THE STeP GLOBAL TESTING PROTOCOLS & PARAMETERS

A best practices guide for testing sanitation technologies in the field

The Sanitation Technology Platform

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GLOSSARY

ACGIH	American Congress of Governmental Hygienenists
AOAC	Association of Analytical Communities
APHA	American Public Health Association
ASTM	American Society for Testing and Materials
BMGF	Bill and Melinda Gates Foundation
BOD	Biochemical Oxygen Demand after 5 days (BOD5)
COD	Chemical Oxygen Demand
dB	decibel
DPD	Dissolved Phase Diluent
DW	Dry Weight
EPA	Environmental Protection Agency
IBI	International Biochar Initiative
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
kWh	Kilowatt hour
Leq	Equivalent Continuous Sound Level
MPN	Most Probable Number
NDIR	Non-Despersive InfraRed
PAH	Polycyclic Aromatic Hydrocarbon
PM	Particulate Matter
Reclaimed water	Recycled water
STeP	Sanitation Technology Platform
TDS	Total Dissolved Solids
TMECC	Test Methods for the Examination of Composting and Compost
TOC	Total Organic Carbon
TP	Technology Partner
TS	Total Solids
TSS	Total Suspended Solids
TVS	Total Volatile Solids
WHO	World Health Organization

OVERVIEW OF SAFETY AND PERFORMANCE TESTING

The goal of the Sanitation Technology Platform (STeP) program is to ensure the safety, validate the performance, inform product design, and drive the market adoption of advanced sanitation technologies.

The STeP program, in collaboration with technology partners (TPs), is developing a spectrum of standardized test measurements to assess the safety and performance of the sanitation technologies. Safety tests are principally focused on health effects via use of and/or exposure to byproducts of the technologies. Performance measurements include the tracking of operational parameters such as material throughput and external energy utilization.

The STeP program provides testing as a service to the TPs with the objectives of

1. evaluating the safety of the technology via an independent third party and
2. collecting operational data to validate the performance of the technology to inform subsequent product design and technology development

This data will provide, in many cases, the first-of-its-kind quantitative assessment of parameter performance over time. Testing will be frequent (typically weekly) over the months of the field testing and recommended sampling frequencies for different measurement categories are listed.

The STeP program has selected a general set of measurements applicable to all technologies, and will collaborate with the TPs to define a limited set of specialized measurements for each technology. The STeP program will provide standardized formats and spreadsheets for data collection, and will aggregate and analyze data.

The selection criteria for the parameters to be monitored include those parameters that are:

1. regulated by local standards or international guidelines,
2. associated with user adoption or relevant for intended use, and
3. relevant for monitoring of the technology operation.

Specifically, testing parameters are based on local regulations, or, if local regulations are not suitable or weak, by international guidelines. Additionally, parameters such as wastewater color or system sound emission will be monitored because they may significantly impact user adoption of the technology. Furthermore, in addition to a general set of parameters, STeP will carry out tests of selected, technology-specific parameters indicated by the technology partner as useful for monitoring performance of the system during field testing.

Resources and Outcomes

In addition to this write-up, which describes measurements and protocols, the STeP program will provide resources such as pdf documents for the standard methods their Web source, pdf document describing customized protocols as well as pdf version of the regulatory publications cited in this document. This document focuses on national standards and regulations in the countries of India, South Africa and Senegal, where field testing will initially take places.

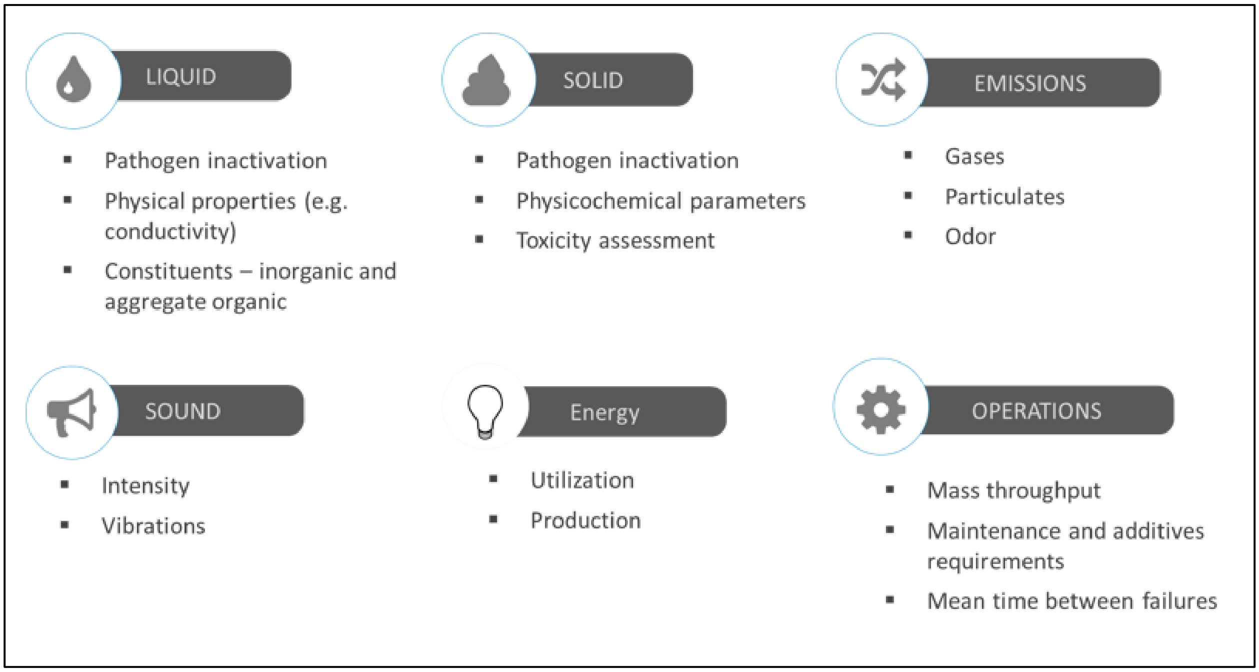
The STeP program will aggregate and analyze the data collected for each sanitation system and provide this information to the respective technology owner through a data platform.

This protocol collection is intended to be a living document and will be updated as the effort develops. A version number will be assigned to each revision. For example, this version v2.0 includes information associated with limits for wastewater for all three countries where initial testing will occur (India, South Africa, Senegal), while we are so far focused only on India standards for the other measurement categories.

Measurement Categories

The testing categories are divided into six categories illustrated in Figure 1. The categories are liquid effluents, solid waste, air emissions, sound generation, energy and operational parameters.

Figure 1. Overview of the Size Categories of Test Measurements



1. Liquid: The water-testing parameters will be defined based on the liquid's intended use (e.g. agriculture or urban reuse such as toilet flushing) according to regional regulations and guidelines from the US Environmental Protection Agency (EPA) and World Health Organization (WHO). A general set of parameters will be augmented with a smaller defined set of technology-specific parameters for each partner. Local vetted laboratories near the test site will carry out these analyses.
2. Solid: Post-processed solid waste or that which accrues will be tested according to standard methods recommended by the International Biochar Initiative and EPA. Local vetted laboratories near the test site will carry out these analyses.
3. Emissions: Waste processing by these technologies is likely to release byproducts into the air. The emissions will be measured before, during and after operation and compared to regional health safety standards or hazard limits. These limits will be supplemented by EPA and American Congress of Governmental Industrial Hygienists (ACGIH) thresholds where regional limits are not available. Samples will be analyzed using field-appropriate (hand-held) instruments to the extent possible.
4. Sound: Noise and vibration generation levels will be measured during operation with appropriate handheld meters to ensure compliance with local regulations dependent on specific placement (e.g. in the home, in a residential area, or in an industrial area).
5. Energy: Energy consumed and energy produced by the technology in kWh (kilowatt hour) will be recorded. The technology operation should include tracking of these parameters and the recorded data will be shared with the STeP program.
6. Operations: STeP will support the determination of the number of users. Operational parameters of the technology including maintenance requirements, material throughput, and failure events during testing will be recorded, and quantified by parameters such as mean time between failures and duration of down time.

Executive Summary of Parameters and Standard Measures for All Categories

Table 1	Wastewater Test Parameters and associated Standard Methods		
#	**Parameter**	**EPA**	**Standard Methods**
1	pH	150.1	—
2	Electrical conductivity	120.1	2510 B
3	Total suspended solid (TSS)	160.2	2540
4	Turbidity (NTU)	180.1	2130 B
5	COD (mg/L)	410.1	5220 C or D
6	BOD5	405.1	5210
7	Colour (hazen)	110.2	2120 B
8	Total chlorine (mg/L)	330.5	4500-Cl G
9	Total Kjeldahl nitrogen (mgN/L)	351.3	4500-Norg B or C
10	Phophorus (mg/L)	365.2	4500-P B and E
11	Chloride (mg/L)	325.3	4500-Cl- C
12	Nitrogen, ammonia (mgN/L)	350.2	—
13	Free ammonia (mgN/L)	—	4500-NH3 B and D
Biological Parameters			
14	Bacterial indicators		
	E. coli	1604	9221, 9222, 9223
	Total coliform	9131	9221, 9222, 9223
	Thermotolerant	1680	9221 E
15	Helminth eggs	Custom Modification of 503.8(b)	

Table 2	Solid Waste Test Parameters and associated Standard Methods			
#	**Parameter**	**EPA**	**ASTM**	**TMECC**
1	pH	9045D	D3838-05	4.11-A
2	Electrical conductivity	9050A	—	4.10
3	Moisture content	160.2	D1762-84	—
4	Ash %	—	D1762-84/E1755-01	—
5	Particle size distribution	—	—	—
6	TDS	160.2	D1762-84	—
7	TVS	160.2	D1762-84	—
8	Phosphorus	6010	—	4.03-A
9	TOC	9060A	D4373-02	—
10	Total carbon	440.0	—	4.02-D
11	Total nitrogen	440.0	D4373	—
12	Nitrate/Nitrite	9056A or 6500	—	4.02-B
13	Fecal coliform	1680		
14	Helminth eggs	Custom modification of 503.8(b)		
15	PAH	8270D or 3540C		

Table 3	Emission, Sound, Energy and Operation Parameters List
# Parameter	**Approach**
Emission	
Toxic gases (CO or others)	Handheld gas analyzer
Flammable gases (H2)	Handheld gas analyzer
PM 2.5 and 10	Handheld PM monitor
Sound	
Sound level in dB (A)	Handheld sound level meter
Energy	
Consumed and produced	kW-hours
Operations	
Number of users	Number of people
Material throughput	Liquid and solid mass processed
Down time	Hours not operating as intended

The sanitation technologies supported by the STeP program are expected to use engineering processes for energy and resource recovery from human waste. Recovery of water is a major area of effort. The uses of reclaimed (or recycled) water include potable water, irrigation, and urban reuse such as toilet flushing[1]. STeP will evaluate water quality with a set of measurements informed by the following three major water quality categories:

- safe to discharge
- nonpotable, reclaimed water
- potable, reclaimed water (not in version v2.0 of this document)

The STeP program identified parameters to measure by evaluating water parameters regulated for discharge and reuse in the test countries of India, Senegal, and South Africa as well as the parameters included in the guidelines for wastewater reuse from the U.S. Environmental Protection Agency (EPA) and World Health Organization (WHO)

The general set of physicochemical water parameters to be measured includes

1. pH,
2. electrical conductivity,
3. total suspended solids (TSS) and total volatile solids (TVS),
4. turbidity,
5. chemical oxygen demand (COD),
6. biochemical oxygen demand after 5 days (BOD5),
7. color,
8. total chlorine,
9. total Kjeldhal nitrogen
10. phosphorus,
11. chloride,
12. nitrogen ammonia, and
13. free ammonia.

