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MINISTRY OF HEALTH - ETHIOPIA

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HEALTHIER CITIZENS FOR PROSPEROUS NATION

Africa CDC Regional Investment Financing Project (P167916)

Addendum 01

to the Environmental and Social Impact Assessment (ESIA) Report for BSL 3 National Reference Laboratory Complex (Updated, 2023)

National Reference Laboratory (NRL) with BSL-3 Containment Complex Waste Management Alternative Analysis Report

January, 2026

Addis Ababa, Ethiopia

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Executive summary

The document presents an in-depth analysis and updated Environmental and Social Impact Assessment (ESIA) addendum for the National Reference Laboratory (NRL) with a BSL-3 Containment Complex in Addis Ababa, Ethiopia. It focuses primarily on waste management alternatives, detailing the characteristics of waste generated and evaluating technical options for both wastewater and solid waste treatment to ensure biosafety, environmental compliance, and operational feasibility within an urban setting.

The NRL complex, part of the Africa CDC Regional Investment Financing Project, is designed to enhance Ethiopia's public health laboratory capacity. It includes multiple BSL-2 laboratories and a dedicated BSL-3 containment suite, occupying about 1.6% of the total 11,919.6 m² facility area at the Ethiopian Public Health Institute (EPHI) campus. The project site benefits from road access on all sides and has undergone an initial ESIA with updates approved by the World Bank and Ethiopian Environmental Protection Authority.

The analysis categorizes healthcare waste according to Ethiopia's 2021 National Guideline into nine classes, highlighting that the NRL generates a mix of hazardous, infectious, and non-hazardous solid and liquid wastes. Estimated daily waste volumes are detailed by laboratory type, including infectious liquids, chemicals, sharps, pathological waste, and sanitary waste.

Waste from BSL-3 operations includes infectious cultures, sharps, chemical wastes, and sanitary effluents, all requiring stringent handling. EPHI laboratories follow biosafety protocols, have accredited quality management systems, and implement autoclaving or chemical disinfection for biological waste. Staff receive biosafety training and vaccinations appropriate to their risk group.

The report evaluated four main wastewater management options, emphasizing the need for pathogen inactivation, environmental protection, and operational safety: including Onsite Wastewater Treatment Plant (WWTP) involving (1) constructing a dedicated WWTP within the EPHI compound using advanced processes such as membrane bioreactors (MBR), ozone dosing, and granular activated carbon filters. It requires significant space, power, and operational expertise. While providing high effluent quality, it is considered overdesigned for the NRL's volume and carries high costs (2) constructing Septic Tank with Municipal Sewer Connection before discharge into the municipal sewer system (3) with a hybrid model combines onsite primary treatment with transport of waste to offsite facilities, including a planned specialized treatment plant by EFDA and MoH for hazardous waste (4) on Sink-Level Decontamination and Centralized Thermal Treatment focusing on inactivating infectious liquid waste at the source using chemical disinfectants or autoclaving within the BSL-3 containment zone. The decision matrix rates Alternative 4 highest (19/20) for biosafety, environmental impact, and local acceptability, recommending it as the core wastewater management strategy, supplemented by Alternative 2 for non-hazardous effluent.

On the Solid Waste Management Alternatives, four solid waste treatment technologies are analyzed including Alternative 1: Incineration with Stabilization and Solidification, Alternative 2 with Ecosteryl Technology; Alternative 3: with Recycling and Recovery; and Alternative 4 on properly engineered. The

report recommends a multi-faceted solid waste approach emphasizing Ecosteryl for infectious waste treatment, recycling for non-hazardous waste, and controlled disposal at Repi Landfill under strict operational standards. Pyrolytic incineration serves as a backup option.

Thus, for wastewater, thermal inactivation within the BSL-3 containment and multi-stage onsite pre-treatment ensure safe discharge. For solid waste, Ecosteryl technology combined with recycling and landfill disposal addresses environmental and biosafety concerns effectively. This integrated approach complies with World Bank, WHO, and Ethiopian EPA guidelines, enhances biosafety, and supports sustainable public health infrastructure development. This comprehensive waste management framework ensures biosafety, environmental protection, and operational sustainability for the NRL with BSL-3 Containment Complex in Ethiopia.

1. Introduction

Under the Africa CDC Regional Investment Financing Project (ACDCP) in Ethiopia, a critical initiative involves the construction and establishment of a National Reference Laboratory (NRL) with a Bio-Safety Level 3 (BSL-3) containment complex. This pivotal project aims to significantly enhance Ethiopia's capacity for essential public health functions. The NRL complex will house various reference laboratories and specialized rooms, equipped with modern, high-tech equipment for advanced clinical diagnostics, analytical testing, public health investigations, and cutting-edge scientific research. While most laboratories within the complex will operate at Bio-Safety Level 2 (BSL-2), a dedicated facility area is specifically designed for BSL-3 operations, ensuring the highest safety standards for handling hazardous biological agents.

The proposed NRL project is strategically located within the existing premises of the Ethiopian Public Health Institute (EPHI) in Gullele Sub City, Woreda 09, on Swaziland Street. The NRL has cover 11,919.6 square meters floor area. The BSL-3 complex will occupy a comparatively small footprint, typically less than 1.60% of the total NRL floor area. It will be comprised of two BSL-3 suits laboratories (8 operators) and their associated support rooms (anterooms, preparation rooms, changing rooms, shower area, materials in/out areas, dedicated autoclave room). This limited size is standard for national reference facilities, which focus on low-volume, high-risk work rather than high-throughput processing. The site benefits from access roads bordering it from all directions. A comprehensive Environmental and Social Impact Assessment (ESIA) for this complex was initially conducted and subsequently updated in June 2023, received full approval from both the World Bank and the Ethiopian Environmental Protection Authority.

The updated ESIA provided specific recommendations for waste management. For hazardous wastewater, it initially recommended on-site storage in a separate safety tank, followed by off-site treatment. To facilitate this, the Ministry of Health had agreed to construct a dedicated wastewater treatment plant (WWTP) as part of the Ethiopian COVID-19 Emergency Response Project, which was to be located at the EFDA Vaccine Laboratory Site. This decision was largely influenced by space constraints at EPHI. Furthermore, for solid waste management, the ESIA recommended the installation of pyrolytic incinerator technology with a 100 kg/hr capacity and a 12-meter chimney height, designed to meet national environmental standards.

However, recent considerations regarding the practicality of available technologies and the significant logistical challenges of transporting infectious waste have emerged. The approximately 25-kilometer distance from EPHI (located in the central part of Addis Ababa) to the EFDA Vaccine Laboratory Site (situated south of Addis Ababa), traversing through a densely populated and crowded urban environment, has raised substantial concerns. These issues necessitate a comprehensive re-evaluation and active consideration of alternative waste management options that can more effectively address the aforementioned logistical and environmental impacts.

