework
4. Model Results
5. Data Collection
6. Data Analysis & Findings
7. Recommendations for further Investigation
8. Reference
9. Appendix: Key Assumptions
Introduction
RTI International is the implementing partner of the Sanitation Technology Platform (STeP) for the Bill and Melinda Gates Foundation (BMGF). STeP supports the Technology and Commercial Partners of the BMGF in the development and launch of new sanitation products by streamlining and de-risking field testing and commercialization, preserving the fullest range of rights in all markets.

STeP sought to understand how the lifecycle costs of omniprocessor (OP) technologies compare to costs of conventional fecal sludge management (FSM), sewer-based (SB), and co-treatment (CT) systems. However, capital and operating costs of conventional sanitation infrastructure are not well understood and data on such infrastructure in the context of India has proven difficult to obtain for the following reasons:

- Inadequate record keeping from existing facilities
- Few attempts to collect, analyze, and compare data
- Estimation tools lack real-world operations data, ignore scaling impacts, and
- Lack of local relationships

Stantec conducted a Techno-Economic Analysis (TEA) Study of Model Fecal-Sludge Management and Sewer-Based Systems in India to help OP technology partners better understand lifecycle costs of “incumbent” solutions, including both FSM, SB systems, and CT system.

The objectives of this study was to:

- Identify 8 model systems that are relevant competitors of OP technologies
- Identify and collect data from existing sanitation systems in India and adjacent countries
- Develop a robust cost analysis framework that will generate capital, operating and all-in cost curves on a per-population-equivalent basis for each model system
Introduction

System boundary

Water supply

User interface

Household containment

Material Flow

Water

Service fee / taxes

Payment for water supply

Financial flow

Excluded from analysis

“Back-end” of Sanitation Value Chain

Vacuum Tanker Operator

Sanitation Service Provider
(e.g. Government, utility, private operator)

Collection / Conveyance

Treatment
(Pre-treatment, SLS, DW, Solids + Liquids Treatment)

Disposal
(Land apply, Landfill)

Reuse
(Energy, water, biosolids)

Infrastructure, land, electricity, chemicals, supplies, labor

Revenue from resource recovery

Infrastructure, land, electricity, chemicals, supplies, labor, tipping fee

Pipes, trucks, fuel, labor,

Pipes, trucks, fuel, labor,

Included costs

- Cost borne by municipality or service provider for: collection/conveyance, treatment, disposal, reuse
- Potential benefit of reuse (based on similar conventional resource as proxy)

Excluded Costs

- Household infrastructure (toilet, septic tank, on-plot sewer)
- Soft costs (community engagement)
- Secondary site infrastructure (e.g. office, fence)
- Cost of water supply to household
- Revenue from septic tank emptying or sewerage tariff
- On-site grey water treatment
- Nutrient removal
1. **Model Systems & System Boundaries**

**Definition**

Model systems include the entire sanitation service chain from collection to transport, treatment, and disposal. A total of 8 model systems, 4 FSM, 3 SB, and 1 CT were identified. They were developed based on existing least-cost sanitation systems in India and designed to vary in technical complexity to produce a range of cost curves and be comparable to decentralized and centralized OP technologies.

Given that each model system or archetype can have different permutations at different stage of sanitation service chain, the goal of this study and subsequently identification of model systems is to provide a range of realistic costs rather than estimates that are based on technical optimization.

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2. **Cost Framework and Cost Curve Development**

The cost framework and cost curves consist of capital and operational costs for each of the model systems for various populations served. Three population ranges were selected for each model system based on typical practice and economic and technical feasibility.

Capital costs were broken down by collection, liquids treatment, and solids treatment. Operating costs consisted of collection, resource recovery, disposal costs, consumables, chemicals, electricity, labor, and capital maintenance. Adjustable inputs allow users to understand cost driver impacts. Cost estimates are considered as Opinion of Probable Construction Cost (OPCC) Class 5 Estimates.

Design parameters were selected based on existing field knowledge and government documents. Most mechanical equipment cost estimates were obtained from manufacturers and vendors in India. Design parameters and cost estimates were calibrated following field data collection, in the subsequent steps.

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**Note:**

1. OPCC Class 5 estimates expected accuracy ranges from low -20% to -50%; high +30% to +100%. The range reflects the fact that estimation is based on very limited design and no site specific information.

2. Exceptions are mechanical dewatering machine (rotary press) for FSTP. Multiple quotations received from Indian manufacturers and vendor were reviewed and determined that they were not technically fit. Thus, quotes were obtained from manufacturers outside of India. Freight, tax and other associated are adjusted.
Methodology

3. Data Collection and Calibration of Framework and Cost Curves

Existing systems, which are currently operational in India and from which data are available, were identified through local partners in India (Stantec’s India office in Pune and the Consortium for DEWATS Dissemination (CDD) Society based in Bangalore).

Data was collected by these partners from 7 FSTPs and 2 STPs in India. Since there was difficulty obtaining enough SB/STP data, a literature review was conducted to fill data gaps.

Data was collected and vetted through multiple site visits and was analyzed before incorporated into the model. The cost framework and model assumptions were calibrated using this data to generate cost curves that best reflect the realistic cost in India. The Data collection and calibration were done in parallel to finalize the cost framework and model.

4. Data Analysis, Comparisons and Conclusions

After the cost framework was built, analyses were conducted to compare data collected from existing systems with cost curves generated by the model. The following were covered in the analyses:

• Cost curve comparison of 8 model systems
• Major cost drivers for CapEx and OpEx
• Comparison of modeled costs versus collected data-supplemental literature data
Model Systems
Each model system includes all phases of the fecal sludge or sewage management sanitation value chain: collection, transport, treatment and disposal/reuse.

First, a long list of existing systems were identified. These candidate systems are combinations of different options for each stage of the sanitation value chain, particularly for treatment and reuse.

Second, a list of criteria were used to select the 8 systems that would be modeled for this study. With the intention of the study to be producing a range of costs for least-cost model systems existing in India that could compete with OP, the criteria include:

- Technological and operational complexity in treatment technology
- Variations in disposal/resource recovery and subsequent impacts on lifecycle cost
- Effluent standards: current/accepted vs future/regulated
- Footprint and subsequent land cost
- Common types of systems found in India and potential competitiveness with OP
- Feasibility of serving necessary population size

Candidate components that were considered but were not modeled include:

**Treatment**
- MBR for liquid or sewage treatment due to its high capital cost compared with other packaged treatment options
- Additional solids drying technology (e.g.: thermal drying, solar drying, pyrolysis) due to limited or none existing application in India
- Anaerobic digestion with municipal solid waste (MSW) due to limited existing application in India\(^1\) and co-digestion with solids waste is out of scope for this study

**Reuse**
- Biochar
- Other types of solid fuel

A summary of 8 model systems is provided in this section in the following page.

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**Note:**

1. We recognize the 2016 Solid Waste Management Rule (SWMR) promotes waste-to-energy facilities and requires biodegradable wastes to be composted or treated in an anaerobic digester. However, our field surveys suggest that co-treating fecal sludge, dewatered sludge from STP with MSW is not a common practice yet.
# Model systems overview

Summary of description of 8 model systems from collection, transport, to treatment, disposal and/or reuse. It is important to note that **solids disposal options are specifically selected to emphasize the potential range of costs and is a major assumption as discussed in later pages for each system.**

<table>
<thead>
<tr>
<th>No.</th>
<th>Collection &amp; Transport</th>
<th>Solids Treatment</th>
<th>Liquids Treatment</th>
<th>Disposal/Resource Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS-1</td>
<td>Vacuum Truck</td>
<td>SDB</td>
<td>WSP</td>
<td>Land apply</td>
</tr>
<tr>
<td>FS-2</td>
<td>Vacuum Truck</td>
<td>SDB + Composting</td>
<td>WSP</td>
<td>Compost</td>
</tr>
<tr>
<td>FS-3</td>
<td>Vacuum Truck</td>
<td>Anaerobic Digestion* + SDB + composting</td>
<td>Aerated Ponds</td>
<td>Biogas Compost</td>
</tr>
<tr>
<td>FS-4</td>
<td>Vacuum Truck</td>
<td>Mechanized Dewatering</td>
<td>Activated Sludge + Chlorination</td>
<td>Landfill</td>
</tr>
<tr>
<td>SB-1</td>
<td>Pipe</td>
<td>--</td>
<td>WSP</td>
<td>Land apply</td>
</tr>
<tr>
<td>SB-2</td>
<td>Pipe</td>
<td>Mechanized Dewatering</td>
<td>Activated Sludge + Chlorination</td>
<td>Landfill</td>
</tr>
<tr>
<td>SB-3</td>
<td>Pipe</td>
<td>Anaerobic Digestion + Mechanized Dewatering</td>
<td>Activated Sludge + Chlorination</td>
<td>Biogas Landfill</td>
</tr>
<tr>
<td>CT-1</td>
<td>Pipe + Vacuum Truck</td>
<td>Mechanized dewatering</td>
<td>Activated Sludge + Chlorination</td>
<td>Landfill</td>
</tr>
</tbody>
</table>

*AD: Anaerobic digester; AS: Activated sludge; SDB: Sludge drying bed; WSP: Waste stabilization pond;
Population points for model systems

Three population points were modeled for each system.

The population ranges were selected based on:
- typical practice
- economic and technical feasibility
- comparison with OP technologies

- The figure shows the population points for each model system
### Model system: FS-1

**LEGEND**
- ➤ Fecal sludge
- ➤ Liquids
- ➤ Solids (sludge)
- ➤ Reusable co-product

#### Process Description
- **Collection**: vacuum tanker
- **Preliminary treatment**: manual screen
- **Solids treatment**: sludge drying bed
- **Liquids treatment**: waste stabilization pond system
- **Disposal**: discharge, land apply\(^1\)

#### Key Features
- **Low complexity**
- **Currently utilized treatment process**
- **Commonly used technologies**
- **Extensive** (large land requirement)
- **Population points**: 5K, 50K, 200K

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**Note:**
1. Use of “land apply” as the solids disposal method for this model system because this is one of the most common solids disposal method in India, and in general does not incur any cost to service providers.
**Model system: FS-2**

**Process Description**
- **Collection**: vacuum tanker
- **Preliminary treatment**: manual screen
- **Solids treatment**: sludge drying bed, co-composting
- **Liquids treatment**: waste stabilization pond system
- **Disposal**: discharge, compost

**Key Feature**
- Low complexity
- Currently utilized treatment process
- Commonly used technologies
- Extensive (large land requirement)
- Resource recovery (compost)
- Population points: 5K, 50K, 200K
Model system: FS-3

### Process Description

- **Collection**: vacuum tanker
- **Preliminary treatment**: manual screen, mixing tank
- **Solids treatment**: anaerobic digestion, sludge drying bed, co-composting
- **Liquids treatment**: aerated pond, maturation pond
- **Disposal**: discharge, compost

### Key Feature

- Medium complexity
- Effluent quality meets higher treatment standard
- Commonly used technologies
- Moderate land requirement
- Resource recovery (compost, biogas)
- Population points: 50K, 200K, 1M

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**Note:** Converting biogas to electricity requires additional infrastructure and treatment steps (e.g: gas purification, combined heat and power plant, etc.). These additional infrastructure cost can be substantial. The model does not include additional infrastructure that convert biogas to electricity.
Model system: FS-4

**Process Description**

- **Collection:** vacuum tanker
- **Preliminary treatment:** manual screen, mixing tank
- **Solids treatment:** mechanical dewatering
- **Liquids treatment:** activated sludge, chlorination
- **Disposal:** discharge, landfill

**Key Feature**

- High complexity
- Effluent quality meets higher treatment standard
- Potential competitor with J-OP
- Small footprint (low land requirement)
- Population points: 200K, 1M, 2M

**Note:**
1. Use of “landfill” as the solids disposal method for this model system because the amount of solids produced after treatment for the population served can be more than the amount that can be land applied. Although disposing solids to landfill site in India does not incur cost yet, in many other countries, disposal of solids to landfill is a substantial cost to service providers. Should the current practice and trend change in India, the model allows solids disposal cost to be captured in order to produce a range of costs for different model systems.
Model system: SB-1

**Process Description**
- **Collection**: sewer pipe
- **Preliminary treatment**: screen
- **Solids treatment**: none
- **Liquids treatment**: aerated pond, maturation pond
- **Disposal**: land apply, discharge

**Key Feature**
- Low complexity
- Currently accepted treatment process
- Commonly used technologies
- Extensive (large land requirement)
- Population points: 5K, 50K, 200K
Model system: SB-2