The biological measures for pathogen indicators are

14. bacteria (total coliform, thermotolerant coliform, and E. coli); and
15. soil transmitted helminth eggs concentration

A.1 Physicochemical Parameters

Table A.1 summarizes the standard limit values for water discharge in inland surface waters and for irrigation use from India[2], as well as WHO[34] and EPA[1] guidelines for water reuse. It should be noted that the values reported in table A.1 are a consolidated list from water categories listed in the referenced documents and include both water for agriculture (with specific requirement of low salinity) and urban reuse (e.g. toilet flushing). Table A.2 lists the wastewater limits for discharge in the environment for South Africa[5] and Senegal[6] and, for comparison, the values from India from table A.1.

We note that constituents such as nitrogen, phosphorus, and ammonia feature prominently in urine composition[7].

The values referring to the India standard in table A.1 are obtained from the general standards for discharge of environmental pollutants into inland surface water (Table A.1 1st column) and on land for irrigation (Table A.2, 2nd column)[2]. For selected parameters (chlorine and chloride) the treated effluent standards from treatment plant are used, from the same document[2]. Bacterial indicator values are obtained from the bathing water standard, also from[2]. Color is required to be "absent" in[2], and the value in the Table A.1, column 1, refers to bathing water standards for the India region of Tamil Nadu[8], where field testing is planned.

The international standard values derive from the 2006 WHO wastewater guidelines, volume 2[3], and for biological indicators, volume 1[4].

The values in the EPA guidelines for water reuse are obtained from multiple categories of use (irrigation, restricted and unrestricted impoundments, and environmental reuse) from[1] hence some of the parameters have a range of values. The parameter for the urban reuse category are listed in a separate column in table A.1, and refer specifically to reclaimed water in nonpotable applications in municipal settings where public access is not restricted; the parameter list in this column highlights the lack of limit values for COD, chloride, nitrogen, ammonia and phosphorus for this use.

The specific pages of the standard and guideline source document used to obtain the values in table A.1 are listed in Supplementary Information S1 to this document.

A later version of this document will address additional parameters required to establish safety for potable use.

Table A.1	India Standards, and WHO and EPA Guidelines for Wastewater Reuse					
# Parameter	**India Inland Surface Water[2]**	**India Irrigation[2]**	**WHO Reuse[3 4]**	**EPA Reuse[1]**	**EPA Reuse Urban[1]**	**Notes**
1 pH	5.5–9	5.5–9	6.5–8.5	6.0–9.0	6.0–9.0	
2 Electrical conductivity	—	2250 uS/cm	800-3000 uS/cm	700 uS/cm	—	dS/m=decisiemes/m = millimho/cm
3 Total suspended solid (TSS) (mg/L)	100	200	100–350	5/60 #	5	# depending on the US state
4 Turbidity (NTU)	—	—	—	2 NTU	2 NTU	
5 COD (mg/L)	250	—	—	—	—	
6 BOD	30*	100*	100–400	10/60#	10	*BOD 3days@27
7 Colour (hazen)	300**	—	—	—	—	**Tamil Nadu bathing water
8 Total chlorine (mg/L)	1	—	1–5	1	1	
9 Total Kjeldahl nitrogen (mg/L)	100	—	30	6	—	
10 Phosphorus	—	—	20	2	—	
11 Chloride (mg/L)	1,000	600	140	65/170#	-	Up to 140 no crop damage
12 Nitrogen, ammonia (mg/L)	50	—		4 (total)	—	
13 Free ammonia (mg/L)	5	—	—	4 (total)	—	
Biological parameters						
14 Bacterial indicators	Fecal 500/ 100mL*	—	*E. coli* 1000/100 mL	Fecal none or 200 in 100 mL***	Fecal none in 100mL	*Indian bathing water; *** depending on crop
15 Helminth eggs	—	—	1 egg/L	—	—	

— = not reported; # depending on the US state

Table A.2	Limits for Wastewater Discharge in Inland Waters for India, South Africa and Senegal					
#	Parameter	India Surface Water[2]	India Irrigation[2]	South Africa Irrigation (up to 2000 m^3 /up to 500 m^3)[5]	Senegal Surface Water[6]	Notes
1	pH	5.5–9	5.5–9	5.5–9	—	
2	Electrical conductivity (uS/cm)	—	2250	700–2000	—	
3	TSS (mg/L)	100	200	25	40	
4	Turbidity	—	—	—	—	
5	COD	250	—	75/400	200	
6	BOD5	30*	100	—	50	*BOD 3days@27
7	Colour (hazen)	300**	—	—	100	**Tamil Nadu bathing water
8	Total chlorine (mg/L)	—	—	0.25#	—	#Free chlorine
9	Total Kjedhal Nitrogen (mg/L)	100	—	—	20 ***	*** total N
10	Phosphorous (mg/L)	—	—	10##	10	## not total but orthophosphate
11	Chloride (mg/L)	1,000	600	—	—	
12	Nitrogen, ammonia (mg/L)	50	–	6	—	
13	Free ammonia (mg/L)	5	—	—	—	
Biological parameters						
14	Coliform (MPN)	500/100 mL	—	1,000 or 10,000 in 100 mL	2,000/100 mL	
15	Helminth eggs	—	—	—	—	

— = not reported

A.2 Health Impact: Pathogen Indicators and Toxicants

Indicators of pathogen presence are used to monitor and enforce standards in water quality because measuring all pathogens in a timely and cost-effective manner is impractical; however the selection of indicator organisms remains controversial because indicators do not always correlate with pathogen content.

Coliform bacteria have been selected for testing because the bacteria are a standard indicator of fecal contamination. Soil Transmitted Helminth eggs are eliminated by the human body through feces and can be present in liquid effluent due to mixing of excreta. Helminth eggs have an outer shell that provides protection from their external environment and are accordingly a difficult pathogen to eliminate from waste. Therefore they are ideal indicators to demonstrate the effectiveness of water disinfection process. Viruses, while often present in human feces, are not required to be tested during field testing of sanitation technologies because of the current complexity of the methods required for their detection.

Determination of total and thermotolerant (fecal) coliform as well as E. coli is recommended.

1. The total coliform group is a large collection of different kinds of bacteria present both in the environment and in human feces and a long-standing indicator of water contamination.
2. Thermotolerant, previously known as fecal, coliforms are a subgroup of total coliforms associated with human or animal wastes, defined as coliform bacteria that can grow at 44.5°C.Thermotolerant coliforms have been documented in organically rich waters or tropical climates in the absence of recent fecal contamination; however, some regulatory documents retain the nomenclature of “fecal” coliform.
3. E. coli are a member of the thermotolerant coliform group and are major inhabitants of the intestines of warm-blooded animals, including humans, and do not occur naturally in soil and vegetation. Roughly 85% of thermotolerant coliform in surface waters are E. coli[9].

While no one indicator is considered entirely suitable for the prediction of contamination of all pathogens and parasites, recently, the two indicators E. coli and thermotolerant coliform used together were suggested as an effective utilitarian approach[10]. E. coli has been adopted as the main bacterial indicator instead of other coliform bacteria by some organizations (e.g. EPA) on the basis of improved correlation with human illness However, total coliform enumeration is still used as a legal limit for water quality assessment in U.S. state and local regulations. Because of the existence of well-established, relatively inexpensive assays, we recommend testing all three coliform groups —total, thermotolerant and E. coli.

National and international regulations report bacterial number limit in unit of MPN, the most probable number, a commonly used serial dilution test that enumerates viable organisms. Therefore, determination of coliform concentration by standard measurements based on MPN is preferred.

National regulations in India, Senegal and South Africa do not address limits of concentration of soil transmitted helminth eggs, however WHO guidelines for water re-use do. Both EPA and WHO have published methods for assessment of soil-transmitted helminth eggs by isolation and enumeration. Experts in the field of helminth assessment in environmental samples have developed modification of the EPA method (EPA 503.8 (b)) over the past 10 years to effectively isolate and enumerate helminth eggs from a variety of matrices relevant to sanitation efforts. A workshop convened by the BMGF in Durban South Africa on August 24-26, 2015 brought together these experts to develop a consensus standard operating procedure. A draft of the proposed consensus procedure will be made available as soon as it is ready. As an interim approach, the protocol developed by the University of KwaZulu-Natal (UKZ-N) in South Africa (pdf available from STeP) is recommended for helminth egg assessment.

With regards to helminth eggs viability, there is currently no convenient accepted viability test method, besides a lengthy organism culture approach. Helminth eggs viability methods based on dye staining or molecular methods would be desirable but need further evaluation.

Heavy Metals and Other Parameters

Metals concentration values are limited according to wastewater environmental regulations. Metals were excluded from the general set of measurements because of their low concentration in urine but will be examined if a specific technology process poses risk of a high metal concentration.

Other wastewater constituents such as sodium are important for water quality and regulated; however, chloride is reasonable proxy for sodium and other constituents will be measured as needed on a case-by-case basis.

A.3 Sampling Frequency

Table A.3 outlines the guidelines for the sampling frequency of these parameters: once a week is the recommended measurement frequency for most cases. Measurements conducted by rapid instrumented method or with rapid assays (e.g. pH, electrical conductivity, color, total chlorine, and ammonia) could be carried out more frequently than once a week, if practical and particularly during the startup period of a newly installed system.