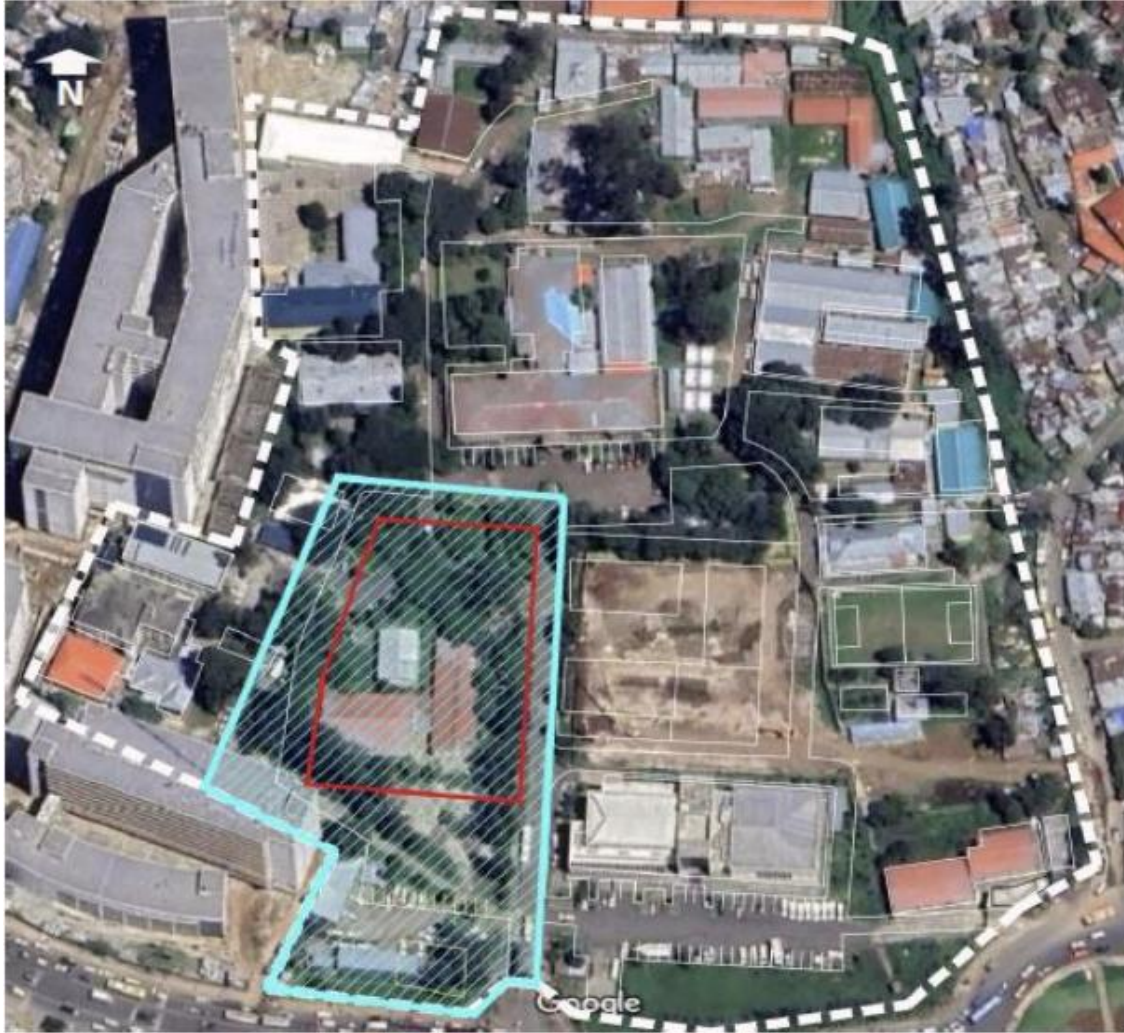


Figure 1: Geographical Overview and Proposed Project Footprint within the EPHI Campus

2. Waste Characteristics and EPHI Waste Management Practices

The Ethiopia Healthcare Waste Management National Guideline 2021 categories HCW into nine classes [(Non-Hazardous Waste (Class 1), Clinical Waste (Class 2), Sharps (Class 3), Pathological and Anatomical Wastes (Class 4), Hazardous pharmaceutical and cytotoxic waste (Class 5), Highly Infectious Wastes (Class 6), Radioactive Wastes (Class 7), Waste with high contents of heavy metals (Class 8), and Effluents (Class 9)] (FMoH 2021).

It is well known that during the operation of these laboratories, solid and liquid waste includes hazardous, infectious and non-hazardous waste.

2.1. Estimated Waste Generation from the NRL

The estimated wastes generated from the existing EPHI laboratories are summarized below in Table 1.

Table 1: Estimated waste generated from the NRL with estimated average quantity, type and source

NRL Department	Level Lab (BSL-1/BSL-2/BSL-3)	Liquid Waste Quantity - Infectious - Volume per day (L/D)	Liquid Waste Quantity - Chemical - Volume per day (L/D)	Liquid Waste Quantity - sanitary - Volume per day (L/D)	Solid Waste Quantity - Infectious waste -weight per day (Kg/D)	Solid Waste Quantity - Pathological waste -weight per day (Kg/D)	Solid Waste Quantity - Sharps -weight per day (Kg/D)	Solid Waste Quantity - Not Infectious -weight per day (Kg/D)	SOLID WASTE EMPTY CHEMICAL CONTAINERS weight per day (Kg/D)	Waste Quantity - Animal Waste -weight per day (Kg/D)
Insectarium	BSL2	40	2	600	20	30	0.5	5	2	0.1
Clinical Chemistry laboratory	BSL2	250	10	900	20	40	0.5	5	2	NA
Immunology/hematology laboratory	BSL2	30	15	600	20	10	0.5	5	5	NA
Quality Control & Method Validation Laboratory	BSL2	20	4	240	10	4	0.5	2	4	NA
New Technology Assessment & Evaluation Laboratory,	BSL2	15	3	240	12	2	1	3	3	NA
Anti-doping Laboratory	BSL2	10	3	180	10	10	0.5	1	0.5	NA
Biological DNA paternity testing laboratory	BSL2	3	2	180	5	1	0.2	1	0.3	NA
Food Science & Nutrition Environmental Health (Chemistry)	BSL2	5	10	420	5	10	0.5	5	1	NA
National Genomic Center	BSL2	25	3	240	15	10	0.5	1	0.5	NA
Pathology Reference Laboratory	BSL2	15	10	240	15	15	1	1	1	NA
Food Science & Nutrition Chemistry	BSL2	10	10	900	10	10	0.5	10	5	NA
Food Science & Nutrition Food Microbiology & Food Safety Research	BSL2	5	8	480	20	15	1.5	5	2.5	NA

National Reference Laboratory (NRL) with BSL-3 Containment Complex Waste Management Alternative Analysis Report

NRL Department	Level Lab (BSL-1/BSL-2/BSL-3)	Liquid Waste Quantity - Infectious - Volume per day (L/D)	Liquid Waste Quantity - Chemical - Volume per day (L/D)	Liquid Waste Quantity - sanitary - Volume per day (L/D)	Solid Waste Quantity - Infectious waste -weight per day (Kg/D)	Solid Waste Quantity - Pathological waste -weight per day (Kg/D)	Solid Waste Quantity - Sharps -weight per day (Kg/D)	Solid Waste Quantity - Not Infectious -weight per day (Kg/D)	SOLID WASTE EMPTY CHEMICAL CONTAINERS weight per day (Kg/D)	Waste Quantity - Animal Waste -weight per day (Kg/D)
General Laboratory (for routine referral services)	BSL2	280	25	1500	40	50	1	10	7	NA
HIV/ADS	BSL2	25	5	300	15	10	0.5	1	1	NA
Malaria & Other Parasitic Disease Research	BSL2	3	4	300	5	1	0.2	1	0.3	NA
Zoonosis Research	BSL2	5	2	420	5	10	0.5	5	1	1
Clinical Bacteriology/Mycology	BSL2	25	2	240	15	10	0.5	1	0.5	NA
Virology Research/Common	BSL2	10	3	240	20	10	1	5	2	NA
Virology Research/Influenza	BSL2	25	4	240	15	10	0.5	1	0.5	NA
Tuberculosis Reference Lab	BSL2	10	4	240	20	10	1	5	2	NA
Virology Research/Measles	BSL2	25	3	240	15	10	0.3	1	0.5	NA
Virology Research/NPL	BSL2	25	2	240	15	10	0.5	1	0.5	NA
BSL 3 Facility	BSL3	210	-	600	8	4	0.1	0.2	0.2	NA
Total		861	134	9180	335	292	13.8	75.2	42.3	1.1

Regarding the proposed NRL complex, clinical waste (class 4), sharps (class 3) highly infectious wastes (class 6), chemical wastes (class 8), and Effluents (Class 9) are expected to be the most generated waste from the EPHI BSL 3 Laboratory complex and the following waste are the lists of wastes generated from the operation of the laboratory:

Waste cultures and stocks of microorganisms or etiologic agents (class 6):

- Cultures and stocks of infectious agents or microorganisms
- Cultures of specimens from medical and pathological laboratories.
- Disposable containers, materials, and supplies that may have been contaminated during the manipulation of microbial cultures and stocks
- Wastes from the production of biological (including all tissue culture materials).

Human pathological wastes including human blood, blood products and their containers Waste (class 4 and 6),

- Pathological waste consists of human tissues; organs; body parts; dialysate; cerebrospinal, synovial, pleural, peritoneal, and pericardial fluids; and their respective containers.
- Human blood and blood products waste (e.g. blood plasma, platelets, red or white corpuscles, and other derived licensed products such as interferon, etc.)
- Items saturated or dripping with human blood or blood products.
- Items caked with dried human blood or blood products.