**Process Description**

- **Collection**: sewer pipe
- **Preliminary treatment**: mechanical screen
- **Solids treatment**: mechanical dewatering
- **Liquids treatment**: activated sludge, chlorination
- **Disposal**: discharge, landfill

**Key Feature**

- **High complexity**
- Effluent quality meets current regulation/standards
- Future technologies of interest
- Medium footprint
- Population points: 200K, 1M, 2M
Model System: SB-3

**Process Description**
- **Collection**: sewer pipe
- **Preliminary treatment**: mechanical screen
- **Solids treatment**: anaerobic digestion, mechanical dewatering
- **Liquids treatment**: activated sludge, chlorination
- **Disposal**: discharge, landfill

**Key Feature**
- High complexity
- Effluent quality meets current regulation/standards
- Higher treated solids quality
- Medium footprint
- Biogas provides benefit from resource recovery
- Population points: 200K, 1M, 2M
Model System: CT-1

**Legend**
- Fecal Sludge
- Sewage
- Combined

**Process Description**
- **Collection:** vacuum tanker & sewer pipe
- **Preliminary treatment:** mechanical screen
- **Solids treatment:** mechanical dewatering
- **Liquids treatment:** activated sludge, chlorination
- **Disposal:** discharge, landfill

**Key Feature**
- High complexity
- Effluent quality meets higher treatment standards
- Separate septage dewatering and sewerage treatment
- Small to medium footprint
- Population points: 200K, 1M, 2M
The following table is a summary of all 8 model systems and an overview of key selection criteria and rationale:

<table>
<thead>
<tr>
<th>Model System</th>
<th>Treatment Description</th>
<th>Footprint and Land Cost</th>
<th>OPEX</th>
<th>Disposal Cost (offset/revenue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS-1</td>
<td>SDB WSP</td>
<td>Low unit cost, large footprint</td>
<td>Low</td>
<td>No or small cost</td>
</tr>
<tr>
<td>FS-2</td>
<td>SDB + Compost WSP</td>
<td>Low unit cost, very large footprint</td>
<td>Low</td>
<td>(Revenue from compost)</td>
</tr>
<tr>
<td>FS-3</td>
<td>AD + SDB + Compost Aerated WSP</td>
<td>Low unit cost, moderate footprint</td>
<td>Moderate</td>
<td>(Revenue from compost, cost offset from biogas)</td>
</tr>
<tr>
<td>FS-4</td>
<td>Mechanized Dewatering AS + Chlorination</td>
<td>High unit cost, small footprint</td>
<td>High</td>
<td>Disposal cost</td>
</tr>
<tr>
<td>SB-1</td>
<td>WSP</td>
<td>Low unit cost, large footprint</td>
<td>Low</td>
<td>No or small cost</td>
</tr>
<tr>
<td>SB-2</td>
<td>Mechanized Dewatering AS + Chlorination</td>
<td>High unit cost, Small to moderate footprint</td>
<td>High</td>
<td>Disposal cost</td>
</tr>
<tr>
<td>SB-3</td>
<td>AD + Mechanized Dewatering AS + Chlorination</td>
<td>High unit cost, Moderate to high footprint</td>
<td>Very High</td>
<td>(cost offset from biogas) Disposal cost</td>
</tr>
<tr>
<td>CT-1</td>
<td>Mechanized Dewatering AS + Chlorination</td>
<td>High unit cost, Small to moderate footprint</td>
<td>High</td>
<td>Disposal cost</td>
</tr>
</tbody>
</table>

AD: Anaerobic digester; AS: Activated sludge; SDB: Sludge drying bed; WSP: Waste stabilization pond;
Capability, Assumptions, User Instruction

Cost Framework
Cost framework capability and limitations

Cost framework capability

The primary outcome of the cost framework is life-cycle cost curves of eight fecal sludge, sewer based and co-treatment archetypes in India. The cost curves help decision makers compare conceptual level economics of different FS and/or SB model systems in India.

The framework, to some extent, is dynamic and allow users to evaluate changes to the cost curves across various model systems when key assumptions change.

- Flexibility was built into the model when technically feasible. We understand that the options for each stage of the sanitation service chain are highly dependent on specific local context, and the model is built on assumptions that falls within a general range in India.

- Users can adjust key assumption variables to evaluate and compare changes to the overall costs and cost breakdowns within the same archetype and across different archetypes.

A complete list of key assumptions, including values used as baseline assumptions in the framework and reference, are included in the Appendix.

Cost framework limitations

This framework is not intended to be a stand-alone planning tool for specific locations for reasons below:

- Although the cost framework allow users to change some site specific characteristics (as discussed in following pages), many other site specific information are assumptions that cannot be easily changed. Change of site specific information should be reviewed by professional engineers for any given site.

- The framework is constructed for a certain range of population for each archetype. Extrapolation outside of the population range may not be technically feasible, and may require changes to input variables

- Specific treatment processes are assumed in the identified model archetypes. But in practice, permutations of unit treatment processes often occurs.

- Estimation of collection cost, especially sewer network, is based on a least-cost scenario with a set of assumptions.

- Mechanical equipment model and cost are obtained from manufacturers. Change of treatment capacity may result in change of equipment model and cost to achieve economy of scale. The model is not dynamic to respond to this change.
Population catchment area calculation for FS and SB collection models

**Population catchment area: FS & SB collection models**

First, the catchment area (A) for the population served is calculated as a function of:

1. Population served (Ps)
2. Population density (d) (based on ranges provided in the CPHEEO Manual, 2012)

The catchment area is idealized as square, population is assumed to be evenly distributed throughout the catchment area, and it is assumed that the entire population within the area is served by the treatment plant.

The method used for calculating area in the models is identical for SB and FS models.

**Population density (CPHEEO Table 3.1)**

<table>
<thead>
<tr>
<th>Type</th>
<th>Maximum population</th>
<th>People per hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Town (5K to &lt;50K)</td>
<td>50000</td>
<td>150</td>
</tr>
<tr>
<td>Small city (50K to &lt;200K)</td>
<td>200000</td>
<td>300</td>
</tr>
<tr>
<td>Medium city (200K to &lt;1M)</td>
<td>1000000</td>
<td>400</td>
</tr>
<tr>
<td>Large city (&gt;=1M)</td>
<td>2000000</td>
<td>500</td>
</tr>
<tr>
<td>Mega city (&gt;=2M)</td>
<td>&gt;=2M</td>
<td>750</td>
</tr>
</tbody>
</table>
Vacuum tanker capacity and number

Vacuum tanker capacity
Cost framework includes 4m$^3$ and 10m$^3$ capacity, formula selects truck capacity based on the daily volume (m$^3$/day) of FS produced by the population served.

Number of vacuum tankers
The number of vacuum tankers required ($n_T$) is automatically calculated in the Cost Framework based on:

- Quantity of FS produced per day by population served ($Q_{FS}$)
- Tanker capacity ($V_T$)
- Average loading ($l$) of tanker (adjustable parameter; 80% assumed for baseline)
- Number of emptying jobs ($n_e$) per tanker per day (adjustable parameter; 2 empties/tanker/day assumed for baseline)
- Tankers are assumed not to be shared (i.e. minimum of 1 dedicated truck required per FSTP)

$$n_T = \frac{Q_{FS}(m^3/d)}{V_T(m^3) \times l(\%) \times n_e(tanker)}$$
Vacuum tanker distance per trip and emptying costs

Distance per trip
- The average one-way distance traveled within the population catchment area is assumed to be \( \frac{1}{2} \) of the catchment area side \( \frac{3}{4}S \) plus a quarter of the catchment area side \( \frac{1}{4}S \) giving a total distance traveled of \( \frac{3}{4}S \) (see figure).
- The vacuum tanker is additionally assumed to travel from the city boundary to the treatment plant \( (d_{TP}) \), assuming the plant is located outside the city limits (adjustable parameter in model; baseline assumption = 5km based on data collection).
- The total roundtrip distance \( (d_{RT}) \) per trip is then calculated as:

\[
d_{RT} = 2 \times \left( \frac{3}{4}S + d_{FSTP} \right)
\]

- Additionally, it is assumed within the model that a 4m³ tanker performs 1 empty per trip and 10m³ tanker performs 2 empties per trip. An additional distance of \( \frac{1}{4}S \) is assumed between emptying sites.

Travel and emptying costs additionally consider:
- Driving fuel efficiency (based on tanker size)
- Idling time and fuel consumption
- Number of full time employees (FTE) per truck (adjustable parameter in model; 2 FTE/truck assumed for baseline)
SB collection model key assumptions

In general, assumptions were made to show the LEAST cost possible for sewer installation as it was expected to be the higher cost collection option.

Capacity required based on:
- Wastewater flow
- Peaking factor
- Groundwater infiltration

Length of sewer pipes required:
- Pipe diameter
- Number of sections per diameter
- Section length per diameter

Manhole size and number:
- Manhole size dependent on pipe diameter
- No. of manholes dependent on length of pipe and pipe size (industry standard and experience)

Other idealized assumptions (made to obtain least cost):
- No lift stations
- No other utility pipe conflicts
- No hard rock in soil
- No trenchless technology for deep excavation
- No significant groundwater issues
- Idealized topography resulting in no deep excavations or force mains

City area, function of:
- Population
- Population density
Cost estimation method: treatment

Assumptions used to estimate size of treatment unit are based on existing literature, CPHEEO Manual on Sewage and Sewage Treatment Systems, manufacture recommendation and industry best practice.

These design criteria assumptions can be location specific. For example, some parameters depend on septage or sewerage characteristics, temperature, and geotechnical information. User may change design parameter assumptions on the input tab, but change should be reviewed by professional engineers for any given site.

Change of design criteria will result in change in cost curve, including:

**CapEx**
- Change of treatment footprint and subsequent construction cost (and land cost, if any)

**OpEx**
- Change of desludging labor cost
- Change of power, chemical, consumable cost
Cost estimation method: disposal and resource recovery

Disposal

Disposal methods for each system are specifically selected to produce a range of costs. Solids disposal method is a major assumption that can be easily changed in the model. Method to estimation cost of disposal is describe below:

- **Land apply**: in general does not incur cost to service providers

- **Land fill**: current practice in India does not incur cost to service providers. Should this trend change, land fill cost is consist of two components, tipping fee to landfill and transportation cost from the treatment facility to landfill site.

\[ C_{\text{landfill}} = (c_{\text{tipping}} + c_{\text{trucking}}) \times V_{\text{solids}} \]

Where:
- \( C_{\text{landfill}} \) = landfill cost (USD$/year)
- \( c_{\text{tipping}} \) = tipping fee to landfill site (USD$/m³)
- \( c_{\text{trucking}} \) = transportation cost to landfill site, depending on transportation distance (USD$/m³)
- \( V_{\text{solids}} \) = volume of solids to be disposed (m³)

Resource recovery

Similar to disposal methods, reuse options are specifically selected and can be easily changed in the framework. Method of estimating benefits (or cost offsets) for each reuse option is described below:

- **Land apply (as benefit)**: In rare cases, solids may be sold as land apply material to nearby farmers, generating a benefit for service providers.

- **Compost**: unit price of compost that can be sold on market. The unit price is location specific and depends on the market.

- **Biogas**: used unit price of raw natural gas as a proxy to estimate value of biogas produced by a model system. Conversion of biogas to electricity requires additional infrastructure which is not included in the framework.

- **Effluent reuse**: field observation suggests that a proportion of effluent from STP may be sold for reuse at a price lower than cost of drinking water supply.

Specific unit cost/price in the model as baseline assumption are discussed in following pages. Sensitivity analyses were conducted for compost and biogas.
Cost estimation method: per-capita annualized cost

After cost components of collection, transportation/conveyance, treatment, disposal and reuse for each model system at each population point were estimated, per-capita costs were estimated in order to compare costs across different model systems.

Because components within a model system have different lifespan, a per-capita equivalent annual cost (EAC) was calculated for each model system at each population point for CapEx, OpEx, and All-in cost.

Calculation of EAC requires a few assumptions, including:
• Annual interest rate (r)
• Number of years being analyzed (t)
• Annuity factor ($A_{t,r}$)

EAC calculates the annual cost of owning, operating and maintaining an asset over its entire life. It is a common method used to compare the cost of various assets that have unequal lifespans.