Table A.3	Recommended Sampling Frequency for Effluent Measurements			
Test #	**Parameter**	**Sample Volume (mL)**	**Measurement Time**	**Recommended Sampling Frequency**
1	pH	20	10 mins	weekly or every other day
2	electrical conductivity	10	10 mins	Weekly or every other day
3	Total suspended solid (TSS)	20–100	2 hrs	Weekly
4	turbidity (NTU)	25	10 mins	weekly or optional, if TSS available
5	COD	50	2 hrs	Weekly
6	BOD	300	3–5 days	Weekly or monthly
7	colour	50	10 mins	Weekly or every other day
8	total chlorine	10	5 mins	Weekly or every other day, if the process involve s chlorine
9	Total Kjeldhal Nitrogen	25-500	3 hrs	Weekly
10	phosphorus	50	2 hrs	Weekly
11	chloride	50	10 mins	Weekly
12	nitrogen, ammonia	400	1 hr	Weekly
13	free ammonia	400	10 mins	Weekly or every other day
	Total volume	~2 L		
	Biological parameters			
14	bacterial tests	200 ml	24–48 hrs incubation	weekly
15	helminth eggs	10L	a couple of days	1 month

Selected parameters, BOD and helminth eggs, can be tested with lower than weekly frequency. The measurement of BOD in pathogen-free waste is ill-defined and, if bacterial indicators in the samples are consistently absent, can be carried out less frequently than weekly.

Turbidity is an indirect but rapid measurement of solid content. If the specific instrument for this measurement is not available, the total suspended solids measurement should serve as an adequate proxy.

The helminth eggs test is recommended with a frequency of at least once a month. Because of the technology treatment, the fact that only a limited number of users may shed eggs, and the presence of eggs in liquid due to fecal contamination, we anticipate low values for helminth eggs in treated liquid and therefore we recommend processing relatively large sample volumes (e.g. 5-10 liters) and carrying out a sample collection specific for this test on a monthly basis.

Liquid Sample Collection and Transport Guidelines

Sample collection should be done with adequate volumes to carry out all tests in triplicate. Sterile glass glass or autoclavable plastic bottles (polypropylene) with a tight-fitting lid should be used for treated sample and clean water control sample. Head space should be minimized and the lid sealed immediately. Liquid samples testing should begin within 4-6 hours from collection (given the environmental sensitivity of parameters such as pH or bacterial content); alternatively samples can be placed on ice immediately after collection and remain on ice or be stored in a refrigerator for up to 24 hour prior to the beginning of the analysis. Once received at the laboratory, personnel should immediately aliquot assay volumes and store as indicated for each assay. Measurement of pH, temperature and electrical conductance should be carried out in situ with a handheld device (e.g. Myron L) and values recorded.

A.4 Technology-specific Tests

Electrochemical Disinfection

Selected advanced sanitation technologies employ electrochemical disinfection to transform chloride from urine into a chlorine-based, pathogen-killing disinfectant. These technologies also produce disinfected waste liquid for water reuse. For these technologies, build-up over time of water residues (e.g. chloride, nitrogen, and phosphorus) is expected and will need to be evaluated. Other properties are associated with, and important for, the disinfection process and include free chlorine, chloride, and alkalinity. For the electrochemical disinfection technologies, it is therefore recommended that the following physicochemical tests are added, for monitoring technology performance:

- Test 16 Free Chlorine
- Test 17 Alkalinity

Solutions for decentralized human waste management treat solids through either a digestion or a thermochemical conversion process; the output products include biosolids, char or ash. The air emissions associated with these processes are addressed in section C of the document. This section address the processes and their solid products, specifically:

- Digestion (either aerobic or anaerobic), defined as a process in which microorganisms break down biodegradable material into a biosolid
- [11].
- Thermochemical conversion processes, such as pyrolysis and combustion, that produce a pyrogenic carbonaceous material in the form of charcoal, biochar, ash, and others.
  - Pyrolysis is the thermochemical decomposition of organic material in the absence of oxygen, at elevated temperatures in a gaseous or liquid environment, without further reactants. Biochar is the solid product of the dry pyrolysis process. The material has to meet a number of material property classifications that relate both to its value (e.g., hydrogen/ organic carbon H/C_{org} ratios relate to the degree of charring and therefore mineralization in soil) and its safety (e.g., heavy metal content). Otherwise, it is known as charcoal. Hydrochar is the product of wet pyrolysis.
  - Combustion is the chemical process in which a substance reacts rapidly with oxygen and converts the waste into ash. Ash is defined as the inorganic, non-aqueous residue remaining after a sample is burned and consists mostly of metal oxides and carbonates[12].

This section aims to characterize the solid products to assess their safety and ensuring a basic standard for product material. It does not address requirement for specific re-use applications such as agricultural use, although it lists some of the characterization parameters that are required for land use. The parameters of interest to the SteP program sanitation technologies are outlined below and grouped by solid product type:

- biosolid
- biochar
- ash

Biosolid testing is informed by the EPA 40 Code of Federal Regulations (CFR) 503 standard, Final rules. Biochar/hydrochar parameters are selected based on the proposed guidelines of the IBI[12], which, in turn, adapted regulations from Test Methods for the Examination of Composting and Compost (TMECC)[13]. For ash, no specific regulations have been identified. EPA 40 CFR Part 60 regulates solid waste incineration but states that EPA has “encountered only anecdotal evidence and proposals for manure combustion units.” It is therefore recommended the EPA regulatory standard 40 CFR Part 257 Subpart D, which regulates coal ash be used[14]. Both coal ash and the ash produced in the combustion of sewage sludge are formed from organic material rich in carbon, oxygen, and hydrogen.

B.1 Physicochemical Parameters

Physicochemical parameters in Table B.1 define the basic characteristics of the solid and, in some cases, define the properties of the process that produced them. For example, organic carbon content is used to define biochar in three classes, and <10% of carbon in ash indicates full incineration[14].

Table B.1 Physicochemical Parameters of Solid Products of Waste Processing Technologies and associated limits

Parameter	Biosolids[12]	Biochar/Hydrochar[12]	Ash[14]
1. pH	5.5-6.5*	Declaration	Declaration
2. Electrical conductivity		Declaration	
3. Moisture content	<25%	Declaration	Declaration
4. Ash %		Declaration	
5. Particle size distribution			Declaration
6. TS	> 75%#		
7. TDS			Declaration
8.TVS	38% reduction	Declaration	
9. SOUR	1.5 mgO2/hour/g solid		
10. Phosphorus	Declaration	Declaration	
11.Total organic carbon		≥ 10%	
12.Total carbon		Declaration	
13.Total nitrogen	Declaration**	Declaration	
14.Nitrate/Nitrite	Declaration***	Declaration	
Pathogens			
15.Fecal coliform	<1000 MPN/g TS	none	none
16. Helminth eggs	<1 per 4 g TS	none	none
Toxicant			
17. PAH	-	300mg/Kg	-

*values recommended for soil application

recommended for vector attraction reduction

** If the biosolid is to be used for agricultural purposes the amount of nitrogen needed is crop dependent and the amount of nitrogen that can be applied per hectare is the responsibility of land owner. A declaration will allow the land owner to determine how much sludge can be applied.

***Biosolids carry the risk of causing nitrate contamination of aquifers. While there is no limit in biosolids knowing the amount of nitrate/nitrite is helpful in the event of water contamination.

The parameters and limit from table B.1 are obtained from documents at the pages indicated in Supplementary section S.3. Chemical measurements on solids are carried out by diluting in solution a known amount of solid and carrying out measurements according to the American Public Health Association (APHA) methods, in a manner analogous to that described for liquid effluent. For example, a 1:20 (w:v) solution of biochar:deionized water can be used for biochar pH and electrical conductivity analysis[15].

Parameters described in the Supplementary section S.2 include Total Dissolved Solids (TDS), TVS, TS, and phosphorus. The remainder of the parameters in Table B.2 are described below.

- For biochar, the $H:C_{org}$ ratio is an important figure of merit. Hydrogen is determined using dry combustion; however, according to ASTM C1457, the sample is combusted at a very high temperature of 1,700°C, and the produced hydrogen is then removed with a carrier gas and purified using chromatography and analyzed using an infrared or thermal conductivity sensor. This is a very specialized test to assess the quality of the product.

- Moisture content is quantified as the loss in weight after drying in an oven at 105°C for 2 hours, according to ASTM-D1762-84.
- Percent ash is determined from ASTM D1762-84, when, after moisture quantification, the sample is exposed to 750°C for 6 hours and then reweighed.
- Particle size distribution is determined by progressive dry sieving, also according to ASTD D1762 84.
- Specific Oxygen Uptake Rate (SOUR) is determined from Part 2710 B Standard Methods. SOUR is a measure of compost stability. SOUR indicates the extent to which the compost material has decomposed while BOD tells us how much oxygen is needed to cause the decomposition.
- Total carbon and total organic carbon (TOC) are determined using EPA Methods 5310 C or D and ASTM D4373. TOC is determined through the oxidation of carbon dioxide by persulfate in the presence of heat or UV light. The produced carbon dioxide is quantified using NDIR, coulometric titration, or membrane separation. Total carbon is determined using the same procedure without the addition of heat or UV light.
- Total nitrogen is determined by the oxidative digestion of all digestible nitrogen to nitrate followed by the quantification of nitrate, according to EPA Method 4500-N C Persulfate Method.
- For nitrate/nitrite, a filtered sample is passed through a column containing granulated copper-cadmium, reducing nitrate to nitrite. The nitrite is determined by diazotizing with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine dihydrochloride to form a colored dye that is measured spectrophotometrically. Separate nitrate-nitrite values are

obtained by carrying out the procedure first with, and then without, the Cu-Cd reduction step, according to EPA Method 353.3.

B.2 Health Impact: Pathogens and Toxicants

Only biosolids are associated with pathogen testing limits because the high processes temperatures needed to create biochar/hydrochar and ash will kill all pathogens[14]. For field testing of sanitation technologies, of the pathogens listed in Table B.1, we recommend testing coliform bacteria and helminth eggs with a rationale similar to the one used for liquid effluent testing. For biochar and ashes, these tests are indicated if there is the possibility of partial or incomplete processing of the waste. In order to demonstrate the disinfection ability of the technology, enumeration of viable helminth eggs from the feedstock and processed waste is needed.

Toxicants in solid waste may be divided into two categories: those that may be present in the feedstocks used (metals), and those that may be produced by the process (e.g., polycyclic aromatic hydrocarbons [PAHs]). Prior to discharge of waste after field testing, PAH content should be determined. If use or disposal on soil is intended for the processed waste, besides PAH, toxicity parameters, germination inhibition assay and a set of metals need to be measured. Furthermore, if agricultural use of the product is intended, additional parameters such as chloride, sulfur, sulfates, sodium and potassium content will be determined.