Used sharps waste (class 3),

This category includes used hypodermic needles, syringes (with or without the attached needles), glass Pasteur pipettes, scalpel blades, blood vials, test tubes, needles with attached tubing,

Broken plastic culture dishes, unbroken glass culture dishes, and other types of broken and unbroken glassware that were in contact with infectious material including microscope slides and covers lips.

Chemical waste (class 8),

Chemicals used in the production of biological, laboratory reagents; film developer; disinfectants (such as formaldehyde, chloroform, phenol, ethyl alcohol, isopropyl alcohol, amyl alcohol, and sodium hypochlorite) that are expired or no longer needed; solvents; outdated, contaminated and discarded chemicals

Non-hazardous waste (class 1),

Although the generation of the non-hazardous waste is almost negligible from the BSL 3 laboratory, there may be paper, cardboard and other non-contaminated materials from BSL 2 laboratories, PTPC, Biobank, central warehouse and LEMC.

Liquid Waste (class 9),

Biological and chemical liquid waste generated in the laboratories

2.2. Waste Management Practices

All biological wastes from BSL-3 are decontaminated and marked as “treated biohazard waste” prior to disposal in designated containers for treated infectious waste. Decontamination and disposal are the responsibility of the person/laboratory generating the waste.

EPHI’s laboratories have Safety Manuals and SOP for waste handling and disposal. EPHI has a regular training program on biosafety and biosecurity and waste management. Most of the staff are trained in biosafety and biosecurity and waste management. Staffs working in the EPHI’s laboratories are vaccinated according to the specific risk group. In addition, laboratories have been implementing quality management systems including biosafety and biosecurity and some of the EPHI’s laboratories (National Reference TB Laboratory, Microbiology laboratories, HIV) have already got accreditation on ISO 15189:2012, Medical Laboratories-Requirements for quality and competence international standards and EPHI Food Science and Nutrition Laboratory got accreditation on ISO/IEC 17025:2005, General requirements for the competence of testing and calibration laboratories international standards. Moreover, a Microbiology laboratory has received a certificate of competency to perform Microbiology tests and Good Laboratory Practice from the American Society for Microbiology (ASM) and Africa society of Laboratory Medicine (ASLM). EPHI has been also operating Polio and influenza laboratories accredited by WHO. Since 2017, EPHI has Mobile BSL 3 lab which also helped to gain some experience in a NRL with BSL3 containment.

EPHI has waste disposal locations, pickup procedures, a safety manual for waste management and a BSL-3 mobile laboratory waste management procedure. The proposed NRL laboratory will have procedures for compliance with all applicable regulations for collecting, storing, processing, and disposing of sanitary liquid wastes, solid wastes and hazardous wastes generated from the BSL-3 lab at EPHI.

All biological waste from the NRL would undergo either autoclaving or chemical disinfection. These wastes would be discharged from laboratory sinks, floor drains, or tissue digesters and would be held and disinfected in retention tanks before being discharged into the sanitary sewer system. Tap water entering the BSL-3 laboratories through spigots in the sinks or shower heads would have backflow preventers to protect the potable water distribution system from contamination. Biological cultures could be disposed of in the sinks after undergoing treatment with chemical disinfectants for an appropriate amount of time. The autoclaving process involves placing waste to be autoclaved in a special container. When autoclaving occurs, an indicator strip on the container changes its colour. This allows facility workers and waste management workers to be able to tell at a glance whether waste has undergone autoclaving.

3. Wastewater Management Alternatives

3.2. Technical Evaluation of Wastewater Management Alternative

The NRL Complex generates diverse liquid waste streams, including pathologic, hazardous chemical and infectious materials. The management of these wastes presents multi-layered risks, particularly during collection, transportation, and disposal. Direct contact with or handling of contaminated liquid waste poses significant health risks to healthcare workers and can lead to environmental contamination. Therefore, a robust and sustainable wastewater management system is critical to mitigate these risks and ensure the safe and compliant disposal of all liquid waste generated by the facility. The primary objective

is to treat liquid waste to meet national and international effluent discharge quality standards before its release.

Key Considerations for Wastewater Management:

Any proposed wastewater management solution for the NRL Complex must address the following critical aspects to ensure safety, compliance, and sustainability:

- A thorough analysis of the daily wastewater volume and its anticipated fluctuations is essential for designing a system with adequate capacity.
- The stringent containment and inactivation of all infectious agents and hazardous chemicals present in the wastewater. This requires proven technologies to neutralize pathogens before discharge.
- The selected technology must be highly efficient and reliable in decreasing the load of all pollutants to meet discharge standards. This includes considerations for disinfection (e.g., heat inactivation, chemical disinfection), physical-chemical treatment, and nutrient removal.
- The system must consistently produce treated effluent that meets or exceeds all national and international discharge quality standards.
- Adherence to World Bank EHS guideline for health care facilities effluent discharge quality standards is paramount,
- Compliance with international best practices is non-negotiable, particularly the World Bank Group's Environmental, Health, and Safety (EHS) Guidelines for Healthcare Facilities.
- The system must incorporate a design that minimizes exposure risks for all healthcare and technical workers involved in the waste management cycle. This includes safe handling procedures, appropriate personal protective equipment (PPE), and automated systems where feasible.
- The solution must be designed to actively prevent the contamination of soil, groundwater, surface water bodies, and air, protecting both the immediate and surrounding environments.
- The proposed solution must be practical and account for the available space for for treatment facilities as well as reliable access to essential utilities like power and water.
- The chosen technology should strike a balancing effective treatment with economic feasibility.

Alternative 1: Construction of Onsite Wastewater Treatment Plant (WWTP)

This alternative involves building a dedicated, comprehensive wastewater treatment plant within the EPHI Compound. The plant would employ advanced treatment technologies to ensure the effluent meets stringent discharge standards.

Process Flow:

Equalization: To stabilize pollutant concentrations and flow rates.

Neutralization and Floating Section: pH adjustment and removal of oil and suspended solids.

Fine Screen: Pre-treatment to remove larger solids and protect downstream membrane systems.

Biological Section: Removal of biodegradable organic matter and nitrogen compounds through biological processes.

Membrane Bioreactor (MBR): Utilized for high-efficiency biological treatment, producing high-quality effluent and minimizing land footprint.

Tertiary Treatment: Further purification using ozone dosing and Granular Activated Carbon (GAC) filters to remove non-biodegradable organic substances.

Sludge Line: A dedicated system for dewatering and volume reduction of sludge, preparing it for appropriate disposal (incineration).

Infrastructure Requirements: Requires dedicated electric power, water supply, and potentially a boiler for heating/sterilization.

Challenges:

- The EPHI compound's location in a densely populated area may present significant space limitations.
- Public perception and acceptance of an industrial-scale treatment plant in a residential/commercial zone could be an issue.
- Advanced treatment technologies like MBR and ozone/GAC filtration involve substantial investment and ongoing operational expenses.

Alternative 2: Onsite Retention using Septic Tank (Primary Treatment) and Connecting to the Existing Municipal Sewer Line

This option involves connecting the non-hazardous liquid waste streams from the EPHI compound to the nearby municipal main or trunk sewer line, which leads to a centralized municipal wastewater treatment plant (Kaliti wastewater treatment plant).

Advantages:

Generally inexpensive compared to building and operating a dedicated onsite plant.

Leverages pre-existing public infrastructure for treatment and disposal.

Challenges:

Hazardous liquid waste from BSL-3 and other laboratories *cannot* be discharged directly into the municipal sewer without prior, verified inactivation/treatment.

Requires temporary measures, such as vacuum truck transport of non-hazardous waste to Kaliti WWTP, until the permanent connection is established.

- Reliance on the municipal plant's ability to handle the specific characteristics of laboratory wastewater, even if "non-hazardous."

Alternative 3: Onsite Retention using Septic Tank (Primary Treatment) and offsite wastewater treatment plant

This alternative proposes a hybrid approach for wastewater management, combining on-site primary treatment with off-site advanced treatment. The alternative focuses on separate septic tanks will be constructed at the waste generation points. These tanks will be dedicated to the primary treatment of non-hazardous liquid waste, allowing for the separation of solids and initial settling of suspended particles. The settled non-hazardous liquid waste from the septic tanks will be regularly collected by vacuum trucks and transported to the existing Kaliti Wastewater Treatment Plant for further treatment to meet discharge standards. Hazardous liquid wastes will be separately collected and transported to a specialized off-site wastewater treatment plant. This dedicated facility will be constructed and operated through a collaborative effort between the Ethiopian Food and Drug Authority (EFDA) and the Ministry of Health (MoH), specifically designed to safely and effectively treat infectious and hazardous wastes from laboratories and other sources.