Cost curves for each model system were derived based on the per-capita EAC at each the population point.

$$EAC = \frac{NPV}{A_{t,r}}, \text{ where } A_{t,r} = \frac{1 - \frac{1}{(1+r)^t}}{r}$$
Overview of Excel Cost Framework

Instructions for model use

The Cost Framework developed within this study was built with the aim of creating a dynamic model, meaning that the model is sensitive to changes in key input parameters that may require adjustment for a specific context. When input parameters are adjusted, design calculations and costs are automatically updated according to adjustments. These adjustable input variables also allow the user to better understand the cost drivers for infrastructure and during operations.

The more complex model systems (FS-4, SB-2, SB-3, CT-1) within this framework are less dynamic as these models were partially developed from vendor quotations, which are often fixed based on set sizes for equipment which are commercially available and for which prices were received. The table at the right indicates which models, design parameters and cost calculations yield adjustments within the framework.

Within the cost framework, input parameters which may be changed within the framework are indicated by a yellow highlighted cell. All cells that are white contain figures or formulas which should NOT be changed:

<table>
<thead>
<tr>
<th>Category</th>
<th>Model Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price assumptions</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Population served</td>
<td>Adjustable only for: FS-1, FS-2, FS-3; SB-1</td>
</tr>
<tr>
<td>Design Parameters</td>
<td>Adjustable only for: FS-1, FS-2, FS-3; SB-1</td>
</tr>
<tr>
<td>Population density</td>
<td>All systems adjustable</td>
</tr>
<tr>
<td>Financial assumptions (discount rate, inflation)</td>
<td>Dynamic</td>
</tr>
<tr>
<td>System and equip. lifespan</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Land price</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Collection (trucked or sewer)</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Treatment: civil works</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Treatment: mechanical(1)</td>
<td>Semi-Dynamic</td>
</tr>
<tr>
<td>Collection</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Labor(2)</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Electricity</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Fuel</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Chemicals</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Consumables(2)</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Disposal costs(3)</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Resource recovery(3)</td>
<td>Dynamic</td>
</tr>
</tbody>
</table>

\(1\) Framework is generally robust with regards to smaller pieces of equipment (e.g. pumps, mixers) but is not robust with regards to more substantial vendor quotes (e.g. MBBR packaged system).

\(2\) Labor & consumable costs update automatically with increasing population

\(3\) Disposal costs and resource recovery benefits robust to changes in pricing.
Overview of Excel Cost Framework

Instructions for model use (cont.)

The Cost Framework can be divided into three sections (elaborated in proceeding slides):

(1) Overview, Assumptions and Summary tabs: user can adjust key assumptions and is provided with a comparison of model outcomes

(2) Input, Output, CapEx (CX) and OpEx (OX) tabs: each of the 8 model systems is developed following this four-sheet structure.

(3) Unit Costs and Reference tabs: contain reference data used to calculate CapEx & OpEx
Overview of Excel Cost Framework

Instructions for model use (cont.)

The **Overview, Assumptions and Summary** tabs are indicated with green tabs. These are the primary sheets in which the user can adjust the assumptions applied to all model systems and view a summary of the key outputs of the cost framework:

- **Overview** tab includes an explanation of system boundary, costs included and excluded in the model, and instructions for model use.

- **Assumptions** tab includes assumptions that are applied to all models. Input variables highlighted in yellow within this sheet may be adjusted by the user. Variables in this sheet are automatically linked to all model system sheets. Non-highlighted (white) cells are fixed and should not be adjusted by the user as the cost framework is not dynamic with regards to these values (i.e. design calculations and costs will not automatically update in the framework).

Excerpt of ‘Assumptions’ tab showing price and FS collection assumptions, where yellow cells can be changed and white cells are fixed (for illustrative purposes only, see Cost Framework for details)
Overview of Excel Cost Framework

Instructions for model use (cont.)

- **Combined Summary** tab provides a comparison of all FS, SB and CT model systems. This sheet contains three cost curve figures and three cost breakdown figures which compare CapEx, OpEx and All-In costs for the 8 model systems. The cost breakdown figures are shown for the 200K population point only as this is the common population analyzed across model systems.

- **FS Summary** tab provides a comparison of all FS model systems. A similar set of figures is shown on this sheet as compared to the Combined Summary tab.

- **SB Summary** tab provides a comparison of all SB and CT model systems. A similar set of figures is shown on this sheet as compared to the Combined Summary tab.

- Costs for all summary sheets are shown in terms of a per-capita equivalent annual cost in USD (US$/capita/year). Costs within these summary sheets will automatically update based on user inputs in the “Assumptions” and “Input” sheets for each model system and thus cells and formulas within this sheet should not be changed.
Overview of Excel Cost Framework

Instructions for model use (cont.)

Each of the 8 model systems are analyzed in a set of 4 sheets: (1) Input tab, (2) Output tab, (3) CX tab and (4) OX tab. For ease of user navigation, the CX and OX tabs are hidden in the final draft of the cost framework.

- **Input** tab contains the design basis for each component of the particular model system. A model description and figure is shown at the top of the sheet. Below this, the design parameters and design loads are shown for three population points. Highlighted yellow cells indicate the model is dynamic with regards to population within the indicated range (i.e. population figures can be adjusted by the user with resulting costs calculated automatically). The conceptual design of the model system is shown below, starting with overall labor costs, followed by calculations for each component of the sanitation value chain: collection, treatment (screening, dewatering, solids treatment, liquids treatment) and disposal or reuse. Key assumptions are automatically linked to the “Assumptions” tab and therefore should not be adjusted in the “Input” sheet. Cells which may be adjusted are highlighted in yellow. However, care should be taken by the user to fully understand the model and parameters before changing inputs.

**Excerpt of 'Input' tab** (FS-1 shown here for illustrative purposes only, see Cost Framework for details)

![Input, Output, CX and OX tabs for model system FS-1. All other model systems have a similar 4-sheet structure.](image-url)
Overview of Excel Cost Framework

Instructions for model use (cont.)

• **Output** tab contains a detailed cost analysis for each model system. Figures shown on this sheet include cost curves (CapEx, OpEx and All-In figures), cost breakdowns at each population point analyzed (CapEx, OpEx and All-In figures) and cash flow diagrams for each model system at each of the three population points analyzed.

• Costs for all summary sheets are shown in terms of a per-capita equivalent annual cost in USD (US$/capita/year). Costs within this sheet will automatically update based on user inputs in the “Assumptions” and “Input” sheets and thus cells and formulas within this sheet should not be changed.

Example of ‘Output’ tab showing cost curves, cost breakdown, and cash flow diagrams for each model system (FS-1 shown here for illustrative purposes only, see Cost Framework for details)
Instructions for model use (cont.)

• **CX** tab includes calculations to estimate capital expenditures. Design calculations from the “Input” tab are automatically linked to the CX tab, in which detailed calculations for material quantities (e.g. earthwork, concrete volumes, steel mass, pipe lengths, etc.) and number of mechanical equipment units (e.g. pumps, mixers, etc.) occur. All quantities for each component are summarized in the grey table at the top of the sheet. All cells and formulas within the CX sheet are automatically linked to the ‘Assumptions’ and ‘Input’ sheet and therefore should not be changed. This tab is hidden for ease of use and navigation.

Example of ‘CX’ tab showing the bill of quantities structure within the sheet (for illustrative purposes only, see Cost Framework for details).

Input, Output, CX and OX tabs for model system FS-1. All other model systems have a similar 4-sheet structure.
Overview of Excel Cost Framework

Instructions for model use (cont.)

- **OX** tab includes calculations to estimate operational expenditures (OpEx). Inputs and design calculations from the “Assumptions” and “Input” tabs are automatically linked to the OX sheet. OpEx within this sheet is broken down into costs for collection during the system operation phase (truck or sewer), labor, electricity, chemicals, consumables, disposal costs (for either solids or liquids disposal), resource recovery benefits and capital maintenance expenditures (CapManEx) for each component of the model system. Cells and formulas within this sheet will automatically update according to inputs in the “Assumptions” and “Input” tabs and therefore should not be changed. This tab is hidden for ease of use and navigation.

Example of ‘OX’ tab showing the structure within the sheet (for illustrative purposes only, see Cost Framework for details)
Overview of Excel Cost Framework

Instructions for model use (cont.)

The Unit Costs, Lookup Table and References tabs include information used for calculating costs, design of model components, and for references. In general, information within these tabs should NOT be changed by users unless the tool is being adapted for a different context.

- **Unit Costs_CX** contains all unit costs for construction materials and mechanical equipment used for capital cost estimates in FS-#_CX and SB-#_CX sheets (based on Delhi Schedule of Rates (2016) and equipment vendor quotations obtained during this study). The cost framework includes individual tabs for FS sheets and SB sheets to allow for varying materials and equipment used.

- **Unit Costs_OX** tab contains all unit costs for calculating operational expenditures in FS#_OX sheets. A variety of sources are used for OpEx unit costs as referenced within the sheet. The cost framework includes individual tabs for FS sheets and SB sheets.

- **Lookup Table** tab contains tables used for formulas within the excel sheets.

- **Reference** tab contains references used in building the cost framework and/or baseline values used.

Excerpt of ‘Unit Costs’ tab showing the bill of quantities set-up (costs based on Delhi Schedule of Rates, 2016) (for illustrative purposes only, see Cost Framework for details)
Model Results
Model results

The model results presented in this section are for a particular set of baseline assumptions. Actual costs will vary depending on the specific context of a location and could vary by as much as an order of magnitude depending on assumptions.

A key feature of the Excel Cost Framework is the ability for the user to test how varying input parameters impacts the model results. Therefore, the static results shown in the following cost curves and cost breakdowns should only be interpreted as one possible outcome for a particular set of assumptions, and NOT as the definitive costs for the systems modeled.

A sensitivity analysis at the end of this section demonstrates how adjusting key assumptions can significantly impact overall model outcomes.

Key baseline assumptions:

- **No cost for land** (rationale: data collection indicates that land for treatment systems is often provided by the municipality or local government)
- **No cost for solids disposal** (rationale: data collection indicates that currently the typical method of solids disposal in India is to land apply – i.e. farmers collect solids at minimal to no price from FSTPs and STPs)
- **No cost or benefit for effluent discharge** (i.e. no resale of effluent)
- **Electricity price** = 7 Rs/kWh (based on data collection)
- **Compost price** = 1.5 Rs/kg (low end of range based on literature and data collection). Equivalent bulking price assumed.
- **Biogas value** = 200 Rs/mmBtu (low end of range based on natural gas as a proxy)
- **Discount rate** = 5% (assumed as real rate)
- **Inflation rate** = 0% (taken into consideration based on real discount rate used)
- **Treatment plant distance from town outer limit** = 5km (based on data collection)
Observations

In general, per-capita CapEx EACs for SB model systems were 4 to 7 times higher than FS model systems even with best case assumptions for sewer installations (comparisons at equivalent population points). A wide range of potential costs for sanitation infrastructure is found, from <$1 to nearly $14 per capita per annum.

Economies of scale (i.e. lower per-capita costs with increasing populations) observed for all model systems.

Among the FS model systems, observations include:
• Per-capita costs are fairly similar at the 200K population point (the common point among systems modeled). Model FS-1, the most basic model, is the least cost option at this population; however this assessment does not include the cost of land.

Among the SB and CT model systems, observations include:
• Per-capita costs for the SB systems are fairly similar at the 200K population point. Model SB-1, (aerated pond system), is the least cost option at this population; however this assessment does not include the cost of land.
• The co-treatment option appears to have a higher cost than the SB models at the 200K population, but a lower cost at the higher populations points modeled. This is likely because the particular co-treatment system modeled assumes mechanical equipment (rotary press) for FS dewatering. At lower populations, a simpler dewatering option (e.g. sludge drying beds) would likely be a more cost-effective option.

Notes:
1. CapEx includes treatment infrastructure only and excludes auxiliary site infrastructure (e.g. road, retaining walls, fence, office, etc.)
2. Household infrastructure (e.g. septic tanks, on-plot sewer connection) are excluded from the analysis.
3. Cost of land excluded from cost curves displayed (but can be considered in model)
Observations on modeled OpEx cost curves

In general, per-capita OpEx EACs for SB model systems were 2 to 3 times higher than FS model systems (comparisons at equivalent population points). Thus, there is less of a cost difference between SB and FS systems for operations as compared to capital costs.

Economies of scale (i.e. lower per-capita costs with increasing populations) observed for all model systems.