PAHs

PAHs are produced when insufficient oxygen results in the incomplete combustion of organic matter, typically above 800 °C, and are recognized priority pollutants hazardous to the environment. The measurement standard is EPA 8270 (2007) using Soxhlet extraction (EPA 3540) with 100% toluene as the extracting solvent.

- At lower temperatures, oxygenated tars such as phenolics and heterocyclic ethers compounds may be produced. We note that dioxins and furans are also possible process-derived toxicants in biochar, but were found in very low concentrations in biochar produced by pyrolysis[16] and therefore are a lower priority analyte.

Germination Inhibition Assay

For agricultural use, the germination inhibition assay is to ensure that the biochar has a positive impact on plant growth. Some biochars may have adverse effects due to the presence of toxic compounds. This test assesses the effects on seedling emergence and early plant growth after exposure to the test substance as compared to an untreated control soil. Lettuce (Lactuca sativa L.) is the most widely recommended species to use in germination assessments. Lettuce seedling are seeded in biochar amended soil and are compared to control soil, and the test result is reported as pass/fail (ASTM E1963, Standard Guide for Conducting Terrestrial Plant Toxicity Tests).

Metals

Heavy metals are contained in human solid waste (e.g.,[17]). According to the IBI guidelines, all of the elements Arsenic, Boron, Cadmium, Calcium, Chromium, Cobalt, Copper, Mercury, Lead, Molybdenum, Nickel, Selenium, and Zinc need to be tested. The upper limits for metal content in solid are listed in table B.2. For metals, except mercury, standard methods are outlined in TMECC and U.S. Composting Council and US Department of Agriculture, 2001. These test methods involve a digestion step followed by a determination step. In some cases, there are multiple digestion and/or determination methods allowable.

Table B.2 Metals of concern in processed solid waste (Limits)

Parameter		Biosolids (mg/kg DW)	Biochar/Hydrochar (mg/kg DW)	Ash
1.	Arsenic	75	13–100	Declaration
2.	Boron		Declaration	Declaration
3.	Cadmium	85	1.4–39	Declaration
4.	Calcium			Declaration
5.	Chromium	3000	93–1200	Declaration
6.	Cobalt		34–100	Declaration
7.	Copper	4300	143–6000	
8.	Lead	840	120–300	Declaration
9.	Mercury	57	1–17	Declaration
10.	Molybdenum	75	5–75	Declaration
11.	Nickel	420	47–420	
12.	Selenium	100	2–200	Declaration
13.	Zinc	7500	416–7400	

B.3 Sampling Frequency

We expect solid waste products to be tested much less frequently than liquid effluents, typically at the end of the field test. While it is dependent on the scale of the system, we expect a small amount of solid waste output from a system field tested for a period of 6 months. Human waste has a relatively small solid content. The amount of solid waste produced by a person is typically

200–400 g/day. Solid waste is mostly water and has a solid content that varies between 5% and 30%. A conservative estimate for 20 people and 180 days of use is 400 g x 0.3 x 20 people x 180 days = 432 kg. Waste treatment will reduce this amount to a fraction, depending on the process.

Sample Collection

Standard procedure for sample collection should be followed and documented. While we anticipate technology dependent approaches, typical collection includes sampling from a grid of 4 or more spatial regions of the material to be analyzed and then the samples blended and subdivided for measurement replicates. Gallon- or quart-sized Ziploc plastic bags (or glass jars) are adequate containers for most of the parameters to be tested. However, because organic pollutants, including PAHs, are prone to volatilization, samples to be tested for those compounds and for the germination inhibition assay must be packaged in special glass containers with Teflon lids, or exclusively Teflon containers.

The proper evaluation of air emissions from differing waste treatment technologies requires an understanding of what types of emissions can be expected from these technologies, their current regulatory thresholds, and any instruments that exist for measuring these pollutants. This document provides a brief overview of the waste treatment technologies along with the types of air pollutants that can be expected to be generated during their operation. Threshold values for these pollutants as determined by the EPA, WHO, or appropriate national or international agencies are also presented. The technologies for assessing each pollutant in the field were examined and a recommended measurement strategy is presented.

Pollutants are categorized as either gaseous or particulate matter (PM). Gaseous pollutants are identified according to their molecular structure when possible (e.g., hydrogen sulfide [H_2S]), in following with the common regulatory framework. PM consists of material in either a solid or liquid state, and, unlike gaseous pollutants, material in PM is not defined on the molecular level in following with common global regulations and health guidelines: $PM_{2.5}$ refers to PM equal to or less than 2.5 µm in size, and PM_{10} refers to PM equal or less than 10 µm.

Common odor-causing compounds (e.g., H_2S and other sulfur-containing compounds) are present as gases and therefore are listed under this heading. The quantitative measurement of an odor is complex and time-consuming due to the subjective nature of odors; however, given the potential impact of this factor to user acceptance of technologies, we outline approaches to odor assessment by methods of dilution to threshold.

C.1 Emissions from Waste Processing Technologies

Biodigestion is a process driven by the breakdown of waste material by bacteria. The major air pollutants produced from this process include carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), hydrogen sulfide (H_2S), and hydrogen (H_2).

Pyrolysis is the thermal decomposition of a material in the absence of oxygen. The feedstock for this process can be dried or wet, in latter case the term hydrothermal carbonization (HTC) is used. Common air pollutants emitted from this process include carbon monoxide (CO), carbon dioxide (CO_2), hydrogen gas (H_2), ammonia (NH_3), methane (CH_4), hydrogen sulfide (H_2S), polycyclic aromatic hydrocarbons (PAHs), and PM.

Combustion occurs when a fuel is combined with an oxidant (air) and heated to induce burning. Combustion can be performed in environments with differing fuel:air ratios. Situations with excess fuel are referred to as "rich," while combustion with excess air is referred to as "lean." "Rich" combustion situations favor PM production and incomplete combustion byproducts, while "lean" combustion situations favor CO_2 and CO production. However, combustion—rich or lean—will produce CO_2, CO, sulfur dioxide (SO_2), PAHs, VOCs, nitrogen oxide (NO_x), and PM.

Electrochemical processes are used to disinfect liquid waste streams through the production of reactive species such as chlorine by potentiostatic electrolysis with electrodes submerged in the liquid waste. This reaction can also produce H_2, which is liberated from the waste stream and can be captured for use.

Microbial Fuel Cell (MFCs) utilize electrochemically active bacteria to produce electricity from the biodegradation of the waste undergoing treatment. The major air pollutant produced by urine and MFCs is NH_3.

C.2 Regulatory Thresholds

Table C.1 lists current regulatory thresholds for all potential air pollutants produced by the listed processes. The threshold values are intended to provide protection of public health, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. Threshold values from the Indian Ministry of the Environment and Forests[18], South African Department of Environmental Affairs and Tourism[19], and Senegalese Direction De L'Environnement Et Des Etablissements Classes[20] were found and listed as primary sources. USEPA threshold values are provided for reference[21]. We listed workplace-related thresholds designated by the American Congress of Governmental Industrial Hygienists (ACGIH)[18] for instances where country specific environmental agencies or USEPA have not instituted thresholds. Sampling periods such as "1 hour," "8 hour," "annual," and "24 hour" reflect agency-specific sampling guidelines.

A few gases produced by the waste treatment technologies do not have specified threshold limits as environmental pollutants, but they could pose a hazard to the public or are a climate forcing gas. CO_2 does not have an exposure limit, and it is reported as a "simple asphyxiant" by ACGIH. This is a gas that can displace oxygen in the air, resulting in possible suffocation from lack of oxygen. Because simple asphyxiants do not have other significant toxic effects, the limiting factor is the available oxygen within a confined space. CO_2 is also a climate forcing gas that contributes to global warming. H_2 and CH_4 do not have health-related exposure limits, but they do have explosive limits (see Table C.2)[19]. Like CO_2, CH_4 is a climate forcing gas that contributes to global warming.

Table C.1	Air Pollutant Threshold Values of Concentration in Ambient Air				
Pollutant	**Indian Ministry of Environment and Forests[18]**	**South African Department of Environmental Affairs and Tourism[19]**	**Senegal Direction De L'Environnement Et Des Etablissements Classes[20]**	**U.S. EPA[21]**	**ACGIH[18]**
CO (ppm[a] or µg/m3[b])	8 hour: 3.2[a] 1 hour: 1.6[a]	8 hour: 10,000[b] 1 hour: 30,000[b]	—	8 hour: 9 1 hour: 35	—
NH_3 (ppb)	Annual: 133.3 24 hour: 534.1	—	—	—	—
SO_2 (ppb[c] or µg/m3[b])	Annual: 17.7[c] 24 hour: 28.4[c]	Annual: 50[b] 24 hour: 125[b] 10-minute: 500[b]	Annual: 50[b] 24 hour: 125[b]	1 hour: 75 3 hour: 0.5	—
NO_x (ppb[c] or µg/m3[b])	Annual: 19.7[c] 24 hour: 39.5[c]	Annual: 40[b] 1 hour: 200[b]	Annual: 40[b] 1 hour: 200[b]	Annual: 53[a]	—
H_2S (ppm)	—			—	10
VOC (ppm[a] or µg/m3[b])	—	Annual: 5[b,1]		—	1000[a,2]
PM (µg/m^3)	$PM_{2.5}$: Annual: 40 24 hour: 60 PM_{10}: Annual: 60 24 hour: 100	PM_{10}: Annual: 40 24 hour: 75	PM_{10}: Annual: 80 24 hour: 260	$PM_{2.5}$: Annual: 12 24 hour: 25 PM_{10}: 24 hour: 150 Annual: 50	—
PAH (ng/m^3)	Annual: 1	—	—	—	—

[a]units are ppm
[b]units are µg/m^3
[c]units are ppb
[1]Benzene
[2]Threshold of C1–C4 aliphatic hydrocarbon gases used as surrogate

Table C.2	Air Pollutant Threshold Values Based on Explosive Hazard
Pollutant	**Lower Explosion Limit (LEL)**
H_2	4%
CH_4	5%

C.3 Measurement Methods

USEPA has promulgated test methods for measuring emission rates (e.g., air concentrations) for all the air pollutants listed in Table C.1. However, these methods are meant for regulatory compliance purposes. As such, the methods specify sophisticated sample collection and processing systems to achieve the strict quality assurance metrics (e.g., accuracy, precision) required by a regulatory standard. These complex air sampling schemes are hard to implement in field testing in emerging countries. ASTM International is another source for standard test methods for air pollutant emissions, however these methods are also too complex for use in field.