Advantages:

- The construction of septic tanks represents a relatively low initial capital outlay compared to a full-scale, on-site advanced treatment plant.
- Septic tanks are straightforward to operate and require minimal day-to-day maintenance, reducing the need for highly specialized on-site personnel.
- This approach allows for immediate, localized primary treatment at the source of waste generation, reducing the volume and immediate impact of raw wastewater.
- Utilizes the established Kaliti Wastewater Treatment Plant for non-hazardous waste, optimizing resource allocation.
- Provides a specific and controlled solution for the safe treatment of hazardous waste, which is crucial for environmental and public health protection.

Limitations:

- Septic tanks only provide primary treatment (solids removal and some BOD reduction). They do not achieve the comprehensive effluent quality standards necessary for direct discharge, nor do they effectively treat hazardous or infectious components.
- Regular and proper removal, transport, and disposal of accumulated sludge from the septic tanks are essential. This can pose logistical challenges and requires a robust management plan to prevent environmental contamination.
- The transportation of infectious and hazardous waste over a 25-kilometer distance from EPHI (located in the central part of Addis Ababa) to the EFDA Vaccine Laboratory Site (situated south of Addis Ababa), traversing through a densely populated and crowded urban environment, raises significant public health and environmental concerns. The long transit route in a congested city significantly increases the probability of traffic accidents, vehicle malfunctions, or human error leading to spills. Such incidents could result in widespread contamination, direct exposure of the public to pathogens or toxic chemicals, and severe environmental pollution of urban areas, including potential impact on water sources. Maintaining the security of hazardous waste during prolonged urban transit is also a significant challenge, raising concerns about potential unauthorized access, diversion, or malicious acts.

- The overall effectiveness of this alternative is heavily reliant on the timely completion, operational efficiency, and sustained capacity of both the existing Kaliti Wastewater Treatment Plant and the planned hazardous waste treatment facility. Delays or operational failures in these off-site components would severely compromise the entire waste management system.
- Relies on frequent vacuum truck transport, which contributes to traffic, fuel consumption, and potential for spills if not handled meticulously.

Alternative 4: Sink-Level Decontamination and Centralized Thermal Treatment (Point-of-Generation Inactivation)

- This alternative emphasizes the immediate inactivation of potentially contaminated liquid waste at the source (e.g., sink, biosafety cabinet) within the laboratory, or its collection for centralized thermal treatment within the building. This approach minimizes the transport of untreated hazardous liquids and significantly reduces the biohazard load entering the building's drainage system.

Mechanism & Application:

Sink-Level Chemical Decontamination: For small volumes of liquid waste from BSL-2 laboratories (and never for BSL-3 primary waste), this involves adding a verified chemical disinfectant (e.g., concentrated bleach, specific virucidal/bactericidal agents) directly to the liquid waste in a designated sink or collection vessel, allowing for a specified contact time. Following inactivation, and after pH neutralization if necessary, the decontaminated liquid may be discharged to the nearby municipal sewer.

Collection for Benchtop/Centralized Thermal Treatment (Autoclaving): This is the preferred method for BSL-2 and mandatory for BSL-3 contaminated liquid waste that is not chemically inactivated at source.

Process: Contaminated liquids are collected in designated, autoclavable containers (e.g., polypropylene bottles, borosilicate glass carboys). These containers are then transported (following strict spill containment protocols) to a dedicated autoclave.

Autoclave Operation: The autoclave uses high-pressure saturated steam (typically 121°C at 15 psi for a minimum of 20-30 minutes, depending on volume and content) to achieve sterilization and inactivate all microbial contaminants, including spores.

Discharge: After the autoclaving cycle is complete and the liquid has cooled, the sterilized liquid is verified (by temperature loggers, biological indicators) and then, following pH neutralization if required, can be safely discharged to the municipal sewer system. This process ensures complete inactivation of pathogens before the liquid enters any shared drainage.

Advantages:

- Pathogens are inactivated at or very near the point of generation, significantly reducing the risk of exposure during collection, transport, and within the drainage system.
- Minimizes the volume of active biohazardous material in transit and in the building's plumbing.

- Lessens the likelihood of laboratory-acquired infections or environmental release from drain failures.
- Thermal treatment (autoclaving) is a standard and highly effective method for inactivating BSL-3 pathogens, ensuring compliance with strict biosafety guidelines.
- Benchtop autoclaves can be placed strategically in labs, or larger central autoclaves can serve multiple labs.

Limitations & Challenges:

- Sink-level chemical decontamination is only suitable for small, manageable volumes. Autoclave capacity limits the volume that can be treated per cycle. Very large volumes of liquid waste require multiple cycles or larger, dedicated effluent decontamination systems.
- Care must be taken to ensure the chosen disinfectant is effective against the specific contaminants and compatible with the sink materials, and that chemical reactions do not produce hazardous byproducts or off gassing.
- While autoclaves provide high confidence, proper operation (temperature, pressure, time) and routine validation are crucial.
- Autoclaves consume electricity and water, contributing to operational costs.

Technical feasibility analysis wastewater management alternatives:

Alternative 1: Construction of Onsite Wastewater Treatment Plant (WWTP),

Alternative 2: Onsite Retention using Septic Tank (Primary Treatment) and Connecting to the Existing Municipal Sewer Line,

Alternative 3: Onsite Retention using Septic Tank (Primary Treatment) and offsite wastewater treatment plant,

Alternative 4: Sink-Level Decontamination and Centralized Thermal Treatment (Point-of-Generation Inactivation)

Alternative 1: Build an onsite WWTP (MBR + disinfection)

Technical feasibility

- Easily achieves conventional BOD/COD/TSS limits; MBRs are compact and robust.
- But: A municipal-style WWTP does not count as pathogen inactivation for BSL-3 unless we add a validated Effluent Decontamination System (EDS) step upstream (heat/chemical) and robust QA (bioindicators, cycle validation).
- High O&M complexity (membranes, blowers, sludge), skilled operators, steady consumables supply chain.
- Grid & utilities
- Continuous aeration/filtration = power-hungry; needs genset/UPS to avoid process upsets during outages.

Pros

Full campus control of quality; buffers weak municipal treatment.

Scales if multiple labs or nearby wards join.

Cons / Risks

Overdesigned for a single BSL-3 lab on volume alone; still requires upstream EDS to be compliant.

Highest lifetime cost & staffing burden.

Alternative 2: Primary treatment in septic tank + connect to municipal sewer

Technical feasibility

- Septic tanks provide settling/anaerobic digestion only; they do not inactivate BSL-3 agents to acceptable biosafety standards. BMBL/NIH call for decontamination before sanitary sewer—a septic tank is not that.
- If point-of-generation EDS (under-sink/autoclave condensate) going to be added so only non-infectious effluent reaches the septic tank, the septic tank becomes a hydraulic buffer—not a safety control.

Grid and utilities

Low energy for the tank itself; reliance shifts to EDS devices

Pros

Lower civil cost than a full WWTP; easy handover to sewer if effluent is pre-inactivated.

Cons / Risks

- Non-starter without EDS; septic alone will likely fail biosafety review and permitting.
- Odor, sludge pumping logistics; septic tanks complicate urban campuses.

Alternative 3: Primary treatment in septic tank + haul to an offsite WWTP

Technical feasibility

Without EDS, trucking infectious liquids is mandatory, which is strongly discouraged for BSL-3 risk management. With EDS upstream, what we're trucking is non-infectious, making the haul unnecessary (we could discharge to sewer).

Grid and utilities

Similar to Alt 2 if we're going to add EDS; add transport coordination.

Pros

Viable in non-sewered areas after inactivation; leverages regional plants.

Cons / Risks

Adds logistics/transport risk and recurring costs; unnecessary if a sewer exists.