Among the FS model systems, observations include:
• Despite additional co-composting revenue generation modeled for FS-2, OpEx at the baseline price of compost is still modeled as greater than FS-1 (which is identical other than the co-composting addition). The higher cost of labor, required for turning compost, is the primary reason for the higher OpEx.
• The most mechanized system (FS-4) was found to have similar or lower per-capita OpEx compared to other modeled FS systems. The lower cost for FS-4 is generally driven by lower labor requirements, which offset chemical and electricity needs. In addition, FS-4 benefits from economies of scale, as this system was modeled for populations 200K and greater, whereas more land-intensive options (FS-1 and FS-2) were not considered realistic for the larger populations modeled.

Among the SB and CT model systems, observations include:
• Similar per-capita OpEx at the 200K population point (common population for all modeled systems).
• Higher per-capita OpEx for the SB-1 system at lower populations are due to economies of scale.

Notes:
1. OpEx includes costs borne by the municipality for collection, treatment and disposal.
2. Costs borne by the household (e.g. for water supply or emptying charges) are excluded from the analysis.
3. Overhead and labor costs for administrative duties, accounting, community outreach activities, etc. are excluded.
4. Revenue generated by resource recovery (e.g. biogas or compost) are included according to the defined model systems. Lower range prices are used for both (see sensitivity analysis). Bulking agent assumed to be same as price of compost.
5. Revenue generated through water sales to households and emptying charges are excluded.
6. Solids disposal cost excluded from cost curves displayed.
Overall (All-In) costs per capita are higher for SB versus FS collection & treatment infrastructure

Observations on modeled OpEx cost curves

In general, per-capita All-In EACs for SB model systems were 3 to 5 times higher than FS model systems (comparisons at equivalent population points).

Wide overall range in costs from $2 to $21 per capita per annum.

Overall economies of scale exist for all systems considered.

Notes:
1. CapEx includes treatment infrastructure only and excludes auxiliary site infrastructure (e.g. road, retaining walls, fence, office, etc.)
2. Household infrastructure (e.g. septic tanks, on-plot sewer connection) are excluded from the analysis.
3. Cost of land excluded from cost curves displayed (but can be considered in model).
4. OpEx includes costs borne by the municipality for collection, treatment and disposal. Solids disposal cost excluded from cost curves displayed.
5. Costs borne by the household (e.g. for water supply or emptying charges) are excluded from the analysis.
6. Overhead and labor costs for administrative duties, accounting, community outreach activities, etc. are excluded.
7. Revenue generated by resource recovery (e.g. biogas or compost) are included according to the defined model systems. Lower range prices are used for both (see sensitivity analysis). Bulking agent assumed to be same as price of compost.
8. Revenue generated through water sales to households and emptying charges are excluded.
CapEx drivers are solids treatment (FS systems) and collection (SB systems)

Observations

The primary CapEx driver for all FS models is solids treatment. Liquid treatment infrastructure is a somewhat higher proportion of costs for the FS-4 model (activated sludge package system) compared to other FS model systems.

The primary CapEx driver for SB models is collection (sewer network), accounting for 60 – 70% of capital costs for all SB model systems, even with idealized least cost assumptions.

Notes:
1. CapEx includes treatment infrastructure only and excludes auxiliary site infrastructure (e.g. road, retaining walls, fence, office, etc.)
2. Household infrastructure (e.g. septic tanks, on-plot sewer connection) are excluded from the analysis.
3. Cost of land excluded from cost curves displayed (but can be considered in model)
Observations

FS versus SB
- FS system OpEx driven by collection and labor costs due to sludge handling requirements
- Electricity use is somewhat important for mechanical FS treatment (FS-4)
- SB treatment OpEx is dominated by electricity (~65% of treatment OpEx)

Passive vs Mechanical Treatment Process
- Chemicals are another relatively important OpEx contributor for both FS and SB systems, which use polymer for mechanical dewatering and chlorine for disinfection (~20% of treatment OpEx)

OpEx cost drivers differ for FS and SB systems

Notes:
1. OpEx includes costs borne by the municipality for collection, treatment and disposal. Solids disposal cost excluded from cost breakdown displayed (but can be considered in model)
2. Costs borne by the household (e.g. for water supply or emptying charges) are excluded from the analysis.
3. Overhead and labor costs for administrative duties, accounting, community outreach activities, etc. are excluded.
4. Revenue generated by resource recovery (e.g. biogas or compost) are included according to the defined model systems. Lower range prices are used for both (see sensitivity analysis). Bulking agent assumed to be same as price of compost.
5. Revenue generated via household water supply and emptying charges are excluded.
6. CapManEx = capital maintenance costs, assumed to be 0.5% of CapEx, incurred on an annual basis.
**Observations**

The primary overall cost driver for SB systems is capital infrastructure costs required for collection (sewer network), accounting for ~50% of overall costs.

Modeled cost drivers for FS systems are (1) capital costs required for treatment infrastructure (30 – 45% of All-In costs) and (2) operational costs for treatment infrastructure (15 – 50% of All-In costs). Collection OpEx accounts for ~15 – 30% of overall costs.

Co-composting FS with municipal organic waste may be an important source of revenue that may potentially offset ~20% of overall costs of FS models. However, a demand for compost must be present to realize this source of revenue.

**Notes:**
1. *CapEx includes treatment infrastructure only and excludes auxiliary site infrastructure (e.g. road, retaining walls, fence, office, etc.)*
2. *Household infrastructure (e.g. septic tanks, on-plot sewer connection) are excluded from the analysis.*
3. *Cost of land excluded from cost curves displayed.*
4. *OpEx includes costs borne by the municipality for collection, treatment and disposal.*
5. *Costs borne by the household (e.g. for water supply or emptying charges) are excluded from the analysis.*
6. *Overhead and labor costs for administrative duties, accounting, community outreach activities, etc. are excluded.*
7. *Revenue generated by resource recovery (e.g. biogas or compost) are included according to the defined model systems. Lower range prices are used for both (see sensitivity analysis).* Bulking agent assumed to be same as price of compost.
8. *Revenue generated through water sales to households and emptying charges are excluded.*

**All-In cost breakdown for FS and SB systems**

<table>
<thead>
<tr>
<th>Model System</th>
<th>OpEx (Treatment, Non-annual costs)</th>
<th>OpEx (Treatment, Benefits)</th>
<th>OpEx (Treatment, Costs)</th>
<th>CapEx (Treatment)</th>
<th>Land Cost</th>
<th>OpEx (Collection, Non-annual costs)</th>
<th>OpEx (Collection)</th>
<th>CapEx (Collection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS-1</td>
<td></td>
<td></td>
<td></td>
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<td>FS-2</td>
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<td>FS-3</td>
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<td>FS-4</td>
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<td>SB-1</td>
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<td>SB-2</td>
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<td>SB-3</td>
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<td>CT-1</td>
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</tr>
</tbody>
</table>
Proportion of costs incurred for collection versus treatment differ in CapEx and OpEx phases for FS and SB models

**Observations**

**CapEx: Collection versus treatment**
- CapEx driven by treatment infrastructure for FS models
- CapEx driven by collection (sewer network) infrastructure for SB systems

**OpEx: Collection versus treatment**
- OpEx driven by collection (vacuum truck) for FS-1 (most basic, passive treatment system). Collection is less of a cost driver for FS-2, 3 and 4, which have either labor or energy intensive treatment processes (e.g. composting and mechanical dewatering, respectively).
- OpEx driven by treatment infrastructure for SB systems

**Notes:**
1. Reuse benefit not considered in collection versus treatment infrastructure
Costs incurred in different phases for FS and SB models

Observations

\textbf{CapEx versus OpEx:}

\begin{itemize}
  \item Slightly higher proportion of costs incurred in the operations phase versus for capital infrastructure for FS models (~50 – 70\% OpEx)
  \item Higher proportion of costs incurred for capital infrastructure versus in the operations phase for SB systems (~70\% CapEx)
\end{itemize}
Sensitivity analysis: land cost significantly impacts CapEx for systems with large footprint

Land cost can significantly increase CapEx, especially for land intensive treatment systems. However, from interviews through data collection, it appears that historically municipalities do not incur a land cost as they already owned land.

**FS systems**
- When land cost is included, overall capital cost for non-mechanical FS system (FS-1, 2, 3) increased 50%.
- Mechanized FS treatment system (FS-4) is unlikely to be significantly impacted by inclusion of land cost due to its small footprint.

**SB & CT systems**
- Overall capital cost for STPs that use conventional pond (or aerated pond) systems (SB-1) will increase sharply if there is a land cost.
- When comparing different SB systems, the addition of land cost, even in the low land cost scenario, can change preference among the 4 archetypes, making pond system (SB-1) the most capital intensive among them.

Notes:
1. Land cost from 15 States found from public available information and vetted through interview with industry experts. Three scenarios of land cost—low, median, and high—were provided in the framework. Land cost of $47 USD/m² is the low land cost scenario.
Sensitivity analysis: solids disposal costs

**Solids disposal cost can significantly increase OpEx** for systems that do not have solids reuse options. Based on interviews during data collection, no-cost (or benefit) land application (including agriculture application) is a common disposal method for FSTPs in India. However, STPs in dense urban areas and with high solid accumulation rates are likely to incur fees associated with tipping and hauling of the solids. In these cases, solids disposal cost may significantly increase OpEx.

The current baseline assumption does not include disposal costs (figure on the right). The above figures indicate the impact of including disposal cost in the different models (figure on the right).

**FS systems**
- OpEx for FS-2 and FS-3 are less sensitive to disposal cost as dewatered solids are converted to reuse product (compost).
- OpEx for FS-1 and FS-4 increases significantly when disposal costs are included as both systems do not have as an endpoint for solids.

**SB & CT systems**
- OpEx increases sharply when there is a solids disposal cost (refer to changes in SB-2, 3, 4).
- A sewer system captures all solids that a community produce and there is little time for decomposition, so there is more dry solids to dispose of and a larger effect is seen in general from higher disposal costs compared to that for FS systems.

**Notes:**
1. Solids disposal cost has two components: landfill tipping fee (INR 2652/m³) and trucking cost. Trucking cost varies depending on distance traveled. For the figure above, it is assumed STP is 10 km away from the MSW site, and the trucking cost is assumed at INR 172/m³.
Sensitivity analysis: impacts of Biogas recovery value\(^1\) on treatment OpEx varies

Depending on how biogas is reused and the method of estimating value of biogas, the impact of biogas on treatment OpEx varies. As illustrated by the figure above, when the value of biogas vary from INR 200/mmBtu (based on the current price of raw natural gas) to INR 825/mmBtu (based on the modeled price of electricity (INR 7/kWh) and assuming a 40% efficiency for the conversion of biogas to electricity), the benefit of biogas recovery changes. Based on this range, the benefit of biogas recovery increases from 6% to 26% of treatment operating costs for FS-3 and from 6% to 25% of treatment operating costs for SB-3 (the systems modeled with anaerobic digestion).

It is important to note that in the case of using biogas value based on price of electricity and efficiency, additional treatment steps, such as gas purification and combustion of biogas, to convert biogas to electricity is not included in the CapEx calculation by the model. The capital cost of these infrastructure can be substantial. Also worth noting is that converting to electricity is not the only way of biogas resource recovery. Biogas can be reused as gas itself. When biogas is converted to electricity, heat generated during the combustion process is often reused in the treatment process as well.

Notes:
1. For purpose of evaluating biogas’s reuse value in terms of cost offset to treatment cost, benefit from composting (FS-2 and FS-3) is assumed to be zero for this sensitivity analysis.
Sensitivity analysis: compost value significantly impacts treatment OpEx

The price assumed for co-compost (FS with municipal organic waste) has a significant impact on the overall operational costs for the FS-2 and FS-3 model systems (the two systems for which co-composting was modeled as a treatment component).

In the figures above the price of compost is varied from INR 1.5/kg to INR 13/kg (based on World Bank figures referenced in J-OP Market Analysis of US $22 to $200 per tonne). Data collection from incumbent systems in India is consistent with this range (e.g. compost is reportedly sold for INR 7/kg at the Devanahalli FSTP). This range of compost prices results in a range of 35% to 105% of overall operating costs for the FS-2 and FS-3 systems. This means that at the high end of this range, co-composting could potentially offset all operating costs of these model FS systems. However, in reality, a sufficient demand for compost must be present to realize such benefits, along with investments in marketing and distribution of compost, which are currently not modelled. Additionally, demand, and therefore price, is likely affected by seasonality – therefore, fluctuations depending on season and/or adequate storage would need to be considered to determine projected benefits in a particular location.