Numerous, recently developed handheld gas and PM sensors are suitable for measuring the air pollutant emissions from sanitation system during field test. These sensors are cost-effective, easy to operate, and readily available from a variety of manufacturers. However, the user must be cognizant of the trade-off between data quality and sensor cost. The ultra-low cost sensors (typically less than $500) may not provide the accuracy, precision, or dynamic range in the measured air pollutant concentrations to determine whether a technology is producing or emitting air pollutants at concentrations that would adversely impact public health or be considered a nuisance. Similarly, not all sensors provide the same data quality even though their cost may be equivalent. Another consideration is how the emissions from the technology will be sampled by sensor. Some sensors are readily adapted to sample from an exhaust pipe (e.g., chimney) while others are meant to sample from a room.

This document will provide some guidance on recommended handheld air pollutant sensors but with the caveat that the sensors discussed may not be recommended for all situations. Because of this need for fit-for-purpose air pollutant sensors, it is recommended the exact sensors selected be matched with the technology being evaluated.

Measurement of Gases

Portable gas pollutant measurement instruments rely on different sensing mechanisms, e.g., electrochemical, non-dispersive infrared (NDIR), and photoionization detection (PID) and can be multiplexed for four and six gas types. Example manufacturers of gas emission instruments are Industrial Scientific, Dräger, Infrared Industries, and RAE Systems Gas Detection. A portable instrument for PAH detection is not available so the recommended method is the USEPA TO13 for sample collection and laboratory analysis.

Handheld gas sensors consist of a measuring unit and sensors, up to 4 to 6 sensors, specific for a gas species. Factory calibrated instruments can be obtained with the sensor configuration required to evaluate the majority of the gas species of interest in emission testing of sanitation technologies. Specifically

- CO: Several methods exist for measuring CO: non-dispersive infrared (NDIR) metal oxide sensors, and electrochemical sensor; a handheld NDIR testing module is preferred.
- Ammonia (NH3) can be measured by handheld electrochemical sensors.
- The measurement of SO_2 can be carried out with electrochemical or NDIR-based handheld sensors. These techniques are nearly interchangeable. However, NDIR measurements of SO_2 suffer from higher than normal baseline drift due to analytical constraints, and care must be taken when performing measurements.
- NOx measurements should be performed by a NDIR handheld sensor.
- Similar to SO_2, H_2S can be detected by electrochemical gas sensors (no commercial NDIR or metal-oxide H_2S sensors are commercially available).
- VOC: Handheld VOC gas analyzer devices are available that use PID (photoionization detection)
- PAH is a term used to describe compounds comprising fused aromatic rings. PAHs can be found in both gaseous and PM pollutants. No portable instrument for PAH detection is available. Analysis of PAH airborne concentrations requires sampling 300 m^3 of air through a specialized polymer-based material, followed by organic solvent extraction performed at a laboratory. The resulting organic liquid is then analyzed by GC-MS or high-performance liquid chromatography for quantitative PAH analysis. This method is identical for Indian and U.S. environmental agencies and is designated as Method TO-13A by the EPA.

For flammable gases

- CH_4: The measurement of methane is conducted by either infrared absorption or catalytic bead sensor. Infrared sensors can be found in large, expensive ambient air monitoring systems as well as smaller handheld instruments. Catalytic bead type sensors are typically only found in handheld devices due to their limited analytical range. The use of handheld infrared or catalytic bead sensors are indistinguishable when the threshold of concern is the LEL. However, the use of the infrared sensor is preferable due to its extended upper detection limit as compared to other sensor types.

- H_2: Hydrogen gas sensing can be performed by a variety of methods including thermal conductivity sensors, and electrochemical sensors. Most of these techniques incorporate the use of palladium metal due to its unique interaction properties with hydrogen gas. An electrochemical-based handheld gas sensor for H_2 detection is recommended

Table C.3 provides an example of instruments for measuring gas emission along with the instrument detection range and resolution. These instruments are adequate for assessing flammable gases and selected toxic gases. We note that for toxic gases like NH_3, SO_2, and NO_x, the detection sensitivity is above the concentration thresholds listed in Table C.1. However, we reasoned that if the pollutant is produced by an exhaust, the concentration at the exhaust is much higher than the values in ambient air. Therefore, placing the handheld gas sensor by the exhaust is the recommended procedure to determine whether a specific gas is emitted by the system.

Table C.3 Instruments and Ranges(± resolution) for Gas Emission Measurements

Gas\Detector	MX6 iBrid	Draeger X-AM 5000	Laboratory Instrument
CO (ppm)	0–1,500 ppm; ± 1 ppm	0–1,500 ppm; ± 1 ppm	—
NH_3 (ppb)	0–500 ppm; ± 1 ppm	0–300 ppm; ± 1 ppm	—
SO_2 (ppb)	0–150 ppm; ± 0.1 ppm	0–300 ppm; ± 0.1 ppm	—
NO_x (ppb)	0–150 ppm; ± 0.1 ppm	0–200 ppm; ± 0.5 ppm	—
H_2S (ppm)	0–500 ppm; ± 0.1 ppm	0–100 ppm ;± 0/1 ppm	—
VOC (ppm)	0–2,000 ppm; ± 0.1 ppm	—	—
PAH	—	—	$3x10^{-3}ng/m^3$
H_2	0–0.2%; ± 1 ppm	0–4%; 0.01%	—
CH_4	0–100%; ± 1%	0–100%; ± 1%	—

Particulate Matter (PM)

Portable PM measurement instruments use light scattering as the detection technique. PM light scattering sensors fall into two categories: particle counters and nephelometers. Particle counters align the sampled PM into a single column for counting and sizing individual particles. A nephelometer detects the light scattered simultaneously from a cloud of particles within the light sensing volume. PM light scattering instruments can measure $PM_{2.5}$ and PM_{10}. The two PM size fractions are most directly associated with acute and chronic adverse health impacts.

Particle counters and nephelometers have their advantages and disadvantages. Particle counters have the ability to size individual particles leading to measurement of $PM_{2.5}$ and PM_{10} simultaneously. This feature also removes the need for a cyclone or impactor to obtain the desire

PM size fraction, thereby reducing maintenance costs. The limitation of a particle counter include: an upper concentration of approximately 1,000 mg/m^3, a higher purchase cost than a nephelometer, and a complex calibration equation to convert the intensity of light scattered to a particle size. Nephelometers do not have the upper concentration limitation or a complex concentration calculation equation. However, nephelometers cannot provide both $PM_{2.5}$ and PM_{10} concentrations simultaneously with a single device.

Suggested commercially available real-time PM monitors are the TSI DustTrak Model 8534, the RTI MicroPEM, and the Dylos 1700 (Table C.4). The first two devices are photometers and the last is a particle counter. The DustTrak and MicroPEM have essentially equivalent performance characteristics. Both measure PM concentrations from 0 to 10,000 µg/m^3 and collect a reference filter for subsequent laboratory analysis. The main differences between the two devices are size and cost. The MicroPEM at 240 grams is a seventh the size and weight of the DustTrak, and less expensive ($2,000 versus $10,000). The Dylos 1700 is a commonly used particle counter with good accuracy and precision, but with a limited dynamic range of approximately 1,000 µg/m^3.

Table C.4 Operational specifications for portable PM measurement devices

Feature	TSI DustTrak 8534	RTI MicroPEM	Dylos 1700
Mode of Operation	Photometer-Particle Counter	Photometer	Particle Counter
Size Segregation	PM_1, $PM_{2.5}$, Respirable, PM_{10}, and Total PM simultaneously	$PM_{2.5}$ or PM_{10},	>0.5 µm and > 2.5 µm
Concentration Range	Not Specified	0 to 10,000 µg/m^3	0 to 350,000 particles/L
Resolution	± 1 µg/m^3	± 3 µg/m^3	± 1 particle/L
Dimensions	13.5 x 21.6 x 22.4 cm	12.7 x 6.4 x 3.8 cm	19 x 13 x 8 cm
Weight	1,500 g	240 g	680 g
Power Source	AC or rechargeable Li Ion battery	AC or 3 AA batteries (alkaline, lithium, or rechargeable)	AC or rechargeable Li Ion battery
Battery Life	4 hours	48 hours (continuous) 96 hours (intermittent)	6 hours
Flow Rate	3.0 Lpm	0.5 Lpm	1.1 Lpm
Operational Temp	0 to 50 °C	-10 to 50 °C	--
Wireless Data Transfer	Yes	Yes	No

C.4 Odors

There is no current threshold for nuisance pollutants (e.g., odors), which, while possibly offensive, do not pose a health risk. The quantitative measurement of an odor is cumbersome due to the subjective nature and variability of odors. Currently, the most frequently adopted method is to obtain an air sample and present it to a panel of trained individuals. Current standards around odors (e.g., ASTM E679 and E544 or CEN:13725) focus on standardizing methods to deliver the odor to the panelist, and ensuring repeatable measurements. Field olfactometers exist[22] for measuring ambient odor dilution-to-threshold (D/T). Testing via odor panels or using field olfactometers such as the Nasal Ranger or Scentroid SM100 can provide a quantitative measurement of the dilution threshold. It may be possible to designate a dilution threshold as a design criteria, but this threshold would have to be determined beforehand. To improve the accuracy and repeatability of the method, one can use a standard chemical (n-butanol is commonly used) to calibrate panelists. The design criteria would mandate that odor produced by the technology would expose users to no greater than a certain dilution-to-threshold.

C.5 Emission Sampling Frequency

The sampling frequency for emission depends on the duty cycle of the source and existing regulations. If the source operates at a constant rate, once a month is recommended, otherwise more frequently.

Detection of potential air pollutants will be carried out as close to the source as possible with handheld instrument. Should secondary analysis be required air samples need to be collected for subsequent laboratory analysis. EPA Method TO-15 details the use of summa canisters or Tedlar bags for VOC sampling, which may be used to collect samples for VOC, CO, CH_4, and H_2 analysis. SO_2 and NO_x analysis may be performed via EPA Method 6 and Method 7, respectively. NH_3 may be sampled using EPA conditional test Method 27and H_2S according to Method 15.

D.1 Rationale for Sound Emission Testing

From an environmental prospective, noise is defined as “unwanted or disturbing sound.” Sound becomes unwanted when it either interferes with normal activities (e.g., sleeping and conversation) or disrupts or diminishes one’s quality of life (http://www.epa.gov/air/noise.html). Noise has also been shown to have deleterious effects on human health and the psychological well-being of people. Noise-generating sources are subject to regulations. For example, in India, noise pollution rules were published in 2000[19]. Thus, the sanitation technologies will be evaluated for noise- and vibration-generation level.