Alternative 4: Sink-level decontamination + centralized thermal treatment (point-of-generation inactivation)

Technical feasibility

- Directly aligned with BMBL/NIH: inactivate at source; validated thermal cycles (typically $\geq 82-134$ °C, time/temperature logged) before any sewer interface.
- Under-sink units exist with documented list prices; batch/continuous EDS options are standard for BSL-3/4. Design sizing follows peak daily volume and redundancy rules.
- Collection for Benchtop/Centralized Thermal Treatment (Autoclaving/EDS): This is the preferred method for BSL-2 and mandatory for BSL-3 contaminated liquid waste that is not chemically inactivated at source.
- Process: Contaminated liquids are either collected in autoclavable containers or, more optimally for BSL-3, directed through a dedicated Effluent Decontamination System (EDS), which is designed to handle the maximum 210 L/day calculated flow.
- Autoclave/EDS Operation: The system uses high-pressure saturated steam or high-temperature hold times (e.g., typically 121°C at 15 psi for a minimum of 20-30 minutes for batch units, or high-temperature continuous flow for EDS) to achieve sterilization and inactivate all microbial contaminants, including spores.
- Discharge: After the thermal inactivation is complete and verified (by temperature loggers, biological indicators), the sterilized liquid is safe for discharge to the municipal sewer system, ensuring complete pathogen inactivation before the liquid enters any shared drainage.

Grid and utilities

Heat requires reliable energy; choose steam, electric, or diesel/gas skids + generator/UPS to ride through outages (a known issue in Ethiopia).

Pros

Best biosafety profile (no infectious liquid beyond the suite).

Simplest to permit: discharge post-validation to municipal sewer within typical standards.

Modular, scalable, and more affordable than a full WWTP for single-lab loads.

Cons / Risks

- Requires power resilience and disciplined QA (biological indicators, cycle logs).

- If municipal sewer is absent, we'll still need a sanitary drain-field or lined holding tank (but liquids are non-infectious at that point).

Table 2: Comparative Evaluation of Wastewater Management Options: Compliance, Complexity, and Operational Requirements

Options	Compliance risk	Tech complexity	Grid dependence
1. Onsite WWTP (MBR) + required EDS upstream	Low if EDS included	High	High (continuous)
2. Septic + Sewer (requires EDS first)	Low if EDS present; High otherwise	Low–Med	Med (EDS)
3. Septic + Offsite WWTP (requires EDS first)	Acceptable only post-inactivation	Med (logistics)	Med
4. Sink-level + Central Thermal EDS	Low (Best alignment with BSL-3 standards for zero infectious discharge)	Medium (Standard equipment with QA/QC protocols)	Med–High (Needs power/steam resilience for heat)

Table 3: Decision Matrix for Wastewater Treatment Alternatives

S.N	Alternative	Pathogen Destruction (5)	Operational Complexity (5)	Environmental Impact (5)	Local Acceptability (5)	Total (20)	Remarks / Rationale
1.	On-site Wastewater Treatment Plant (WWTP) (MBR + disinfection + EDS)	5	2	3	3	13 / 20	Excellent effluent quality; but high capital and operation expenditure, space demand, power-dependent, and complex O&M. Overdesigned for single BSL-3 load.
2.	Septic Tank (Primary) + Municipal Sewer Connection (with EDS upstream)	4	4	4	4	16 / 20	Moderate pathogen control if EDS used; easy operation and integration with existing sewer; acceptable environmentally and socially if effluent is pre-treated.
3.	Septic Tank (Primary) + Off-site WWTP	3	3	3	2	11 / 20	Adds transport risk; high logistical and safety challenges; not preferred in urban context; acceptable only if liquids are pre-inactivated.
4.	Sink-Level Decontamination + Centralized Thermal Treatment (Point-of-Generation Inactivation)	5	4	5	5	19 / 20	Best biosafety and pathogen destruction; compliant with discharge requirement and scalable; minimal off-site risk; requires reliable power and QA discipline.

Recommended/Selected Wastewater Management Technology Alternative

Preferred Technology: Alternative 4 – Sink-Level + Central Thermal Treatment (EDS)

Reasons: Highest biosafety rating, no need to transport untreated waste, environmentally sound, locally acceptable, and technically feasible for the NRL’s BSL-3 setting.

Secondary (Support) System: Alternative 2 – Septic Tank + Sewer (with EDS upstream) - Serves as a non-hazardous effluent route after pathogen inactivation.

The most feasible and compliant wastewater management strategy for the NRL Complex integrates elements from the evaluated alternatives, emphasizing a multi-tiered approach based on the biosafety level and nature of the waste. The core principle is segregation at source and appropriate treatment prior to discharge.

General Principles for BSL-2 Laboratories

For BSL-2 laboratories, general sink drainage is considered non-infectious and can be connected directly to the sanitary sewer network, provided strict operational protocols are in place.

Contaminated liquid waste must undergo appropriate decontamination procedures:

Thermal Sterilization (Autoclaving): Using designated glass or autoclavable polycarbonate containers. Following thermal treatment and proper pH neutralization, treated liquids may be discharged into the standard wastewater drainage system.

Chemical Inactivation: Liquids collected in containers, temporarily stored in a designated holding area, and subsequently managed as hazardous waste by certified disposal contractors (similar to waste from automated analyzers).

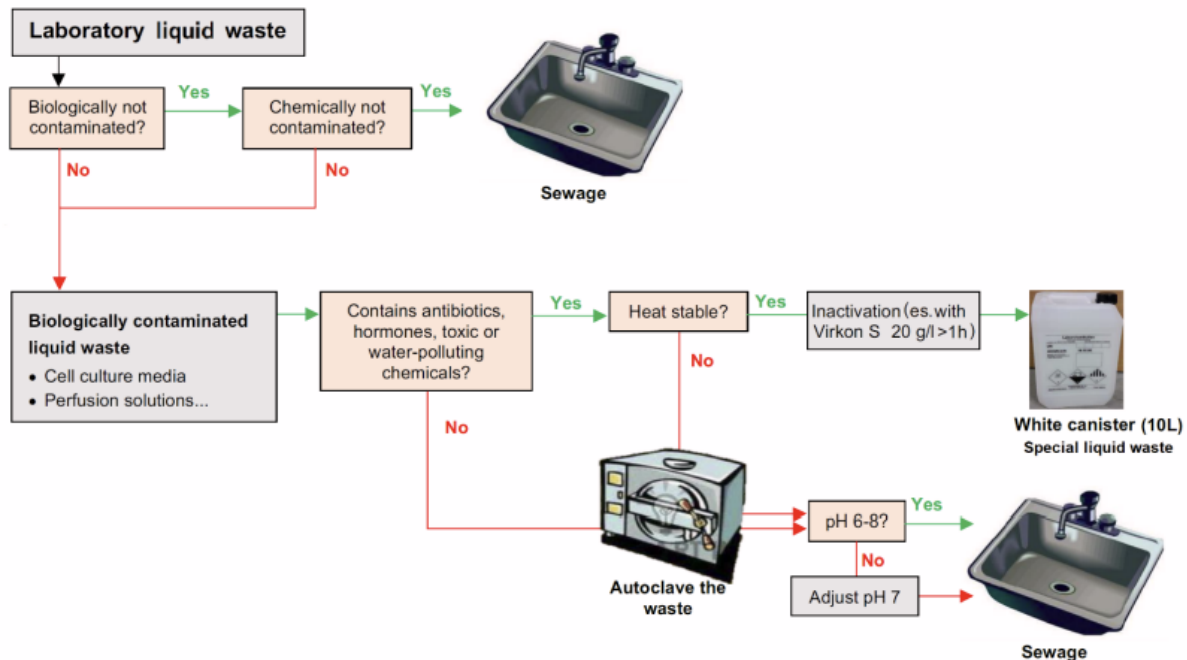


Figure 2: Schematic of the Infectious Liquid Waste Management System: From Source Collection to On-site Treatment

Specific Wastewater Disposal System for NRL Laboratory:

- ✓ The BSL-3 laboratory requires a highly specialized and contained wastewater disposal system due to the high risk associated with the pathogens handled. The overall management procedure is analogous to BSL-1/2 in principle (segregation and decontamination), but with enhanced engineering controls:
- ✓ Sink and shower effluents from the BSL-3 lab do not discharge directly into the sanitary sewer. Instead, they flow into a dedicated, separate drainage network designed for biologically and chemically contaminated wastewater.
- ✓ Piping and drainage systems are constructed from robust, corrosion-resistant materials (e.g., stainless steel, PE-HD, PP) to ensure longevity and prevent leaks.
- ✓ Wherever possible, piping and drainage systems are visible and accessible to facilitate maintenance, inspection, and leak detection.
- ✓ In sensitive or concealed areas where visible piping cannot be implemented, double-walled pipes with leak-tightness monitoring are employed to prevent any potential leakage.
- ✓ Drains containing pathogens are connected to a vacuum suction system that directs wastewater to dedicated thermal treatment units within the BSL-3 area. This prevents backflow and aerosol generation.
- ✓ All wastewater from the BSL-3 laboratory, including emergency shower water, is considered potentially contaminated and undergoes mandatory thermal treatment (steam sterilization/autoclaving or dedicated effluent decontamination systems) within the BSL-3 containment area to sterilize effluents containing pathogens.
- ✓ A safety system is in place to depressurize pipelines, preventing cross-contamination through the sewage system and ensuring efficient and safe operation without issues like pressure buildup or backflow.