Note: The figures above assume the cost of bulking agent supplied to the FSTP is equal to the price of compost in order to avoid assuming that the bulking agent generates additional revenue. The typical cost of a bulking agent supplied at scale to a FSTP is unclear. Data collection at incumbent systems in India indicates municipal organic waste may be supplied to FSTPs at no additional cost (as the municipality may be responsible for both the FSTP and solid organic waste disposal). However, FSTPs from which this data is collected require relatively low volumes of bulking agent. At larger scales, there may be an additional cost incurred for the bulking agent to ensure sufficient and reliable volumes.
Existing System Data Collection
Financial data collected from 7 FSTPs and 3 STPs and 1 CT system in India

Operational system data collection used to calibrate and validate model assumptions and cost curves

<table>
<thead>
<tr>
<th>Operational system</th>
<th>Type and design capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kanchipuram, Tamil Nadu</td>
<td>FSTP (23 KLD)</td>
</tr>
<tr>
<td>Ooty, Tamil Nadu</td>
<td>FSTP (36 KLD)</td>
</tr>
<tr>
<td>Ponnampatti, Tamil Nadu</td>
<td>FSTP (2 KLD)</td>
</tr>
<tr>
<td>Leh, Ladakh</td>
<td>FSTP (12 KLD)</td>
</tr>
<tr>
<td>Puri, Orissa</td>
<td>FSTP (50 KLD)</td>
</tr>
<tr>
<td>Devanahalli, Karnataka</td>
<td>FSTP (6 KLD)</td>
</tr>
<tr>
<td>Jabalpur, Madhya Pradesh</td>
<td>FSTP (50 KLD)</td>
</tr>
<tr>
<td>Mysore, Karnataka</td>
<td>STP: WSP (68 MLD)</td>
</tr>
<tr>
<td>Nesapakkam, Chennai</td>
<td>STP (40 MLD &amp; 54 MLD)</td>
</tr>
<tr>
<td>Mylasandra, Bangalore</td>
<td>CT (70 MLD)</td>
</tr>
</tbody>
</table>

FSTP: Fecal sludge treatment plant; STP: Sewage treatment plant; CT: Co-treatment
## System summary

<table>
<thead>
<tr>
<th>Operational system</th>
<th>Design Capacity</th>
<th>Actual Load Received</th>
<th>Start of operations</th>
<th>Design Lifespan (years)</th>
<th>Land provision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kanchipuram, Tamil Nadu</td>
<td>23 KLD</td>
<td>14 KLD</td>
<td>2017</td>
<td>30</td>
<td>Provided by municipality at no cost</td>
</tr>
<tr>
<td>Ooty, Tamil Nadu</td>
<td>36 KLD</td>
<td>1.3 KLD</td>
<td>2016</td>
<td>20</td>
<td>Located on a private estate (no payment)</td>
</tr>
<tr>
<td>Ponnampatti, Tamil Nadu</td>
<td>2 KLD</td>
<td>0.4 KLD</td>
<td>2017</td>
<td>15</td>
<td>Provided by municipality at no cost</td>
</tr>
<tr>
<td>Leh, Ladakh</td>
<td>12 KLD</td>
<td>4 KLD</td>
<td>2017</td>
<td>30</td>
<td>Leased from local authority (monthly payment)</td>
</tr>
<tr>
<td>Puri, Orissa</td>
<td>50 KLD</td>
<td>12 KLD</td>
<td>2017</td>
<td>20</td>
<td>Located at STP (no payment)</td>
</tr>
<tr>
<td>Devanahalli, Karnataka</td>
<td>6 KLD</td>
<td>2.5 KLD</td>
<td>2015</td>
<td>15</td>
<td>Provided by municipality at no cost</td>
</tr>
<tr>
<td>Jabalpur, Madhya Pradesh</td>
<td>50 KLD</td>
<td>30 KLD</td>
<td>2016</td>
<td>15</td>
<td>Provided by municipality at no cost</td>
</tr>
<tr>
<td>Mysore, Karnataka</td>
<td>68 MLD</td>
<td>51 MLD</td>
<td>2002</td>
<td>N/A</td>
<td>Provided by municipality at no cost</td>
</tr>
<tr>
<td>Nesapakkam, Chennai</td>
<td>40 MLD</td>
<td>43 MLD</td>
<td>2006</td>
<td>10+</td>
<td>Provided by municipality at no cost</td>
</tr>
<tr>
<td>Nesapakkam, Chennai</td>
<td>54 MLD</td>
<td>54 MLD</td>
<td>2014</td>
<td>10+</td>
<td>Provided by municipality at no cost</td>
</tr>
<tr>
<td>Mylasandra, Bengalore</td>
<td>75 MLD</td>
<td>76.5 MLD</td>
<td>2005</td>
<td>25</td>
<td>Provided by municipality at no cost</td>
</tr>
</tbody>
</table>
Data on incumbent FSTPs was collected through on-site investigations and categorized according to the defined model systems

**On-site data collection methods**

Data for incumbent FSTPs operating in India were collected through site visits, interviews with treatment plant and vacuum tanker operators and review of project documents (detailed project reports, bills of quantities) and review of logbooks where available.

A detailed template was prepared by the Stantec Team for collecting data on (1) vacuum tanker collection and (2) FSTPs. All on-site data collection was conducted by the Consortium for DEWATS dissemination (CDD).

Data collected was limited to financial and operational data used to estimate costs per capita. Treatment performance data was collected from plant operators where available. No samples were taken by the data collection team as treatment performance was not a primary objective of this study.

In total data was collected from 7 FSTPs across India and 10 vacuum tanker operators (4 government operated tankers and 6 privately operated tankers).

**Incumbent systems categorized according to defined model systems**

Incumbent systems were assigned to the defined Model Systems according to the model system they most closely resembled. In reality, differences exist between incumbent systems and model systems (for example, the exact treatment components may differ slightly).

Overall, 5 incumbent systems were assigned as Model System FS-1; 1 incumbent system was assigned as Model System FS-3 and 1 incumbent system was assigned as Model System FS-4.

No incumbent system investigated was assigned as Model System FS-2 (similar to FS-1, but with the addition of composting). Although several existing system operators indicated that co-composting with municipal organic solid waste was planned, only one system operator reported regular co-composting at the time of the study. This system was assigned to the Model System FS-3 category instead as anaerobic digestion was included as a system component.
Existing System
Data Collection

Calculation of an EAC per capita for CapEx, OpEx and All-In Costs

Comparison to cost framework curves

In order to compare data collected from incumbent systems with the cost curves modeled in the cost framework, the population served and total costs for CapEx, OpEx and All-In costs needed to be calculated. To arrive at these figures, a number of assumptions and data analysis methods were required:

• Costs to be included and excluded
• Population served by the FSTP
• Allocation of collection cost (vacuum tankers) to the FSTP

These are elaborated further in the following sections.

Costs included

• Cost borne by municipality or service provider for: collection/conveyance, treatment, disposal, reuse infrastructure and operations
• Financial benefit through reuse of by-products (dried sludge, compost, biogas) (based on price that by-products are reportedly sold at)

Costs excluded

• Cost borne by household for on-site containment, and water supply
• Revenue from water supply or septic tank emptying
• Secondary site infrastructure (e.g. road, retaining walls, fence, office, etc.) Where available, the additional cost for site infrastructure was collected during site visits (though not included in CapEx) – according to this data collected, the additional cost for site infrastructure may be substantial, adding an additional 50% to 100% to capital costs.
• Land Cost – For nearly all FSTPs investigated, the land the treatment system is constructed on was reportedly provided by the local authority or municipality. Therefore, the cost of land is excluded in the comparison of incumbent FSTPs and cost curves.
• Municipality overhead costs and labor costs for administrative, accounting, community outreach activities.
Estimating population served by FSTP

Population served – the number of people served by the incumbent FSTP systems is required to compare costs with the modeled cost curves on a per-capita equivalent annual cost basis. Because all FSTPs investigated were reportedly receiving lower volumes of FS per day compared to their design capacities, the population served was estimated according to the load received at the time of the study.

Estimating the population served for FSTPs can be difficult as emptying is often done on an “as-needed” basis rather than at set intervals or within designated areas. Within this study, two methods were used to estimate population served by each FSTP investigated. The average of the two methods was assumed as the population served.

Method 1: Based on the assumed design parameters used to calculate curves within the cost framework, the mean volume of FS received per day ($FS_v$) and the % total solids (TS) content ($FS_{TS}$):

- Cost framework design parameters:
  - 0.5 LPCD FS accumulation (wet)
  - 2.5% TS content
- Therefore, total solids accumulation per-capita per day:
  
  $0.5 \text{ LPCD} \times 2.5\% \text{ TS} = 0.0125 \text{ LPCD of TS (dry)}$

- Then, population served ($P_s$) for the FSTP was estimated as:

  $P_s = \frac{FS_v(KLD) \times FS_{TS} (%)}{0.0125 \text{ LPCD TS}}$

- If the % total solids for incoming FS was available for the FSTP, this figure was used. Otherwise, 2.5% TS was assumed (in accordance with the framework assumptions).
Calculating the population served by FSTP (cont.)

**Method 2:** Based on the number of loads received per year, the mean number of people per household or facility and the frequency of desludging. If more than one type of facility is served by the FSTP (e.g., households, commercial, institutional facilities, etc.) the percentage of each type of facility was used to estimate the population served ($P_s$):

$$P_s = (L \times p_1 \times f_1 \times %_1) + (L \times p_2 \times f_2 \times %_2) + \ldots + (L \times p_n \times f_n \times %_n)$$

Where:
- $L$ = loads per year received at FSTP (loads/year)
- $p_1$ = number of people served by facility 1
- $f_1$ = frequency of desludging for facility 1 (years)
- $%_1$ = percent of loads from facility 1 received at FSTP

Allocating collection costs to FSTP

While government operated trucks often reported discharge only at the FSTP, private operators typically reported discharge of FS in locations other than the FSTP (for example, discharge on farmlands was reported as a common practice). In such situations, only a share of the vacuum tanker capital and operating cost ($C_{VT, alloc}$) was allocated to the overall FSTP cost. This allocated share was calculated as:

$$C_{VT, alloc} = \frac{L_{FSTP}}{L_{VT}} \times C_{VT}$$

Where:
- $C_{VT, alloc}$ = Cost (CapEx or OpEx) of vacuum tanker allocated to FSTP
- $L_{FSTP}$ = vacuum tanker loads received at the FSTP per day
- $L_{VT}$ = average number of loads discharged at FSTP per vacuum tanker per day
- $C_{VT}$ = average reported cost of vacuum tanker (either for CapEx or OpEx)

If a vacuum tanker was reported to serve only the FSTP, all vacuum tanker costs were allocated to the FSTP.
Field Visits and Interviews

Stantec and CDD identified two existing STPs and applied for approval for site visits.

- **STP A (~SB-1):** aerated pond system and no solids treatment, desludging or disposal
- **STP B (~CT-1/~SB-2):** conventional activated sludge plant that also receives trucked fecal sludge

At least two site visits and interviews with on-site engineers, managers, and operators were planned for both sites.

- **STP A:** CDD obtained available records on CapEx, most recent O&M costs, and a report of treatment performance over multiple site visits.
- **STP B:** After one visit, the Urban Local Bodies (ULB) denied access and was reluctant to share any additional cost information or performance data.
- **STP C and STP D:** Two additional STPs (~SB-3) were identified. Site visits were not granted, but general descriptions of treatment processes, total capital costs and an estimation of annual O&M costs were provided through in person communication.

Supplementary literature review for addition SB cost information

Given the challenge of obtaining access for field visits and in-person interview to collect data, this study conducted a search through publicly available information. Sources include:

- Limited cost information published by Tamil Nadu Water Supply and Drainage Board (TWSD) and Bangalore Water Supply and Sewage Board (BWSSB).
- A report from the World Bank Group (2016), which includes a few sewer network and treatment combined cost information as well as notes on field visit.
- A peer reviewed journal article, Balaji et al. (2015), with information on capital costs of sewer connection for cities in Tamil Nadu.
- In person communication with contractors in India, industry experts in India and else who are familiar with the Indian context.