The limits to be considered depend on the placement of the technology (e.g., in the home, a residential area, or an industrial area) and will be evaluated on a case-by-case basis. An example of noise standards in India include a limit of 45 dB (A) Leq for a residential area at night time; also, the peripheral noise level at the boundary of the private place shall not be exceeded by more than 5 dB (A), the ambient noise standards specified for the area in which it is used. The units of sounds are “decibel.” “A” denotes the frequency weighting in the measurement of noise and corresponds to frequency response characteristics of the human ear. “Leq” is an energy mean of the noise level over a specified period of time.

D.2 Sound Measurement Approach

Sound level meters are devices that determine the acoustic intensity; they are commercially available, handheld devices designed for environmental monitoring and occupational health and safety monitoring. Some of the devices are sound- and vibration-level meters and include vibration measurements by recording acceleration, velocity, and displacement. Manufacturers names include Svantek, Venier, Brüel & Kjær, and Larson Davis. These commercial instruments provide calibrated readings of sound intensity according to the sounds level standards of the International Electrotechnical Commission (IEC) 61672:2002 and vibration standard ISO 10816-1.

The sound emission measurement will be carried out if qualitative assessment of the system or features of the technology warrant it. Sampling periods will include before and during the system operation, with a monthly frequency or an as-needed basis.

E. ENERGY v1.0

Energy in the form of electricity, heat, chemical potential, or other is a key parameter characterizing the performance of the sanitation technology and major factor in market adoption. An accurate accounting of the energy that goes into and comes out of the system is necessary in order to evaluate its performance.

Both the electrical energy consumed and produced should be quantified to provide a measure of the total of the energy (Joules or kW-hrs) associated with the operation the system, specifically

- **Electrical energy consumed (Joules or kW-hrs):** This includes any electrical energy consumed by the system, regardless of the source. The source can be a utility line connection, a battery, a solar panel, and others.
- **Electrical energy generated (Joules or kW-hrs):** This includes any electrical energy generated by mechanical motion, photovoltaic cells, thermoelectric energy harvesting, steam engines, and others.

If applicable, heat energy (Joules or kW-hrs) should also be measured. All heat that flows into the system (e.g., running heated air or burning natural gas) should be recorded, and all heat that flows out should be estimated.

E.1 Energy Measurements Sampling Frequency

The energy parameters should be recorded as the daily average for each day for the duration of the field testing. It is the responsibility of the TP to provide these figures to the STeP program and it is anticipated that these values are obtained by the control electronics of the system as a matter of standard operations.

F. OPERATIONAL PARAMETERS v1.0

Besides energy, other operational parameters defining the performance and burden of the system will be recorded including material throughput, maintenance requirements, additives, and system failures.

In order to have a frame of reference for the specific power use of a technology, the energy utilization, both consumption and production, needs to be normalized to the solid/liquid mass flows through the system.

Throughput measurements include the following:

1. Number of users (people per day): The number of people who use the toilet should be recorded or at least estimated
2. Quantity of waste processed (kg of waste or L): If the technology is a toilet system, the volume of toilet effluent (including human waste, flush water, and wash water) should be recorded daily. If the technology is for solid waste treatment, the total daily mass intake should be recorded.
    a. If the technology features energy production by either solid or liquid mass, the respective energy source should be quantified.
    b. If inorganic solids are a necessary input for system operation, their input should be measured as well. For mass balances, if the system produces any liquid or solid outputs for utilitarian applications, those should be measured and recorded as well.
3. If the technology includes a sink or other washing functionality or other functionality involving liquids or solids, those masses should be recorded as well.

Additives include the following:

- Any gas, liquid, or solid, particularly inorganic solid, required for operation of the technology and not included in the throughput measurements should be recorded and will be listed as an additive.
- Maintenance requirements, including labor to reset systems or empty containers and use of replacement parts such as water filters

System Failures

During field testing, downtime in which the system is not in operation as intended will be measured in hours. Down time due to external causes such as lack of electrical grid power in a systems that depends on it will be separately recorded. The number of individual events causing downtime should also be recorded and used as the basis to generate standard performance parameters such as mean time between failures and average down time.

F.1 Operational Parameters Sampling Frequency

Daily average values should be obtained for mass throughput parameters.

The STeP program will be responsible for determining the number of users of the technology (e.g., through monitoring by support personnel and survey) and will support maintenance activities and manual readings of meters where needed. To the extent possible, throughput measurements and operations event should be recorded with appropriate solutions incorporated in the system.

S.1 Source for Liquid Limits

The tables S1, S2 and S3 list the page number in the source document from which the values in table A.1 were obtained from.

Table S1.1 Source Page and Document from India Values in Table A1

		India Inland Surface Water Discharge			India Irrigation		
#	Parameter	Document	Page #	Notes	Document	Page #	Notes
1	pH	India 1	545	Column (a)	India 1	545	Column(c)
2	Electrical conductivity	—	—	—	India 2		Class E
3	Total suspended solid (TSS) (mg/L)	India 1	545	Column (a)	India 1	545	Column(c)
4	Turbidity (NTU)	India 1	546	Column (a)	—	—	—
5	COD (mg/L)	India 1	546	Column (a)	—	—	—
6	BOD5	—	—	—	India 1	546	Column (c)
7	Colour (hazen)	India 1	448	Column (a)	India 3	19	Class B
8	Total chlorine (mg/L)	India 1	546	Column (a)	—	—	—
9	Total Kjeldahl nitrogen (mg/L)	—	—	—	—	—	—
10	Phosphorus (mg/L)	India 1	448	Column (a)	—	—	—
11	Chloride (mg/L)	India 1	546	Column (a)	India 1	448	column (b)
12	Nitrogen, ammonia (mg/L)	India 1	546	Column (a)	—	—	—
13	Free ammonia (mg/L)	India 1	546	Column (a)	—	—	—
Biological parameters					—	—	—
14	Bacterial indicators	India 1	501	Table 1	—	—	—
15	Helminth eggs	—	—	—	—	—	—

India 1 The Environmental (Protection) Rules, 1986 [2]

India 2 http://www.cpcb.nic.in/Water_Quality_Criteria.php

India 3 Tamil Nadu standards TNPCB & You [8]

Table S1.2	Source Page and Document from WHO Values in Table A1		
		WHO	
# Parameter	Document	Page #	Notes
1 pH	WHO 1	120	Table 8.1
2 Electrical conductivity	WHO 1	116	Table 8.1
3 Total suspended solid (TSS) (mg/L)	WHO 1	119	Table 8.1
4 Turbidity (NTU)	—	—	—
5 COD (mg/L)	—	—	—
6 BOD5	WHO 1	116	Table 8.1, Organic matter
7 Colour (hazen)	—	—	—
8 Total chlorine (mg/L)	WHO 1	178	Table A1.1, slight to moderate
9 Total Kjeldahl nitrogen (mg/L)	WHO 1	115	Table 8.1
10 Phosphorus (mg/L)	WHO 1	115	Table 8.1
11 Chloride (mg/L)	WHO 1	7 [117]	Table 9 [Table 8.1]
12 Nitrogen, ammonia (mg/L)			
13 Free ammonia (mg/L)	—	—	—
Biological parameters	—	—	—
14 Bacterial indicators	WHO 2	55	Table 5.1
15 Helminth eggs	WHO 2	55	Table 5.1
	WHO 1	120	Table 8.1

WHO 1 Volume 2 Guidelines for the safe use of wastewater, excreta, and greywater[3]

WHO 2 Volume 1 Guidelines for the safe use of wastewater, excreta, and greywater[4]

Table S1.3	Source Page and Document from EPA Values in Table A1					
	EPA Water Reuse			EPA Urban Water Reuse		
# Parameter	**Document**	**Page #**	**Notes**	**Document**	**Page #**	**Notes**
1 pH	EPA	page 4-9	Table 4.4	EPA	page 4-9	Table 4.4, Unrestricted
2 Electrical conductivity	EPA	page 3-7	Table 3.4	—	—	—
3 Total suspended solid (TSS) (mg/L)	EPA	page 4-28	Table 4.9, Florida, NJ, NC	EPA	page 4-26	Table 4.7, Fl, Hawaii, Nevada, NC, WA
4 Turbidity (NTU)	EPA	page 4-9	Table 4.4, food crops	EPA	page 4-9	Table 4.4, Unrestricted
5 COD (mg/L)	—	—	—	—	—	—
6 BOD5	EPA	page 4-9	Table 4.4, food crops	EPA	page 4-9	Table 4.4, Unrestricted
7 Colour (hazen)	—	—	—	—	—	—
8 Total chlorine (mg/L)	EPA	page 4-9	Table 4.4, food crops	EPA	page 4-9	Table 4.4, Unrestricted
9 Total Kjeldahl nitrogen (mg/L)	EPA	page 4-32	Table 4-13, Nutrients, Florida	—	—	—
10 Phosphorus (mg/L)	EPA	page 4-32	Table 4-13, Nutrients, Florida	—	—	—
11 Chloride (mg/L)	EPA	Appendix D-64	Table 1, Denver	—	—	—
12 Nitrogen, ammonia (mg/L)	EPA	page 4-32	Table 4-13, Florida, North Carolina	—	—	—
13 Free ammonia (mg/L)	EPA	page 4-28	Table 4.9, Other, North Carolina	—	—	—
Biological parameters						
14 Bacterial indicators	EPA	page 4-9	Table 4-4, food crops	EPA	page 4-9	Table 4-4, Unrestricted
15 Helminth eggs	—	—	—	—	—	—
	EPA	page 4-9	Table 4.4			

S.2 Liquid Test Details

Test 1 – pH and Test 2 – Electrical Conductivity

Significance: pH is listed in most regulations for water reuse. Electrical conductivity is an integrated measurement of the salinity of the solution.

Time for measurements: 10 minutes each

Preferred measurements: pH meter (typically 20 mL volume is requires) and conductivity meter (typically 5–20 mL volume needed)

Test 3 – Total Solids (TS), TSS, and TVS

Definition of parameter: TS = TSS + total dissolved solids (TDS). TSS includes silt and clay particles, plankton, algae, fine organic debris, and other particulate matter. These are particles that will not pass through a 2 µm filter. TDS pass through the filter. TVS are obtained by exposing the sample to high temperatures to measure the organic content.

Significance: Total solids is the measurement of weight of the particulates in a solution. Total solids affect water clarity and high concentration of suspended solids can serve as carriers of toxics and pathogens, which readily attach to suspended particles. The suspended solids then act as a shield helping to prevent disinfection. The selection of TS, TSS, TDS, or TVS measurements to report on for evaluation will depend on the technology and properties of the treated liquid. If the liquid turbid appearance is determined by particles smaller than 2 µm, for example, TSS is a small value, but TS may be more a more informative parameter to track.