Overall Wastewater Management for the NRL Building

Considering the different laboratory types within the NRL building, the overall wastewater management strategy is as follows:

BSL-2 Laboratories:

- General Waters from sinks, considered non-infectious, are discharged through the standard drainage system.
- Potentially chemical liquids generated during work under laminar flow hoods are automatically collected in designated containers. These containers are disposed of as special hazardous waste by an external specialized company.
- In the event of an emergency shower use, the water is not drained but contained on the floor, and specific operational procedures for environmental re-sanitization are activated.

Clinical Chemistry Laboratory:

Sink water follows the same protocol as BSL-2 labs.

Reagents and hazardous chemical waste from analyzers are collected in containers directly connected to the analyzers and are subsequently disposed of as special hazardous waste by an external specialized company.

BSL-3 Laboratory:

All water and liquids, including emergency shower water, are considered potentially contaminated.

A dedicated thermal wastewater treatment system is provided inside the BSL-3 area to inactivate all pathogens before discharge from the containment zone.

The NRL's complex will adhere to the principle of inactivation at source. All potentially infectious liquid waste will be decontaminated before it leaves the BSL-3 primary barrier.

Infectious Liquid Waste (Class 6 – treated On-site):

All biological liquid waste, including contaminated media and bulk liquids, will be collected in dedicated, sealed, autoclavable containers for Centralized Thermal Treatment (Autoclaving) within the BSL-3 suite's dedicated decontamination area, or treated via a validated Effluent Decontamination System (EDS). This ensures complete pathogen inactivation. The total estimated flow of potentially infectious effluent requiring decontamination is 210 L/day (comprising sink discharges and autoclave condensate).

Discharge: Only verified sterilized liquid, after cooling and pH adjustment (if necessary), will be discharged into the sanitary sewer system.

Chemical-Contaminated Liquid Waste (Class 8 & 9 – Managed by Segregation):

Source Segregation: Liquid waste containing hazardous chemicals (e.g., concentrated solvents, fixatives, heavy metals) must be strictly segregated from the biological waste stream. Such chemically-hazardous waste must not be processed via the EDS or standard drainage due to chemical compatibility and safety risks.

Source-Level Chemical Inactivation: This waste will be chemically neutralized on-site (e.g., pH adjustment). The laboratory staff is responsible for source-level classification and safe packaging. When BSL-3 infectious materials are mixed with chemical waste (e.g., formaldehyde fixatives), the waste is immediately collected in designated containers. The chemical component often acts as the primary decontaminant. However, for disposal, the chemical component must be managed: the mixed waste is sealed and labeled for collection as hazardous chemical waste (Class 8/9). The segregated, sealed hazardous chemical waste will be collected and transported for specialized off-site management (Alternative 3).

Sanitary Liquid Waste (Exit Shower Water): The estimated 600 L/day from mandatory exit showers is classified as sanitary waste and is routed directly to the municipal sanitary sewer system, provided it does not mix with the primary infectious drain lines.

Integrated Approach for Non-Hazardous Effluent and Final Disposal

Segregated Hazardous Waste: Limited quantities of hazardous wastewater from BSL-2 and Clinical Chemistry labs, as well as the decontaminated effluent from the BSL-3 thermal treatment system, are collected in containers/tanks and disposed of as special waste by external specialized companies. This minimizes the volume requiring off-site specialized hazardous waste treatment.

Non-Hazardous Wastewater Flow: Non-hazardous wastewater from BSL-2 laboratories (after strict segregation) and sanitary facilities flows into the general wastewater drainage system outside the building.

Onsite Pre-treatment for Discharge to Public Network:

The wastewater drainage network outside the building is designed with a primary treatment system consisting of septic tanks. These tanks serve to separate floating and solid substances and initiate the digestion of organic matter.

To meet the quality standards for discharge into the existing public sewer network along the main road to the south of the compound (especially during the temporary period before a potential future larger WWTP connection), the installation of a percolating filter is provided. This filter utilizes a biological film of bacteria on high-specific-surface fillers to further degrade polluting substances.

A tertiary treatment stage of UV disinfection is also included to ensure final effluent quality before discharge to the municipal sewer system, especially regarding microbial load.

4. Solid Waste Management Alternatives

4.1. Technical Evaluation of Alternatives

Effective solid waste management is crucial, especially for specialized facilities like the EPHI National Reference Laboratory. This section explores various alternative technologies for managing waste, considering their advantages, disadvantages, and applicability to the EPHI context.

Alternative 1: Waste Incineration Technology with Stabilization and Solidification

Incineration, when properly operated, is effective at eliminating pathogens and significantly reducing waste volume. However, certain hazardous waste types, such as pharmaceutical or chemical waste, demand higher temperatures for complete destruction. While higher operating temperatures and advanced exhaust gas cleaning can limit atmospheric pollution and odors, the existing incinerator at the facility (100 kg/hr capacity, 750-1050°C, 200 liters/day diesel consumption, 8-meter stack height) does not meet the minimum emission standards set by the WB EHS Guidelines for Healthcare Facilities (2007).

Given the specific characteristics of waste generated from the EPHI NRL, constructing a new incinerator that complies with these guidelines is the preferred incineration option. This would involve a pyrolysis incinerator with a 100 kg/hr capacity, equipped with an advanced emission reduction device. This device, specifically a fabric filter coated with a catalyst (PTFE), offers parallel dedusting and significantly lower contamination of filter dusts due to PCDD/PCDF destruction at the catalytic surface, achieving a high-efficiency reduction of dioxin to less than <0.1 ng TEQ/m³.

The incinerated waste further undergoes to waste stabilization and solidification. This process involves mixing hazardous ash with binding agents like cement to immobilize contaminants before disposal, thereby enhancing the safety of landfill disposal. While it can improve the safety profile of waste, it requires additional processing steps and materials. Furthermore, it may not eliminate all risks associated with the contaminants.

Alternative 2: Ecosteryl Technology (treatment and recycling of infectious waste)

The Ecosteryl technology is capable of decontaminating and recycling all sorts of infectious waste using only electricity. The process starts with powerful shredding of waste, including solids, plastics, pathological, sharps and any other elements considered as medical waste. It reduced the volume by up to 80%. This shredded material is then decontaminated by the action of microwaves and electrical resistors, finally yielding a dry by-product that can be recycled on account of an air injection separation and a laser optical sorting line. The disinfection level reaches 99.999%. The system generates no polluting emissions (no discharge of water, fumes, chemicals, or gases), thereby avoiding health risks indirectly created through the release of pathogens and toxic contaminants into the environment when using traditional technologies like incineration. A key advantage of Ecosteryl is its ability to facilitate the recovery of materials from waste, promoting recycling and reducing reliance on new raw materials. The equipment is also more compact, making it suitable for various healthcare settings, including smaller facilities, and potentially leading to long-term cost savings through waste volume reduction and material recovery.