A table summarizes available cost information from fields visits and literature review is presented in this section in the following page.
Available existing SB/CT cost data are limited and comes from different sources

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Type of Source</th>
<th>No. STPs</th>
<th>Sewer Network CapEx</th>
<th>Sewer Network OpEx</th>
<th>Treatment CapEx</th>
<th>Treatment OpEx</th>
<th>Treatment Process Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>STP A</td>
<td>Field visits, in-person interview</td>
<td>1</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>STP B</td>
<td>Limited field visit</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STP C and D</td>
<td>In person communication</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TWSDB (2018)</td>
<td>Website</td>
<td>41</td>
<td>√</td>
<td></td>
<td>Some</td>
<td></td>
<td>Some</td>
</tr>
<tr>
<td>BWSSB (2018)</td>
<td>Website</td>
<td>7</td>
<td></td>
<td></td>
<td>Some</td>
<td></td>
<td>Some</td>
</tr>
<tr>
<td>Water Intelligence (2018)</td>
<td>Industry global megazine</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

According to a report published by the Central Pollution Board of India\(^1\), there are 816 STPs installed all over India and 522 STPs are operational as of March of 2015. Treatment technologies for STPs range from conventional ASP, UASB, oxidation pond to advanced ones such as SBR and MBR. Although general categorization of the status of a STP (i.e.: operational, non-operational, proposed, under construction), actual treatment capacity and categorization of treatment technology are available, more specific information of STPs such as population served, construction cost, O&M cost, effluent quality, solids treatment and disposal method are not available.

Moreover, results from the search suggest that publicly available information on sewer networks, treatment processes and performance, and costs of conveyance, treatment and disposal are not only limited but fragmented. For the same city/municipality, not all cost data are available for the entire sanitation value chain. The table above summarizes sources of data and the associated cost component for which data is available. Note that capital and O&M costs may not both be available for a given city.

Note
2. Sewer network and treatment per capita cost are summarized in 6 population range. Total number of STPs used to derive the cost is not available.
Assumptions for SB data collection analysis

Estimating population served by STP

*Population served* – similar to the term used for FSTP, this term refers to the number of people served by the existing SB systems. It is used to compare costs with the modeled cost curves on a per-capita equivalent annual cost basis.

Because all STPs investigated or researched were reported with designed and actual treatment capacity. Without sewer connection data, it was unclear the actual population being served by the STPs. Therefore, population served by STP, based on actual treatment capacity, was estimated as

\[
P_s = \frac{\text{STP Capacity (MLD)}}{\text{LPCD}_{SB} \times \text{water return efficiency}}
\]

Where
* LPCD<sub>SB</sub> = 135 liter per capita per day
* Water return efficiency = 80% for wastewater

Same assumptions were used in the cost framework.

Estimating EAC in 2016 value

In order to make a comparison with modeled cost curve, per-capita EAC were estimated for SB systems data.

Calculation of EAC in 2016 value requires knowledge of system lifespan, year of commissioning, and historical discount rate. In many cases, these information are not available. Under such case, the following assumptions were made:

* System lifespan = 30 years
* Discount rate = 5%
* Year of commission = 2000
Challenges with data collection

Collecting data from field visits and in-person interviews with engineers, managers, and operators proved to be challenging. Most existing FSTPs and STPs in India are owned and operated by the municipality. Site visits and access to cost information and performance data require formal approval from local government, which is often difficult to obtain. This was particularly true for STPs.

- **Limited access to existing sites, particularly sewage treatment plants**
  - Cost information and treatment performance data are being considered sensitive information. For fear of being scrutinized, some municipalities have low or no willingness to share data or to grant access to site visits.

- **Incomplete records of cost information**
  - Records of cost information are more available for FSTPs than STPs due to recent commission. All FSTPs that were visited during this study were constructed and commissioned within the past 5 years.
  - From STPs visited and mentioned in the literature review, cost information and performance data are often incomplete.

- **Little cost breakdown is available from available records**
  - Detailed CapEx breakdown by collection, transportation/conveyance, different treatment components, and disposal/reuse is rarely available or have records for both FSTP and STPs.
  - OpEx breakdown data on electricity, labor, chemical/consumables are available for recent FSTPs. OpEx breakdown is not available for sewer collection and most STPs, except for electricity consumption or bills in rare cases.
  - Since sewer network and STPs are both owned and operated by the municipality and considered sanitation service, when limited OpEx data is available, it mostly includes both sewer connection and treatment O&M costs.
Comparison between Modeled Costs and Field Data

Data Analysis and Findings
Notes on data analysis

Modeled CapEx cost curves are within the expected range of accuracy compared to data collected from existing systems according to OPCC Class 5 estimates.\(^1\)

The FS-1 Model System CapEx cost curve is generally consistent with CapEx data collected from similar existing systems. Key observations include:

- **FSTP-B (~FS-1)** – CapEx EAC per capita was slightly lower than the modeled cost curve. The reason for this discrepancy is likely due to the varying system components compared to Model System FS-1 – (FSTP-B consists of a planted sludge drying bed and horizontal constructed wetland, whereas FS-1 is modeled as a sludge drying bed and pond system).

- **FSTP-C (~FS-1)** – CapEx EAC per capita is notably higher compared to CapEx for other systems, likely due to the low number of people estimated to be served by this system. The CapEx EAC per capita does, however, appear to follow the cost curve trend modeled for FS-1.

The FSTP-G (~FS-4) CapEx EAC per capita appears to be substantially lower than the modeled FS-4 cost curve. This is likely due to differences in system components – in particular costs for the existing system (FSTP-G) does not include the cost of solids treatment after dewatering as thickened sludge is reportedly transported and treated at sludge drying beds located at a nearby STP. The cost of this infrastructure was not captured in the existing system CapEx. Additionally, dewatering is performed by sludge thickening tanks in the existing system (FSTP-G), while for the modeled FS-4 cost curve, rotary presses are assumed for dewatering – likely at a significantly higher cost.

Notes:

1. Color of existing system data points aligns with assigned model system
2. Existing systems labeled as A – G for anonymity to protect financial data
3. Per capita costs are calculated according to estimated number of people served based on average daily load received at time of data collection (not design capacity).
4. CapEx of FSTP includes treatment infrastructure only and excludes site infrastructure (e.g. road, retaining walls, fence, office, etc.)
5. Cost of land excluded from cost curves and data collection shown here.
6. Vacuum tanker collection costs are assumed to be shared if operators report discharge at locations other than the FSTP (see methods).

Note: 1. OPCC Class 5 estimates expected accuracy ranges from low -20% to -50%; high +30% to +100%
Modeled OpEx cost curves are generally consistent with data collected from FSTPs

Notes on data analysis

Modeled OpEx cost curves are within the expected range of accuracy compared to data collected from existing systems according to OPCC Class 5 estimates.¹

The FS-1 Model System OpEx cost curve is generally consistent with OpEx data collected from similar existing systems. A notable exception includes:

- **FSTP-D (~FS-1)** – the OpEx EAC per capita is somewhat higher than the modeled cost curve, likely due to the higher labor costs reported for this existing system. Reported labor costs were nearly 50% of collection costs and over 90% of treatment costs.

- **FSTP-F (~FS-3)** – the OpEx EAC per capita is somewhat lower than the trend indicated by the Model System FS-3 curve. A possible reason for this discrepancy is the relative simplicity of the existing system compared to the model system. Although both include anaerobic digestion as a system component, no mixing or pumping is used in the existing system, while both are assumed in the model system. Additionally, liquid treatment is performed by passive systems for the existing FSTP (anaerobic baffled reactor and horizontal constructed wetland), while aerated ponds, which require a substantial amount of electricity for aeration, are assumed in the FS-3 model.

Notes:
- Color of existing system data points aligns with assigned model system
- Existing systems labeled as A – G for anonymity to protect financial data
- Per capita costs are calculated according to estimated number of people served based on average daily load received at time of data collection (not design capacity).
- Vacuum tanker collection costs are assumed to be shared if operators report discharge at locations other than the FSTP (see methods).

Note: 1. OPCC Class 5 estimates expected accuracy ranges from low -20% to -50%; high +30% to +100%
Notes on data analysis

In general, the All-In cost curves modeled within the Cost Framework are fairly consistent with data collected from existing systems and are within the expected range of accuracy according to OPCC Class 5 estimates. Discrepancies observed between modeled and collected data are explained in the preceding slides displaying CapEx and OpEx EACs.

Overall observations on the comparison of All-In cost curves versus data collected from existing systems include:

- **Economies of scale are observed for both modeled cost curves and existing system data collection** – i.e. per-capita EACs reduce as populations increase.
- **However, in reality, there may be a practical limit on the extent to which cost reductions through increasing population served may actually occur.** Estimated populations served by existing systems are generally lower than the upper range of populations modeled in the Cost Framework (mean population served by existing systems = 14,000; maximum = 48,000). Additionally, the estimated populations served by existing systems at the time of data collection were lower than the treatment system design capacities.
- **These lower population figures may be because implementation of FSTPs in India are still in early stages of development and are yet to be scaled up to larger capacities.**
- **However, lower populations served may also be due to practical limits on the treatment plant catchment area as it may be financially unattractive for vacuum tanker operators to travel far distances to a centralized FSTP.** Within this study, operators reported an unwillingness to travel greater than roughly 10km one-way. Additionally, several drivers interviewed reported discharge of FS at nearby farmlands, with a reported 200 – 500 Rs. paid by farmers for such loads, suggesting a demand for untreated FS.
- **These insights suggest that although economies of scale may be theoretically achieved through increasing the population served, systems designed to serve a large coverage area may not receive expected FS loads.**

Modeled All-In cost curves are generally consistent with data collected from FSTPs

![Chart showing All-in (EAC) cost curves for different systems](chart.png)

**Notes:**
1. Color of existing system data points aligns with assigned model system
2. Existing systems labeled as A – G for anonymity to protect financial data
3. Per capita costs are calculated according to estimated number of people served based on average daily load received at time of data collection (not design capacity).
4. CapEx of FSTP includes treatment infrastructure only and excludes site infrastructure (e.g. road, retaining walls, fence, office, etc.)
5. Cost of land excluded from cost curves and data collection shown here.
6. Vacuum tanker collection costs are assumed to be shared if operators report discharge at locations other than the FSTP (see methods).
Labor is the primary OpEx cost driver for collection and treatment for existing systems.

- Labor accounts for 25 – 60% of collection OpEx.
- Fuel is also an important cost driver, accounting for 6 – 60% of collection OpEx.

- Labor accounts for 60 – 90% of treatment plant OpEx (excluding FS-4).
- Energy is an important cost driver for FS-4 only (activated sludge for liquid treatment) accounting for ~40% of treatment OpEx.
- Labor cost trends are consistent with model system estimates for labor costs.
Cost trends for collection versus treatment for existing systems are consistent with modeled systems

Observations

The general cost trends for collection versus treatment in the CapEx and OpEx phases are consistent between data collected from existing systems and the modeled systems. Specifically, these trends are:

- **CapEx:** treatment infrastructure is primary cost driver
- **OpEx:** collection and treatment costs are relatively proportional

However, for both the CapEx and OpEx phases, collection costs are proportionally higher for the existing versus modeled systems (on average, collection accounts for 31% vs 12% of costs for CapEx and 57% vs 44% of costs for OpEx for the existing systems versus modeled systems, respectively). This may be due to the idealized assumptions used to develop the collection model in the Cost Framework (e.g. entire population within the catchment area served, equal spacing between households, etc.)
Context for comparison between collected data and modeled cost curves for SB & CT systems

Because of the fragmented data availability, modeled SB cost curves were compared with data in the following three ways:

- Sewer network and treatment cost combined for CapEx and OpEx
- Comparison of sewer network CapEx
- Comparison of STP CapEx and OpEx

The objectives of comparing model results with data are:

- Calibrate model assumptions
- Better understand model cost curves capabilities and limitations
- Check if model cost curves are of similar magnitude as existing systems. However, with limited data availability and necessary information, caution needs to be taken when making the comparison.

To help with the comparative analysis, CapEx are presented in two ways:

- Equivalent Annual Cost (EAC) for comparison with model cost curve

- Treatment CapEx per MLD (USD$ / MLD)
  A common method of expressing treatment Capex used in Industry is CapEx per treatment capacity. Using this method to compare the modeled results and the data also helped reduce uncertainties from the assumptions made from calculating EAC in 2016 value for the data and estimation of population served.
Data Collection

Findings

A total of 7 data points were obtained for this comparison (WBG 2016):

• 1 data point for ~SB-1
• 3 data points for ~SB-2
• 3 data points for ~SB-3

The limited available data suggests that CapEx of existing SB systems is higher than the modeled cost.

This finding is not surprising because

• modeled collection cost is based on a least-cost scenario
• collection capital cost is much more significant compared with treatment CapEx
Two data points are available for combined collection and treatment OpEx data.