Time for measurements: 2 hours

Preferred measurements:

- TS are measured by weighing the amount of solids present in a known volume of sample. This is done by weighing a beaker, filling it with a known volume, evaporating the water in an oven, completely drying the residue, and then weighing the beaker with the residue.
- TSS is measured using 7 mL/cm^2 of filter area, passing a well-mixed sample through a glass fiber filter (according to EPA 160.2), and drying the residue at 103°C –105°C.
    - The sample must provide at least 1.0 mg of residue.

- TDS and TVS can be determined by collecting the filtrate and exposing it to a temperature of 550°C. The lost weight represents the volatile portion, and the remaining material is the dissolved portion.

Preferred methods: TSS EPA 160.2 instrument glass fiber filter, drying oven, applicable range of 4–20,000 mg/L

Interferences: Samples high in dissolved solids can cause positive interference.

Test 4 – Turbidity

Definition of parameter: Turbidity is the cloudiness or haziness of a fluid, the measure of water clarity. It quantifies how much material is suspended in the water by measuring the amount of light that is scattered from the sample. It is reported in nephelometric turbidity units (NTU) when a white light source is used and formazin nephelometric units (FNU) when an infrared light source is used.

Significance: Turbidity is a measure similar to TSS that quickly but indirectly determines the suspended microparticles in water. Contaminates such as bacteria and viruses can attach to suspended solids. The suspended solids then act as a shield helping to prevent disinfection. High turbidity levels can reduce the amount of light reaching lower depths in lakes, rivers, and reservoirs, inhibiting the growth of aquatic plants and the species dependent on them.

Time for measurements: 10 minutes

Preferred measurements: The concentration of suspended particles in a sample of water is determined by measuring the incident light scattered at right angles from the sample, reported in NTU or FNU.

Preferred methods: EPA and WHO both require reporting in FNU or NTU 180.1 nephelometric turbidity (other methods are 2130B, GLI2). The instrument is a turbidity meter (online and bench top). The applicable range is 0–40 NTU, and the volume required is meter dependent, typically ~25 ml.

Calibration measures: Primary (initial meter calibration) and secondary (daily calibration) standard suspensions using formazin polymer (standard solution)

Interferences:

- Low readings: rapidly settling particles, presence of true color, and light-absorbing materials
- High readings: finely divided air bubbles

Test 5 – COD

Definition: COD is the capacity of water to consume oxygen during the decomposition of organic (carbon-containing) compounds and oxidation of nonorganic compounds in the sample. COD is reported as mg/L of solution. Nearly all organic compounds can be fully oxidized to carbon dioxide with a strong oxidizing agent under acidic conditions.

Significance: COD decreases the amount of dissolved oxygen available for aquatic organisms, creating dead zones and increasing the threat of toxic algae blooms.

Time for measurements: 2 hours

Preferred measurements:

- A 50 mL sample in potassium dichromate in 50% sulfuric acid solution at reflux temperature is used to oxidize compounds. Silver sulfate is used as a catalyst, and mercuric sulfate can be added to remove chloride interference. Excess dichromate is titrated with standard ferrous ammonium sulfate using orthophenanthroline ferrous complex as an indicator.

Preferred methods:

- EPA 410.1 (mid-level), 410.2 (low-level), titrimetric, applicable range is 5–50 mg/L for low-level, and >50 mg/L for mid-level volume required ~50 mL, instrument reflux apparatus
- EPA 410.4 colorimetric—applicable range 3–900 mg/L, 2.5 mL volume, spectrophotometer, standard solutions needed

Interferences:

- Trace organic material from glassware or atmosphere can cause a positive error.
- Chlorides are oxidized by the dichromate to give high readings.

Test 6 – BOD

Definition of parameter: BOD is the amount of dissolved oxygen needed by aerobic biological organisms to break down constituents in an aqueous solution at a certain temperature.

Significance: BOD is more specific than COD. BOD is the amount of oxygen consumed by bacteria in the decomposition of material. It also includes the oxygen required for the oxidation of various chemicals in the water (e.g. sulfides, ferrous iron, and ammonia). While a dissolved oxygen test reveals how much oxygen is available, a BOD test tells reveals how much oxygen is being consumed.

BOD is determined by measuring the dissolved oxygen level in a freshly collected sample and comparing it to the dissolved oxygen level in a sample that was collected at the same time but incubated under specific conditions for a certain number of days. The difference in the oxygen readings between the two samples in the BOD is recorded in units of mg/L.

Time for measurements: 5 days

Preferred measurements:

- An empirical bioassay-type procedure measuring dissolved oxygen consumed by microbial life and oxidizing organic material present; oxygen membrane probe (360.1) or Winkler (360.2) methods
- The dissolved oxygen (DO) content of a 300 mL sample is measured at collection and then again after 5 days of incubation at 20°C in an airtight glass container.
  - The initial DO concentration must be at least 7.5 mg/L.
  - The DO residual at day 5 must be at least 1.0 mg/L and have had a consumption of at least 2 mg/L.
- The standard method (method 5210.B in the "Standard Measures"[20] recommends to seed samples with microorganisms if the initial population is not sufficiently high. We recommends to carry out this measurement without adding any pathogen to obtain figures that address the legal limit regulations.

Preferred methods: EPA 405.1 probe method (references EPA methods 360.1), 5 days at 20°C, instrument dissolved oxygen membrane probe (other methods are Modified Winkler 360.2 and EPA 5210B); note that the Indian standard is 3 days at 27°C.

Interferences:

a. Sulfite, thiosulfate, polythionate, mercaptans, free chlorine, hypochlorite, organic compounds hydrolyzed in alkaline solutions, free iodine, and intense color or turbidity (Winkler method only)
   i. Membrane electrodes provide an excellent method for DO analysis in polluted waters, highly colored waters, and strong waste effluents.
   ii. Na_2SO_3 can remove chlorine interference.

Test 7 – Color

Definition of parameter: APHA/platinum-cobalt (Pt-Co)/hazen color is used as a metric for purity in the water, chemical, oil, plastics, and pharmaceutical industries. This scale serves to quantify the appearance of trace amounts of yellowness. It is also called Pt-Co color, as this visual color scale is based on stable liquid color standards made from chloroplatinate solutions.

Significance: Consumers may not use water that is visually unpleasing.

Time for measurements: 5–10 minutes

Preferred measurements:

- Color is measured visually by comparison of the sample with Pt-Co standards.
  - 1 mg/L platinum = 1 unit of color
  - If turbidity has not been removed, it should be reported as apparent color.
  - If a sample has been centrifuged to remove turbidity, it should be reported as true color.
  - The scale ranges from distilled water at 0 (“water-white”) to a stock solution of 500 (parts per million of Pt-Co to water).

Preferred methods: 110.2 colorimetric Pt-Co (other methods: EPA 110.1 colorimetric American Dye Manufacturers Institute (ADMI) [nonyellow waters], 110.3 spectrophotometric) Nessler tubes, 50 mL, 0–500 units

Interferences:

- Turbidity
- pH dependent

Test 8 – Total Chlorine

Definition of parameter: Total chlorine is the chlorine concentration remaining after the chlorine demand of any organics has been met. It is the sum of the amount of the combined chlorine (that which has reacted with nitrates, chloramine which is a weak disinfectant, and others) and free chlorine (the chlorine available for disinfection, Cl2, hypochlorite ion OCL-, hypochlorous acid HOC). It is always higher than or equal to free chlorine and is also called total residual chlorine. It is reported as mg/L Cl or ppm.

Significance: Total chlorine causes leaf burn and can be toxic to aquatic life. It can form carcinogens in reactions with organics in the water.

Time for measurements: 5 minutes

Preferred measurement: Colorimetric method

- Chlorine and chloramines liberate iodine at pH 4 or less.
- Liberated iodine reacts with dissolved phase diluent (DPD) to produce a red-colored solution that is read at 515 nm.

Preferred methods: EPA 330.5 (other methods: EPA 330.1, 330.2, 330.3, 330.4; may be more convenient for high concentrations titrimetric methods are applicable in a range of >0.1 mg/L), 10 mL sample, 0.2–4 mg/L applicable range, instrument spectrophotometer 515 nm

Interferences:

- Any oxidizing agents
- High turbidity

Test 9 – Total Kjeldahl Nitrogen (TKN)

Definition of parameter: TKN is a combination of organically bound nitrogen and ammonia in wastewater (sum of organic nitrogen, ammonia, and ammonium). Note that total nitrogen is obtained by adding TKN to (nitrate, nitrite).

Significance: TKN is an essential nutrient for plants and animals, but excess in waterways can lead to low levels of dissolved oxygen negatively impacting aquatic life.

Time for measurements: 2.5+ hours

Preferred measurements: Bound organic nitrogen is released from organic matter by digestion with sulfuric acid.

- The sample is added to a digestor tube with 5 mL of digestion solution and digested at 160°C for 1 hour then 380°C for 1.5 hours.
- The residue is cooled, diluted, and made alkaline.
- The ammonia is distilled and quantified by nesslerization, titration, or potentiometry.

Preferred methods: 351.3 total Kjedhal nitrogen distillation or 351.4 block digestion potentiometric (other methods EPA 351.1, 351.2) digestion apparatus, distillation apparatus, spectrophotometer; applicable range depends on the alternative chosen within method 351.3 (titrimetic >1 mg/L, nesslerization < 1 mg/L, potentiometric 0.05–1,400 mg/L) 25–500 mL sample size based on content

Interferences: High nitrate concentrations

Test 10 – Phosphorus

Definition of parameter: Total phosphorus is a measure of the three different forms of phosphorus: orthophosphate also called reactive phosphorus (phosphate molecule), condensed phosphates or polyphosphates (complex inorganic phosphate compounds including ATP), and inorganic phosphate (such as inorganic salts). Phosphorus is measured in urine as total phosphorus with about 1/3 of total phosphorus being inorganic phosphorus. It is reported as mg P/L.

Significance: Low phosphate levels are an important limit to growth in some aquatic systems. The vast majority of phosphorus compounds are consumed as fertilizers. Phosphate is needed to replace the phosphorus that plants remove from the soil.

Time for measurements: 2 hours

Measurement (s):

- Ammonium molybdate and antimony potassium tartrate are reacted in the presence of phosphorus.
- The blue color of the produced complex is proportional to the phosphorus concentration.