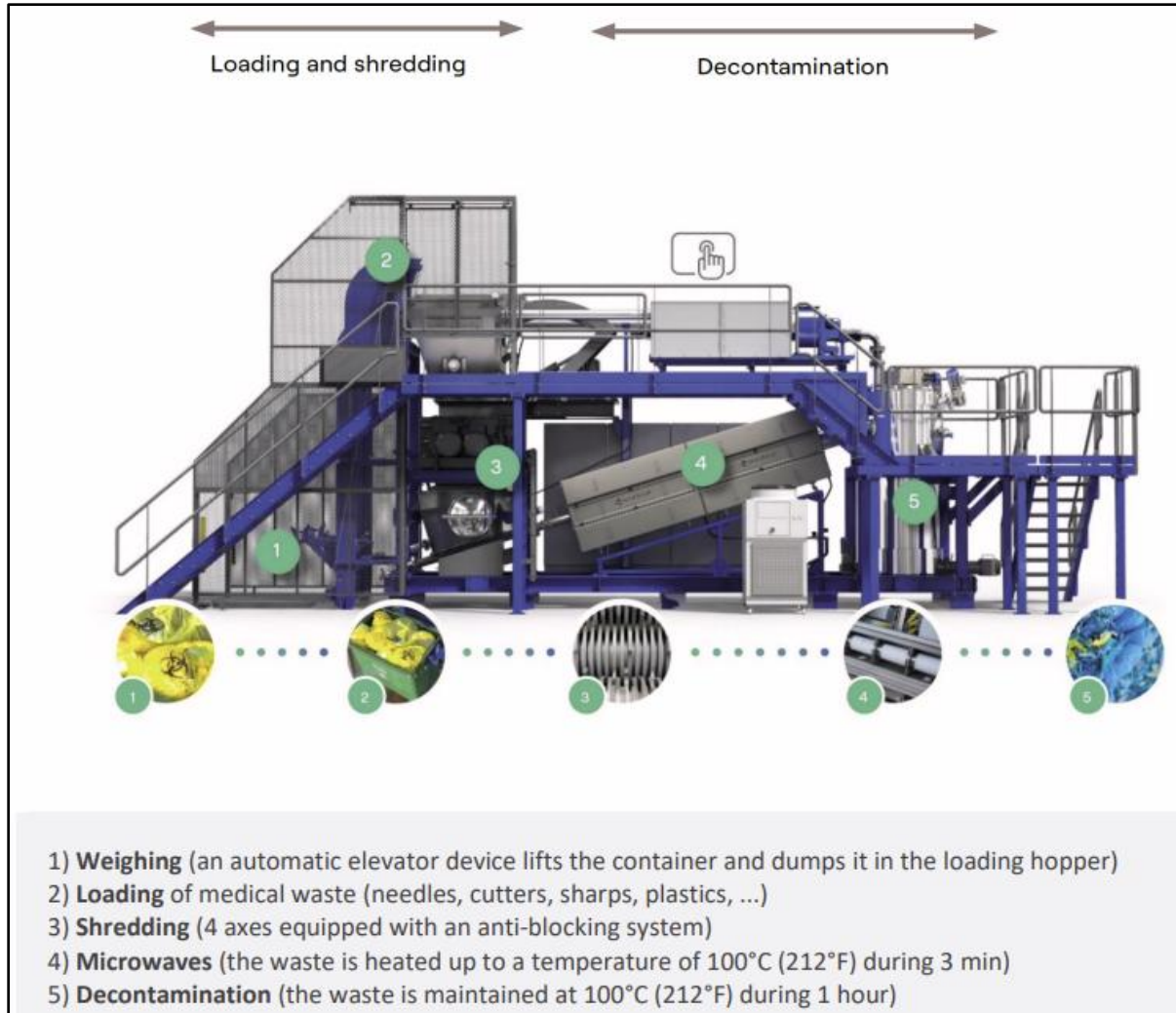


Figure 3: Operational Process Flow of the Ecosteryl 250 Microwave Decontamination System

The Ministry of Health is currently advancing a critical pilot implementation of the **Ecosteryl** system across three major medical facilities: St. Paul Hospital, ALERT Hospital, and Black Lion Specialized Hospital. This initiative represents a significant shift toward modern, non-incineration medical waste treatment to enhance public health and environmental safety. The primary installation, located adjacent to the Ethiopian Public Health Institute (EPHI) at the St. Paul site, boasts a substantial processing capacity of 250 kg/hr, which translates to approximately 3,334 liters/hr, based on an assumed waste density of 0.075 kg/liter. This capacity positions the **Ecosteryl 250** as an ideal solution capable of treating between **2 to 7 tons of medical waste per day**, depending on operational shift scheduling.

To ensure the success and sustainability of the pilot, several crucial issues must be addressed beyond the technical specifications. Operationally, a dedicated **Waste Transportation Van** will be provided to establish a secure and scheduled logistics network for collecting waste from the generating hospitals and transporting it to the central Ecosteryl site, which necessitates implementing a robust Chain of Custody system for tracking. Furthermore, the pilot's effectiveness will be evaluated against SMART objectives, including validating the assumed waste density, confirming pathogen inactivation rates, and establishing

the true cost per kilogram of treatment (covering energy, consumables, and labor) under local conditions. Critical preparatory steps also include ensuring stable utilities (power and water) for the equipment, providing comprehensive training for all involved personnel—from waste handlers to machine operators, which will collectively determine the feasibility of scaling the Ecosteryl model nationally.

Technical data - Ecosteryl 250

Dimensions (L x W x H)	11.9 m (+3 or 6 m conveyor) x 3.6 m x 5 m
Recommended height	7 m
Weight	15.5 tons
Type of process	Automatic and continuous process
Electrical powers	4 axes shredder, 37 kW power Microwave generator, 24 kW power and 2450 MHz frequency
Average power consumption	60 kWh
Staff required	1 person can operate 2 machines
Installation, commissioning and training	On-site, by our team
Options	Remote monitoring via Wi-Fi or 4G Automated container registration using barcode Link to the R-steryl sorting center



Figure 4: Current installation status Ecosteryl 250 at St. Paul Hospital and its specifications

Alternative 3: Recycling and Recovery

Recycling and recovery focus on retrieving certain components from hazardous waste, such as refillable containers, packaging materials, and metals, for reuse. This alternative significantly reduces waste volume and promotes resource recovery. However, it's important to note that not all waste is suitable for recycling, and this method requires access to specialized facilities for processing.

Alternative 4: Sanitary Landfill

Sanitary landfills, when properly constructed and operated, can provide a relatively safe disposal method for municipal solid waste, including healthcare waste. This method, however, requires a substantial land area for the compaction of daily waste, and crucially, there is no readily available sanitary landfill in Addis Ababa capable of safely receiving and disposing of healthcare waste.

4.2. Solid Waste Management Alternatives Feasibility Analysis

1) Alternative — Waste Incineration (medical waste incinerator)

Technical summary

- High-temperature thermal destruction (single-chamber or multi-chamber) that reduces waste to ash; effective for all infectious materials including pathological waste and sharps.
- Stack emissions require good secondary combustion, flue gas cleaning (if clinical waste plastics present) and monitoring to meet air quality rules.
- Reliable in low-humidity, low-electricity settings if fuel (diesel/LP/gas) available; many small units require skilled operators and regular maintenance.

Technical feasibility (developing country)

- **Pros:** Complete destruction of pathogens; volume reduction ~90%; suitable for sharps/non-segregated waste.
- **Cons:** Air emissions (dioxins, particulates) if poorly designed/operated; fuel costs; operator skill; community acceptance; pollution controls increase complexity and cost.

2) Alternative — EcoStery1 (Dry-microwave + Shredder)

Technical summary (official process integrated)

Continuous, fully electric dry-microwave system that: (1) weighs & automates loading, (2) shreds the waste (volume reduction up to ~80%), (3) microwave preheats to ~100°C in <3 min, then (4) maintains ~100°C for ~1 hour in a retention tank to ensure disinfection. The final output is dry, disinfected, and unrecognizable; suitable for direct municipal collection or further sorting/recycling (R-Stery1).

Technical feasibility (developing country)

- **Pros:**
 - Validated disinfection for a very broad range of medical waste **including sharps and pathological pieces** (manufacturer claim).
 - Fully electric → **no combustion emissions**, no pressurized vessel risk, low odor, low water use and no contaminated condensate.

- Integral shredding reduces volume and makes waste unrecognizable, enabling safe recycling routes (if local market / QA exists)
- Lower maintenance and labor compared with steam autoclaves and incinerators per vendor comparison.
- **Cons / constraints:**
 - **Requires reliable electricity** (though continuous process may allow battery/UPS/generator backup design).
 - Vendor support and spare parts lead times can be longer in low-resource settings; service contract advisable.
 - Cytotoxic/radioactive wastes are excluded by manufacturer — these require alternate handling.