Even though data comes from different sources (for the two figure above) the model estimates higher OpEx (combined and treatment alone) than available field data. Interviews with industry experts and review of published site visit notes indicated that most STPs are often not operating at industry standard or as designed. Operators tend to apply practices that help reduce O&M cost, such as reducing operation time of equipment that requires a lot of electricity. The model OpEx assumption were made based on industry standard, manufacture recommendation, and most importantly, sufficient such that effluent and disposal quality target can be achieved under existing regulation. In addition, model OpEx assumes annual maintenance for all equipment, including civil structures, which in reality is often left to decay.
Data used for comparison were obtained from two sources: Tamil Nadu Water and Drainage Board online publication and a research paper by Bajali et al (2015).

The comparison shows that capital cost of existing sewer network from the obtained data locations are higher than modeled sewer network capital expense. This finding confirms the model assumption of least-cost scenario for sewer network.

The wide range of per capita sewer network exhibited from the data is likely to be contributed by differences in location specific factors such as geology, topography, existing road infrastructure.

Both findings supports the model assumption. More importantly, the findings reinforces that capital cost for sewer network is highly location specific; thus modifications on geographic, topographic, land layout, population density and other sewer network related assumptions need to be made if the model were to be used to approximate costs for a specific location.
**Findings**

**SB-1**: Only 1 data point is available for comparison. The model cost curve seems to be consistent with the only data point, if the curve is to be extrapolated to the population point.

**SB-2**: 5 data points are available for comparison. The model cost curve is consistent with 2 of the points, and is higher than the rest. The discrepancy may be driven by different specific treatment units, type of mechanical equipment used and different construction cost due to location difference.

**SB-3**: 2 data points are available for comparison. The model cost curve is higher than the data points. This is surprising since SB-3 model include additional treatment units (anaerobic digesters and gas storage); thus, the cost of SB-3 systems should be higher than SB-2 system. However, data points of ~SB-2 and ~SB-3 is inconsistent. Interview with experts in India also seem to suggest the two ~SB-3 STPs costs were too low compared with industry rules-of-thumb.

**CT-1**: Only 1 data point is available for comparison. The model cost curve is higher than the data. The discrepancy is driven by difference in solids treatment and septage pre-treatment prior to being combined with sewage. The model assumes separate screening and mechanical dewatering unit and mechanical dewatering for sludge from sewage, while the STP of the data point does not have separate infrastructure for septage and uses SDB for combined solids dewatering.
Sewer treatment All-in cost comparison

Six data points are obtained for this comparison

In general, comparison for all 4 model cost curves show higher treatment costs than the data points. As discussed in the earlier page, model cost curve has higher OpEx and in general, higher CapEx, than data. It is not surprising that SB model all-in cost curve is higher than data.
Recommendations for Further Investigation
Recommendation on areas of further investigation

The scope of this study develops a cost framework to estimate and compare 8 existing fecal sludge, sewer based or co-treatment model systems in India. From findings of field visits and modeled cost curves, a few areas may worth further studies to better understand the sanitation market in India, including:

- Co-digestion with MSW

- Other treatment processes that enable reuse options. For example, further solids drying process that produce solids fuel as an alternative to existing reuse options of compost and biogas

- Market research for different reuse options, such as demand and willingness-to-pay (WTP) for different reuse options at various locations

- Choice of centralized versus de-centralized systems to serve a realistic range of population

In addition to these areas that are outside of the scope of this study, it might be worthwhile to deepen existing understanding of the two reuse options—compost and biogas—modeled in this study:

- The 2016 Solid Waste Management Rule promotes use of either composting or anaerobic digestion for solids waste management. This implies that either compost or biogas may be competing system with OP technologies

- Current understanding and investigation of resource recovery value of biogas and compost can be further refined. Potential areas include:
  
  **Biogas**
  - Cost and investment return ratio of additional infrastructure to convert biogas to electricity
  - Full range of resource recovery value of biogas, not limited to conversion to electricity

  **Compost**
  - Ability of municipality to reliably supply bulking agents
  - Demand and WTP for compost in urban and peri-urban areas.
References


Appendix: Key Assumptions
## Key Assumptions

### Price assumptions

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (Benefit)</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price of land</td>
<td>Varies ($0 assumed as baseline)</td>
<td>US$/m²</td>
<td>$0/m² baseline assumption (no cost for land). Low land price = $47/m²; Median land price = $228/m²; high land price = $588/m² (<a href="http://www.ideasforindia.in/topics/macroeconomics/land-in-india-market-price-vs-fundamental-value.html">http://www.ideasforindia.in/topics/macroeconomics/land-in-india-market-price-vs-fundamental-value.html</a>). Included as drop-down menu with possibility for user input in Cost Framework.</td>
</tr>
<tr>
<td>Electricity</td>
<td>7 Rs/kWh</td>
<td></td>
<td>7 Rs/kWh baseline assumption. Data collection (price for commercial establishment as per govt' norms may vary from 4 - 8 Rs/kWh). Based on data collection.</td>
</tr>
<tr>
<td>Natural gas</td>
<td>200 Rs/mmBtu</td>
<td></td>
<td>200 Rs/mmBtu baseline assumption. Economic Times (India Times) (2018); With conversion to electricity, potential biogas value may be up to 825 Rs/mmBtu (assuming an electricity price of 7 Rs/kWh and gas engine efficiency of 40% for conversion of natural gas to electricity).</td>
</tr>
<tr>
<td>Water</td>
<td>25 Rs/m³</td>
<td></td>
<td>25 Rs/m³ baseline assumption. IBNET (2009): Cost of water supplied, Delhi</td>
</tr>
<tr>
<td>Sludge disposal - Land Apply: Cost</td>
<td>0 Rs/m³</td>
<td></td>
<td>0 Rs/m³ baseline assumption (no cost or benefit) (i.e. local farmers collect at no charge)</td>
</tr>
<tr>
<td>Sludge disposal - Land Apply: Benefit</td>
<td>0 Rs/m³</td>
<td></td>
<td>0 Rs/m³ baseline assumption (no cost or benefit) (i.e. local farmers collect at no charge)</td>
</tr>
<tr>
<td>Sludge disposal - Land Fill:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landfill Tipping Fee</td>
<td>0 Rs/m³</td>
<td></td>
<td>No cost for landfill tipping fee assumed for baseline assuming that treatment plant and landfill operated by ULB (based on data collection and input from sanitation experts in India). In situations where tipping fee is required, costs may range from 1800 - 3500Rs/tonne assuming tipping fee is similar to disposal cost for ash (i.e. sludge may require similar regulations as a hazardous waste) (J-OP market landscape)</td>
</tr>
<tr>
<td>Distance to Landfill</td>
<td>10 km</td>
<td></td>
<td>10km baseline assumption (recommended range ~ 10 - 20km based on input from sanitation experts in India)</td>
</tr>
<tr>
<td>Transport cost per m³ sludge</td>
<td>172 Rs/m³</td>
<td></td>
<td>Cost per m³ varies according to distance traveled. Delhi Schedule of Rates (2016) (Vol. 1, Item 1.1.3)</td>
</tr>
</tbody>
</table>
### Key Assumptions (cont.)

**Price assumptions (cont.)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (Benefit)</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid discharge: Cost</td>
<td>0</td>
<td>Rs/m3</td>
<td><em>0 Rs/m3 baseline assumption (assume no discharge fee)</em></td>
</tr>
<tr>
<td>Liquid reuse: Benefit</td>
<td>0</td>
<td>Rs/m3</td>
<td><em>0 Rs/m3 baseline assumption (assume no benefit for resale of water)</em></td>
</tr>
<tr>
<td>Compost: Price (market value)</td>
<td>1.5</td>
<td>Rs/kg</td>
<td><em>1.5 Rs/kg baseline assumption for conservative benefit estimate. J-OP Market analysis: US $22 - $200 per ton = 1.5 - 13Rs/kg, average = 7Rs/kg; (World Bank); Data collection (Devanahalli treatment system) = 7Rs/kg.</em></td>
</tr>
<tr>
<td>Bulking Agent Price (market value)</td>
<td>1.5</td>
<td>Rs/kg</td>
<td><em>Bulking agent may be supplied at no cost by municipality, however to avoid assuming bulking agent adds revenue, assume minimum price of bulking agent is equal to price of compost.</em></td>
</tr>
</tbody>
</table>
## Key Assumptions (cont.)

### Population density

<table>
<thead>
<tr>
<th>Type</th>
<th>Maximum population</th>
<th>People per hectare</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Town (5K to &lt;50K)</td>
<td>50000</td>
<td>150</td>
<td>150 people/hectare baseline assumption. CPHEEO: Chapter 3, Table 3.1</td>
</tr>
<tr>
<td>Small city (50K to &lt;200K)</td>
<td>200000</td>
<td>300</td>
<td>300 people/hectare baseline assumption. CPHEEO: Chapter 3, Table 3.2</td>
</tr>
<tr>
<td>Medium city (200K to &lt;1M)</td>
<td>1000000</td>
<td>400</td>
<td>400 people/hectare baseline assumption. CPHEEO: Chapter 3, Table 3.3</td>
</tr>
<tr>
<td>Large city (&gt;=1M)</td>
<td>2000000</td>
<td>500</td>
<td>500 people/hectare baseline assumption. CPHEEO: Chapter 3, Table 3.4</td>
</tr>
<tr>
<td>Mega city (&gt;=2M)</td>
<td>&gt;=2M</td>
<td>750</td>
<td>750 people/hectare baseline assumption. CPHEEO: Chapter 3, Table 3.5</td>
</tr>
</tbody>
</table>
## FS collection assumptions

<table>
<thead>
<tr>
<th>Item</th>
<th>Figure</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from town/city to FSTP</td>
<td>5</td>
<td>km</td>
<td>5km baseline assumption (Data collection from 9 truck operators in India: range = 2.5 to 25km)</td>
</tr>
<tr>
<td>Average driving speed</td>
<td>30</td>
<td>km/h</td>
<td>30km/h baseline assumption (Data collection from 9 truck operators in India: range = 25 - 40km/h)</td>
</tr>
<tr>
<td>Average empties per truck per day</td>
<td>2</td>
<td>empties/truck/day</td>
<td>2 empties per day baseline assumption (Data collection from 9 truck operators in India: range = 1 to 3 empties per day)</td>
</tr>
<tr>
<td>Average % loading</td>
<td>80%</td>
<td>%</td>
<td>80% baseline assumption (assumed)</td>
</tr>
<tr>
<td>Full-time employees (FTE) per truck (including driver)</td>
<td>2</td>
<td>FTE/truck (including driver)</td>
<td>2 FTE / truck baseline assumption (Data collection from 9 truck operators in India: range = 2 to 4 FTE/truck)</td>
</tr>
</tbody>
</table>

### Vacuum tanker details:

<table>
<thead>
<tr>
<th>Carrying capacity (m³)</th>
<th>4</th>
<th>10</th>
<th>4m3 and 10m3 volume truck assumed (typical range based on data collection from 9 truck operators in India)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost (Rs.)</td>
<td>2,500,000</td>
<td>3,500,000</td>
<td>2.5M Rs. assumed for 4m3 truck and 3.5M Rs. assumed for 10m3 truck (based on data collection from 9 truck operators in India; costs reflective of government rates; private sector rates may be lower).</td>
</tr>
<tr>
<td>Driving fuel consumption (L/km)</td>
<td>0.34</td>
<td>0.59</td>
<td>Baseline assumption: 0.34 L/km for 4m3 volume truck; 0.59 L/km for 10m3 volume truck. Tong et al., (2015) (Assuming Class 6 vehicle for 4m3 tanker; Class 8 for 10m3 tanker).</td>
</tr>
<tr>
<td>Idling fuel consumption (L/h)</td>
<td>1.7</td>
<td>1.7</td>
<td>1.7 L/h assumed for 4m3 and 10m3 truck. Energy.gov (2015). Assuming “Medium/heavy truck diesel 6-10 L”</td>
</tr>
</tbody>
</table>

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### Key Assumptions (cont.)