Preferred methods: Total Phosphorus EPA 365.2 or 365.3 (other methods EPA 365.1, 365.4, 365.5), 50 mL sample, 0.01–0.5 mg/L applicable range, instrument spectrophotometer 650 nm or 880 nm. The preferred method provides subsections for measuring the individual forms of phosphorus, if desired.

Interferences: Iron may cause precipitation

Test 11 – Chloride

Definition of parameter: Chloride CL- is an essential electrolyte for maintaining body fluids acid/base balance. Limits for water reuse are 600 mg/mL and 1,000 mg/mL, and urine content is anywhere between 1,800 mg/mL and 8,400 mg/mL.

Significance: Chloride is corrosive to metals.

Time for measurements: 10 minutes (depending on time it takes to titrate)

Preferred measurements: An acidified sample (50 mL, but not exceeding 20 mg of chloride, to avoid large titration volumes) is titrated with mercuric nitrate in the presence of a blue indicator. The formation of a blue-violet complex is the endpoint.

Preferred methods: EPA 325.3 titrimetric mercuric nitrate blue indicator or 9253 titrimetric silver nitrate orange indicator (other methods EPA 325.1, 325.2), 50 mL sample, applicable for all concentration ranges, titration

Interferences: Sulfate

Test 12 – Ammonical Nitrogen

Definition of parameter: Ammonium is an ionized form of ammonia. The chemical structure for ammonium is NH_4^+. The chemical structure for ammonia is NH3. It is reported as mg/L.

Significance: A measure of NH_3 + NH_4^+. Ammonia is a toxic pollutant that can be poisonous to humans and aquatic life.

Time for measurements: 1 hour

Preferred measurements:

- A 400 mL sample is distillated.
- A 100 mL sample of distillate is buffered at a pH of 9.5 and then distilled.
- Ammonia in distillate is determined colorimetrically, titrimetrically, or potentiometrically.

Preferred methods: EPA 350.2 (other methods EPA 350.1, 350.3), 400 mL sample, applicable range 0.05-1 mg/L colorimetric, 1-25 mg/L titrimetric, 0.05-1400 mg/L electrode method and Instrument Spectrophotometer 650 or 880 nm.

Interferences:

- Amines
- Cyante
- Residual chlorine—removed with sodium thiosulfate

Test 13 – Free Ammonia

Definition of parameter: Free ammonia is a measure of NH_3 only—this is the toxic form. It is reported as mg/L.

Significance: Free ammonia is the toxic form. We measure it separately from parameter 12, nitrogen ammonia, because Indian discharge standards list them separately.

Preferred methods: EPA 4500-NH3 B and EPA 4500-NH3 D 400 mL sample, applicable, 0.05–1,400 mg/L electrode method; other methods: EPA 4500-NH3 C, 4500-NH3 E, 4500-NH3 F, 4500-NH3 G, 4500-NH3 H

Preferred measurements: The difference from ammonical nitrogen is the pH at which the test is conducted.

- A 400 mL sample is distillated.
- A 100 mL sample is buffered at a pH of 11. The reading is recorded using an ammonia selective electrode and compared to the standard curve.

Time for measurements: 10 minutes

Interferences:

- Amines
- Urea
- Residual chlorine—removed with sodium thiosulfate

Test 14 – Bacterial Tests

Definition of parameter: Total coliform bacteria are rod-shaped, gram-negative bacteria that ferment lactose at 35°C. Thermotolerant coliforms are a group of coliform bacteria that produce gas from lactose in 48 hours at 44.5°C. E. coli is a species of thermotolerant coliform, present in fecal flora of warm-blooded animals.

Significance: The detection of these three coliform bacteria are considered established indicators for the presence of other more difficult to detect pathogenic organisms.

Time for measurements: 24–48 hours; 24 hours for colilert and 48 hours for Petrifilm

Recommended methods: multiple standard methods exist and are acceptable for coliform enumeration and include

1. MPN
2. Membrane filtration
3. Agar plate

Notwithstanding which method is used, we recommend to test a positive and negative control together with the liquid sample, specifically a clean water sample and a raw wastewater sample. If the tests are conducted weekly or more frequently, control samples should be run at least with the first sample and monthly after that.

For each of these methods, selective reagents are used to obtain E.coli and total coliform, even simultaneously, while for thermotolerant coliform assay require an additional specific conditions, incubation at the temperature of 44.5 C, different from the standard 37C incubator temperature.

1. The MPN detection method utilizes multiple tubes, selective or enzymatic media, to estimate the target organism density by using a most probable number table (Standard method 9221 and 9223). Most probable number is an estimate of the mean density of coliforms in the sample. Precision is based on the number of tubes used. Typically done in 5 or 10 tube trials
    - A predetermined volume of sample is added to a glass tube containing selective, enzymatic, or predispensed colilert reagent.
    - Incubate at 37°C for 24 hours.
    - Positive for total coliforms when acid, gas, or yellow color is present depending on method used (9221B, 9223B)
    - Positive for E. coli when yellow color and fluorescence using 365 nm UV light are present
    - Results are read from a 5 or 10 tube MPN chart.

Commercial predispensed reagent from colilert are available for this assay

2. In the membrane filtration method a sample or dilution is filtered through a membrane that retains the bacteria found in the sample (Standard method 9222). The filter is then placed in a petri dish on an absorbent pad containing selective media for the desired organism. The filter containing petri dish is then incubated for 24 hours at a specific temperature. After incubation colonies are counted and reported as CFU. Commercial reagent exists, m m-ColiBlue24, for simultaneous determination of E.coli and total coliform, according to 9222H.
3. The agar culture method is described in Standard Method 9212. Colonies are identified and counted. Reported as CFU.
    - the sample is incubated at 37°C for 24–48 hours.
    - Positive for E. coli, total, or fecal coliform is based on the presence of colored colonies and associated air bubbles.
    - Fecal are determine by the presence of colored colonies and air bubbles after incubation at 44.5 °C

Commercial products like Petrifilm (6404, 6410, 6414) provide pre-dispensed dehydrated gel for use. While not an APHA standard method, it is in agreement with standard AOAC 991.14.

Interferences:

- Heterotrophic bacteria if the assay is read after the time designated by the assay
- High turbidity
- High chlorine content

Test 15 – Helminth Egg Detection

The isolation and enumeration procedure developed by UKZ-N is recommended and will be updated with the standard operating procedure developed from 2015 Durban workshop. A pdf is available from the STeP program. A large volume of 5 to 10 liters is needed, so that a limit of 1 egg/liter corresponds to 5–10 eggs to be counted using the enumeration method.

Definition of parameters: Eggs of Ascarius, Trichuris, and all other species

Test volume: 5–10 liters

Time for measurements: ~1–2 days of work

Preferred measurements: Sieving, sedimentation, floatation, and enumeration

- Sieve with 20 and 100 um, use $ZnSo_4$ flotation
- On microscope slide and enumerate

Interferences: This method requires expert personnel because of the microscopic recognition of eggs (from background of dirt).

Test 16 – Free Chlorine

Definition of parameter: The chlorine available for disinfection, Cl_2, HOCl, OCL is reported as mg/L or ppm.

Significance: Free chlorine deactivates disease-causing microorganisms and provides residual disinfection during storage and transport.

Time for measurements: 5 minutes

Preferred measurements: Colorimetric

- The sample is added to DPD buffer in the absence of iodine.
- The reaction produces a red/pink color that is read at 515 nm.

Preferred methods: EPA 4500-Cl G (other methods EPA 4500-Cl B, 4500-Cl C, 4500-Cl D, 4500-Cl E, 4500-Cl-f), 10 mL sample, 0.2–4 mg/L applicable range, instrument spectrophotometer 515 nm

Interferences:

- Color and turbidity—use effluent as blank
- Chromate—add thioacetamide

Test 17 – Alkalinity ($CaCO_3$ Equivalent)

Definition of parameter: Alkalinity is the capacity of an aqueous solution to neutralize an acid. The alkalinity of water is due primarily to the presence of bicarbonate, carbonate, and hydroxide ions, reported as mg/L $CaCO_3$.

Significance: Alkalinity determines a body of water's ability to neutralize acidic pollution. In wastewater treatment, alkalinity is an important parameter in determining the amenability of liquid waste to the treatment process.

Time for measurements: 10 minutes (depending on the time it takes to titrate)

Preferred measurements: A 50 mL unaltered sample is titrated to an electrometrically determined endpoint of pH 4.5.

Preferred methods: EPA 310.1 titrimetric pH 4.5, 20 mL sample, applicable for all concentration ranges, titration apparatus

Interferences: Salts of weak organic and inorganic acids

S.3 Data Source for Solid Waste Chapter

Table S3.1 Physicochemical Parameters of Solid Products of Waste Processing Technologies (Source pages)

Parameter	Biosolids[12]	Biochar/Hydrochar[12]	Ash[14]
1. pH	Pg 94	Pg 13	pg 21500
2. Electrical conductivity		Pg 13	
3. Moisture content	Pg 310	Pg 13	pg 21386
4. Ash %		Pg 13	
5. Particle size distribution			
TS	Pg 310		
6. TDS			pg 21500
7. TVS		Pg 16	
TS	Pg 310		
8. Phosphorus		Pg 16	
9. TOC		Pg 13	
10. Total carbon		Pg 13	
11. Total nitrogen	Pg 286	Pg 13	
12. Nitrate/Nitrite	Pg 193	Pg 16	
Pathogens			
13. Fecal coliform	Pg 305	none	none
14. Helminth eggs	Pg 307	none	none
Toxicant			
15. PAH	-	Pg 15	-

With regard to metal limits in table B.2.

Table S3.2	Metals of concern for Solid Products of Waste Processing Technologies (Source pages)		
Parameter	**Biosolids**	**Biochar/Hydrochar**	**Ash**
1. Arsenic	Pg 288	Pg 15	pg 21500
2. Boron		Pg 15	pg 21500
3. Cadmium	Pg 288	Pg 15	pg 21500
4. Calcium			pg 21500
5. Chromium	Pg 288	Pg 15	pg 21500
6. Cobalt		Pg 15	pg 21500
7. Copper	Pg 288	Pg 15	
8. Mercury	Pg 288	Pg 15	pg 21500
9. Lead	Pg 288	Pg 15	pg 21500
10. Molybdenum	Pg 288	Pg 15	pg 21500
11. Nickel	Pg 288	Pg 15	
12. Selenium	Pg 288	Pg 15	pg 21500
13. Zinc	Pg 288	Pg 15	

Biosolids

40 CFR Part 257 et al, Standards for the use and disposal of sewage sludge, final rules

Pg 288 Table 1 of Section 503.130 Ceiling concentrations

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