Environmental & safety

- Minimal air pollutants (no combustion); low odor and no contaminated steam discharges. Safer for nearby communities and staff than open burning or poorly controlled incineration.

3) Alternative — Recycling & Recovery (segregation → material recovery)

Technical summary

- Recovery of non-infectious materials (glass, metals, some plastics) after validated treatment/segregation. Requires careful chain-of-custody and QA to ensure no infectious material enters recycling streams.

Technical feasibility

- **Pros:** Potential revenue or cost-offset; reduces landfill burden and plastic waste.
- **Cons:** For BSL-3 infectious waste, **very limited:** only waste that has been validated as sterile can enter mainstream recycling. Requires excellent segregation systems, microbiological QA, and local recycling markets.

4) Alternative — Sanitary Landfill (engineered)

Technical summary

- Engineered landfill with lining, leachate collection and cell design. For infectious waste, landfill **must** receive only pretreated (sterile/stabilized) waste and follow local regulations.

Technical feasibility

- **Pros:** Lowest marginal cost for disposal if treated waste is permitted; proven for final disposal.
- **Cons:** Requires robust pre-treatment; land availability and long-term monitoring; if untreated infectious waste is landfilled, public health and legal risks are high.

Table 4: Decision Matrix for Waste Treatment Options

S. N	Treatment Option	Pathogen Destruction (5)	Operational Complexity (5)	Environmental Impact (5)	Local Acceptability (5)	Total (20)	Remarks

1.	Ecosteryl	4	3	5	5	17 / 20	Excellent environmental profile; suitable for healthcare and lab waste.
2.	Incineration	5	3	2	2	12 / 20	High pathogen kill rate but poor environmental and social acceptability.
3.	Recycling and Recovery	5	3	5	5	Conditional	Only feasible if prior sterilization ensures pathogen-free material
4.	Sanitary Landfill	n/a	4	3	4	Conditional	Requires prior treatment (Ecosteryl or incineration)

4.3. Recommended/Selected Solid Waste Management Technology

Given the diverse waste streams generated by the proposed NRL, a multi-faceted approach combining several technologies is essential for effective and sustainable waste management. For non-hazardous waste, recycling and reuse are paramount to significantly reduce the volume requiring final disposal. After rigorous diversion of recyclable materials, residual non-hazardous waste should be directed to the Repi Landfill. This landfill, however, must operate under a formal agreement ensuring adherence to best practices in landfill operation, including leachate management, gas collection, and environmental monitoring.

Infectious waste, which poses a significant biohazard, necessitates specialized on-site treatment. Pyrolytic incineration with advanced air pollution control systems, and/or the Ecosteryl Technology are the two primary potential technologies recommended. Incineration effectively eliminates pathogens and reduces waste volume, while the Ecosteryl Technology offers a non-thermal treatment, converting infectious waste into a non-infectious, shredded material suitable for recycling or disposal at the Repi-Landfill. Notably, the Ministry of Health is currently implementing Ecosteryl medical waste treatment and recycling technology for solid waste management at St. Paul Hospital, which is adjacent to EPHI, providing a local precedent and expertise.

In summary, the Repi Landfill, subject to stringent controls, is deemed suitable for the disposal of residual non-hazardous waste after extensive recycling and reuse efforts within the EPHI. Conversely, on-site technologies, including Ecosteryl for infectious waste management, are essential for the safe and responsible management of the facility's specialized waste streams. This integrated approach ensures environmental protection, regulatory compliance, and minimizes the facility's environmental footprint.

5. Conclusion

The establishment of the National Reference Laboratory with BSL-3 Containment Complex is a vital step in strengthening Ethiopia's public health infrastructure. However, the successful and safe operation of such a facility hinges critically on a meticulously planned waste management system. The analysis of various alternatives for both wastewater and solid waste highlights the complexities and inherent risks,

particularly those associated with the transport of hazardous materials through densely populated urban areas.

For wastewater management, the initial proposal of off-site treatment for hazardous waste at the EFDA Vaccine Laboratory Site, 25 kilometers away, presents unacceptable public health and environmental risks due to the prolonged transit through Addis Ababa's crowded urban environment. Instead, the recommended strategy prioritizes on-site thermal inactivation for all BSL-3 wastewater within the containment zone, followed by a comprehensive on-site pre-treatment system (septic tanks, percolating filter, and UV disinfection) for all non-hazardous and pre-treated BSL-3 effluent before compliant discharge into the municipal sewer network. This approach effectively eliminates the need for transporting untreated hazardous liquid waste, significantly mitigating a major identified risk.

For solid waste management, a multi-faceted approach is crucial. While recycling and adherence to best practices for non-hazardous waste disposal at the Repi Landfill are important, the core of the strategy for infectious waste must reside in on-site advanced treatment technologies. The adoption of pyrolytic incineration with advanced air pollution controls at the EPHI site and Ecosteryl technology at the St. Paul Hospital will ensure the effective inactivation and safe processing of infectious and hazardous solid waste.

Table 5: Selected Waste Treatment Technologies and Rationale (NRL with BSL-3 Containment Complex)

S.N	Waste Type / Source	Selected Treatment Technology	Key Processes / Components	Rationale for Selection
1.	BSL-3 Laboratory Infectious Liquid Waste	On-site Thermal Treatment (Autoclaving / Steam Sterilization)	High-pressure steam sterilization within containment zone before discharge	Ensures complete pathogen inactivation inside the BSL-3 zone; eliminates need for off-site transport of infectious effluent; complies with WHO, WB EHS, and EPA biosafety standards.
2.	BSL-2 Laboratory Infectious Liquid Waste	Chemical or Thermal Decontamination at Source (Sink-level or Centralized)	Disinfection with verified chemicals or autoclaving of small volumes before discharge	Reduces risk of pathogen release into drains; manageable within existing lab infrastructure; meets biosafety level requirements.
3.	Hazardous Chemical Waste (e.g., reagents, solvents)	Collection and Off-site Disposal by Licensed Hazardous Waste Contractor	Containerized storage and periodic transport under permit	Avoids cross-contamination; ensures safe disposal per hazardous waste regulation; not suitable for on-site treatment.
4.	Non-Hazardous Laboratory Wastewater &	On-site Pre-treatment: Septic Tank → Percolating Filter →	Multi-stage biological and disinfection process	Provides compliant effluent quality before release; feasible in limited space;

S.N	Waste Type / Source	Selected Treatment Technology	Key Processes / Components	Rationale for Selection
	Sanitary Waste	UV Disinfection → Municipal Sewer Discharge		avoids need for new WWTP; cost-effective and environmentally sound.
5.	Infectious Solid Waste (e.g., cultures, sharps, contaminated materials)	Ecosteryl Microwave-based Decontamination and Recycling System	Shredding + Microwave heating + Air injection separation + Optical sorting	Non-thermal, zero-emission technology; safe on-site treatment; supports recycling and material recovery; already adopted by St. Paul's Hospital, ensuring local technical capacity.
6.	General (Non-infectious) Solid Waste	Segregation, Recycling, and Disposal at Repi Sanitary Landfill	Waste separation, recycling, and transport to controlled landfill	Minimizes landfill volume; promotes circular economy; Repi Landfill selected under strict operational standards (leachate & gas control).
7.	Alternative/Backup Infectious Waste Treatment Option	Pyrolytic Incineration with Advanced Air Pollution Control	100 kg/hr unit, catalytic fabric filter (PTFE) for dioxin removal	Provides high pathogen destruction efficiency (≥99.99%); serves as redundancy for Ecosteryl; compliant with WB EHS air emission standards.
8	Residual Hazardous Ash (from incineration)	Stabilization and Solidification before Disposal	Mixing with cement/binders for immobilization	Prevents leaching of heavy metals and contaminants; ensures safe long-term disposal in lined landfill.

Integrated Rationale Summary

- On-site treatment minimizes hazardous waste transport through congested Addis Ababa, avoiding major biosecurity and environmental risks.
- Thermal and microwave-based technologies ensure pathogen destruction while minimizing air and water pollution.
- Modular systems (autoclaves, Ecosteryl, UV treatment) are space-efficient and adaptable to laboratory-scale operations.
- Aligns with World Bank, WHO, and Ethiopian EPA environmental health and biosafety requirements.

ANNEX VIII: List of Experts Involved in the Addendum Preparation

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