#### SB collection assumptions

<table>
<thead>
<tr>
<th>Item</th>
<th>Figure</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from town/city to FSTP</td>
<td>5</td>
<td>km</td>
<td>5km baseline assumption <em>(Data collection from 9 truck operators in India: range = 2.5 to 25km)</em></td>
</tr>
<tr>
<td>Average number of people per connection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Town (5K to &lt;50K)</td>
<td>50000</td>
<td>5</td>
<td>5people/conn baseline assumption. Assumed based on field observation and industry expertise</td>
</tr>
<tr>
<td>Small city (50K to &lt;200K)</td>
<td>200000</td>
<td>5</td>
<td>5people/conn baseline assumption. Assumed based on field observation and industry expertise</td>
</tr>
<tr>
<td>Medium city (200K to &lt;1M)</td>
<td>1000000</td>
<td>10</td>
<td>10people/conn baseline assumption. Assumed based on field observation and industry expertise</td>
</tr>
<tr>
<td>Large city (&gt;=1M)</td>
<td>2000000</td>
<td>15</td>
<td>15people/conn baseline assumption. Assumed based on field observation and industry expertise</td>
</tr>
<tr>
<td>Mega city (&gt;=2M)</td>
<td>&gt;=2M</td>
<td>20</td>
<td>20people/conn baseline assumption. Assumed based on field observation and industry expertise</td>
</tr>
</tbody>
</table>
### Financial analysis assumptions

<table>
<thead>
<tr>
<th>Item</th>
<th>Figure</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount rate</td>
<td>5%</td>
<td>%</td>
<td>5% baseline assumption for real discount rate. World Bank, 2013; Hutton and Vargues, 2016</td>
</tr>
<tr>
<td>Inflation</td>
<td>0%</td>
<td>%</td>
<td>0% baseline assumption as inflation is taken into consideration using &quot;real&quot; discount rate</td>
</tr>
<tr>
<td>Period of analysis</td>
<td>30</td>
<td>years</td>
<td>30y baseline assumption. Design period selected based on lifespan of main structures for STPs (CPHEEO Manual, Chapter 2, Table 2.1)</td>
</tr>
<tr>
<td>Annuity factor</td>
<td>15.4</td>
<td>-</td>
<td>Calculated</td>
</tr>
<tr>
<td>Exchange Rate</td>
<td>67</td>
<td>Rs / US$1</td>
<td>67Rs/USD. World Bank, 2016 (Official exchange rate (LCU per US$, period average))</td>
</tr>
<tr>
<td><strong>Additional Costs: Mechanical Equipment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taxes</td>
<td>18%</td>
<td>%</td>
<td>18% Goods and services tax (GST). Government of India</td>
</tr>
<tr>
<td>Freight</td>
<td>3%</td>
<td>%</td>
<td>3% baseline assumption according to vendor quotes</td>
</tr>
<tr>
<td>Cost (% of mechanical equipment) for valves and pipes</td>
<td>10%</td>
<td>%</td>
<td>10% baseline assumption per vendor and industry expert recommendation for common practice</td>
</tr>
<tr>
<td>Cost (% of mechanical equipment) for Misc. items</td>
<td>5%</td>
<td>%</td>
<td>5% baseline assumption per vendor and industry expert recommendation for common practice</td>
</tr>
<tr>
<td>Cost (% of mechanical equipment) for I&amp;C</td>
<td>10%</td>
<td>%</td>
<td>10% baseline assumption per vendor and industry expert recommendation for common practice</td>
</tr>
<tr>
<td>Cost (% of mechanical equipment) for Electrical</td>
<td>20%</td>
<td>%</td>
<td>20% baseline assumption per vendor and industry expert recommendation for common practice</td>
</tr>
<tr>
<td>Cost (% of mechanical+Elect+Instru equipment) for erection and commission</td>
<td>10%</td>
<td>%</td>
<td>10% baseline assumption per vendor and industry expert recommendation for common practice</td>
</tr>
</tbody>
</table>
Key Assumptions (cont.)

Financial analysis assumptions (cont.)

<table>
<thead>
<tr>
<th>Item</th>
<th>Figure</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional Costs: Overall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost (add'l %) for general conditions</td>
<td>15%</td>
<td>%</td>
<td>15% baseline assumption. Industry expert recommendation for common practice in India</td>
</tr>
<tr>
<td>Cost (add'l %) for misc infr. (SB-1, FS-1, FS-2, FS-3)</td>
<td>5%</td>
<td>%</td>
<td>5% baseline assumption per industry expert recommendation for common practice in India. Includes health &amp; safety infrastructure, handrails, ladder/stair access to infr.</td>
</tr>
<tr>
<td>Cost (add'l %) for misc infr. (SB-2, SB-3, CT-1, FS-4)</td>
<td>15%</td>
<td>%</td>
<td>15% baseline assumption per industry expert recommendation for common practice in India. Includes health &amp; safety infrastructure, handrails, ladder/stair access to infr.</td>
</tr>
<tr>
<td>Cost (add'l %) for construction management</td>
<td>3%</td>
<td>%</td>
<td>3% baseline assumption per industry expert recommendation for common practice in India</td>
</tr>
<tr>
<td>Cost (add'l %) for insurance</td>
<td>1%</td>
<td>%</td>
<td>1% baseline assumption per industry expert recommendation for common practice in India</td>
</tr>
<tr>
<td>Cost (add'l %) for bank guarantee</td>
<td>10%</td>
<td>%</td>
<td>10% baseline assumption per industry expert recommendation for common practice in India</td>
</tr>
<tr>
<td>Cost (add'l %) for interest on working capital</td>
<td>3%</td>
<td>%</td>
<td>3% baseline assumption per industry expert recommendation for common practice in India</td>
</tr>
<tr>
<td>Cost (add'l %) for engineering design</td>
<td>15%</td>
<td>%</td>
<td>15% baseline assumption per industry expert recommendation for common practice in India</td>
</tr>
<tr>
<td>Cost (add'l %) for overhead and profit</td>
<td>15%</td>
<td>%</td>
<td>15% baseline assumption per industry expert recommendation for common practice in India</td>
</tr>
<tr>
<td>Contingency</td>
<td>20%</td>
<td>%</td>
<td>15 - 40% contingency for Class 5 Opinion of Probable Construction Costs (AACE)</td>
</tr>
<tr>
<td>Cost for capital maintenance</td>
<td>0.5%</td>
<td>%</td>
<td>0.5% baseline assumption per industry expert recommendation for common practice</td>
</tr>
</tbody>
</table>
Key Assumptions (cont.)

System lifespan assumptions

<table>
<thead>
<tr>
<th>Item</th>
<th>Design Period (years)</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum tanker</td>
<td>20</td>
<td>years</td>
<td>20y baseline assumption based on data collection from 9 truck operators in India</td>
</tr>
<tr>
<td>Civil works (primary structures)</td>
<td>30</td>
<td>years</td>
<td>30y baseline assumption. CPHEEO Manual, Chapter 2, Table 2.1</td>
</tr>
<tr>
<td>Conventional sewers (A)</td>
<td>30</td>
<td>years</td>
<td>30y baseline assumption. CPHEEO Manual, Chapter 2, Table 2.1((A) Typical underground sewers with manholes laid in the roads)</td>
</tr>
<tr>
<td>Pumps (heavy-duty)</td>
<td>15</td>
<td>years</td>
<td>15y baseline assumption. CPHEEO Manual, Chapter 2, Table 2.1</td>
</tr>
<tr>
<td>Pumps (light-duty)</td>
<td>10</td>
<td>years</td>
<td>10y baseline assumption based on vendor quotes</td>
</tr>
<tr>
<td>Mixers</td>
<td>10</td>
<td>years</td>
<td>10y baseline assumption based on vendor quotes</td>
</tr>
<tr>
<td>Manual screens (steel)</td>
<td>10</td>
<td>years</td>
<td>10y baseline assumption (based on experience)</td>
</tr>
<tr>
<td>Rotary Press</td>
<td>20</td>
<td>years</td>
<td>20y baseline assumption per vendor quote</td>
</tr>
<tr>
<td>Centrifuge</td>
<td>15</td>
<td>years</td>
<td>15y baseline assumption per vendor quote</td>
</tr>
<tr>
<td>Geomembrane liner (ponds)</td>
<td>15</td>
<td>years</td>
<td>15y baseline assumption per supplier quote</td>
</tr>
<tr>
<td>Surface aerator (ponds)</td>
<td>15</td>
<td>years</td>
<td>15y baseline assumption per vendor quote</td>
</tr>
<tr>
<td>All other mechanical equipment</td>
<td>15</td>
<td>years</td>
<td>15y baseline assumption</td>
</tr>
<tr>
<td>Mechanical shredder (composting unit)</td>
<td>10</td>
<td>years</td>
<td>10y baseline assumption per vendor quote</td>
</tr>
<tr>
<td>Tools (laborer / operator tools)</td>
<td>5</td>
<td>years</td>
<td>5y baseline assumption (assumed based on experience). Includes basic operator tools (e.g. shovel, etc.)</td>
</tr>
</tbody>
</table>
Key Assumptions (cont.)

### FS design parameter assumptions (cont.)

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Figure</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sludge accumulation rate</strong></td>
<td>0.5</td>
<td>LPCD</td>
<td>0.5LPCD baseline assumption. RTI (Various studies)</td>
</tr>
<tr>
<td><strong>Total solids content (TS)</strong></td>
<td>2.5%</td>
<td>%</td>
<td>2.5% TS content baseline assumption. RTI (Various studies)</td>
</tr>
<tr>
<td><strong>Total suspended solids (TSS)</strong></td>
<td>22000</td>
<td>mg/L</td>
<td>22000 mg/L baseline assumption. Various studies / data collection in India</td>
</tr>
<tr>
<td><strong>BOD concentration</strong></td>
<td>10000</td>
<td>mg/L</td>
<td>10000mg/L baseline assumption. Various studies / data collection in India</td>
</tr>
<tr>
<td><strong>COD concentration</strong></td>
<td>25000</td>
<td>mg/L</td>
<td>25000 baseline assumption. Various studies / data collection in India</td>
</tr>
<tr>
<td><strong>VS (% of TS)</strong></td>
<td>50%</td>
<td>%</td>
<td>50% baseline assumption. Various studies / data collection in India</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>25</td>
<td>°C</td>
<td>25°C assumed for India</td>
</tr>
<tr>
<td><strong>Sludge density</strong></td>
<td>1000</td>
<td>kg/m³</td>
<td>1000 kg/m³ assumed</td>
</tr>
<tr>
<td><strong>FSTP operating hours per day (basic system type)</strong></td>
<td>8</td>
<td>hours/day</td>
<td>8h/day baseline assumption for basic system types (FS-1, FS-2, FS-3) (assumed)</td>
</tr>
<tr>
<td><strong>FSTP operating hours per day (mechanized system)</strong></td>
<td>12</td>
<td>hours/day</td>
<td>12h/day baseline assumption for mechanized system types (FS-4) (assumed)</td>
</tr>
</tbody>
</table>
## Key Assumptions (cont.)

### SB and CT design parameter assumptions (cont.)

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Figure</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SB design parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water supply per capita</td>
<td>135</td>
<td>LPCD</td>
<td>135LPCD baseline assumption. CPHEEO: Chapter 5, Table 5.4 (supersedes table 5.1)</td>
</tr>
<tr>
<td>Water return coefficient</td>
<td>80%</td>
<td>%</td>
<td>80% baseline assumption. CPHEEO: Chapter 5, Table 5.4 (supersedes table 5.1)</td>
</tr>
<tr>
<td>TS per capita</td>
<td>80</td>
<td>g/cap/day</td>
<td>80gpcd baseline assumption. CPHEEO: Chapter 5, calculated based on TSS/TS ratio from Table 5.1.</td>
</tr>
<tr>
<td>BOD per capita</td>
<td>27</td>
<td>g/cap/day</td>
<td>27gpcd baseline assumption. CPHEEO: Chapter 5, Table 5.4 (supersedes table 5.1)</td>
</tr>
<tr>
<td>COD per capita</td>
<td>47</td>
<td>g/cap/day</td>
<td>47gpcd baseline assumption. CPHEEO: Chapter 5, Table 5.4 (supersedes table 5.1)</td>
</tr>
<tr>
<td>VSS per capita</td>
<td>28</td>
<td>g/cap/day</td>
<td>28gpcd baseline assumption. CPHEEO: Chapter 5, Table 5.4 (supersedes table 5.1)</td>
</tr>
<tr>
<td>TSS per capita</td>
<td>41</td>
<td>g/cap/day</td>
<td>41 gpcd baseline assumption. CPHEEO: Chapter 5, Table 5.4 (supersedes table 5.1)</td>
</tr>
<tr>
<td>VSS as % of TS</td>
<td>68%</td>
<td>%</td>
<td>68% baseline assumption. Calculated from VSS/TSS from values above</td>
</tr>
<tr>
<td><strong>CT design parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sewerage coverage (urban) (2011)</td>
<td>33%</td>
<td>%</td>
<td>World Bank Financial Requirements of Urban Sanitation In India: An Exploratory Analysis (2016)</td>
</tr>
<tr>
<td>On-site FS</td>
<td>67%</td>
<td>%</td>
<td>&quot;</td>
</tr>
</tbody>
</table>