Optimizing Healthcare Waste-Treatment Asset Lifecycle Performance: From Installed Incineration Capacity to Safe, Sustainable, and Environmentally Responsible Service Delivery

Bruno Houessou[1]; Abdel Malik Garba Gambari[2]

[1]Researcher and International Expert in Hospital Medical Asset Management, Biomedical Engineering, and ISO 55000 Asset Governance, Founder & Executive Director, MedAsset Insight Director, Hospital Medical Asset Governance Research Initiative (HMAG-RI) Mississauga, Ontario, Canada
[2]Sanitary & Biomedical Engineer, Environmental Health Expert: Water and Sanitation Public Health Expert, QHSE Manager, MedAsset Insight

Publication Date: 2026/08/31

Abstract: Healthcare waste-treatment technologies are frequently evaluated through procurement completion, installation status, technical functionality, or nominal treatment capacity. Although useful, these indicators provide only a partial account of whether an installed asset is delivering sustained value to a health system. Incinerators illustrate this distinction particularly clearly because effective waste treatment depends not only on combustion equipment but also on waste segregation and transport, supporting infrastructure, energy and fuel availability, operator competence, operating procedures, maintenance, occupational protection, environmental safeguards, performance information, financing, and governance. This study examined the lifecycle performance of healthcare waste-treatment assets across eight anonymized sites within a resource-constrained health system. A retrospective multi-site technical assessment combined documentary review, structured stakeholder interviews, direct site inspection, functional verification, and comparison between planned, installed, and observed conditions. Analysis was organized around five interconnected dimensions: asset and infrastructure readiness, operational performance, waste-treatment service delivery, safety and environmental performance, and lifecycle sustainability. Although the core incineration equipment was generally technically functional where installation had been completed, effective service delivery varied considerably. Energy failures, incomplete operating cycles, inadequate waste-flow arrangements, absence of preventive maintenance, incomplete operator protection, weak performance documentation, and dependence on project-based recurrent financing constrained performance. Cross-site analysis revealed successive distinctions between installed capacity, operational capacity, effective treatment capacity, safe service capacity, and sustainable lifecycle performance. These states are not proposed as a new asset-management framework or maturity model. Rather, they represent analytical performance boundaries through which the conversion of capital investment into health-system and environmental value can be examined. Lifecycle optimization of healthcare waste-treatment assets therefore requires management of the complete asset-service system rather than the combustion equipment alone.

Keywords: *Healthcare Waste; Incineration; Asset Lifecycle Management; Healthcare Technology Management; Waste-Treatment Capacity; Environmental Safety; Maintenance; Sustainability; ISO 55000; Health-System Value.*

How to Cite: Bruno Houessou; Abdel Malik Garba Gambari (2026) Optimizing Healthcare Waste-Treatment Asset Lifecycle Performance: From Installed Incineration Capacity to Safe, Sustainable, and Environmentally Responsible Service Delivery. *International Journal of Innovative Science and Research Technology*, 11(8), 2124-2134. https://doi.org/10.38124/ijisrt/26aug780

I. INTRODUCTION

Healthcare activities generate waste streams that may present biological, chemical, pharmaceutical, physical, and environmental hazards. Although most healthcare waste is non-hazardous, a smaller proportion requires specific management because it may contain infectious materials, sharps, pharmaceuticals, hazardous chemicals, or other substances capable of harming workers, patients, communities, and the environment [1–4].

Healthcare waste management is consequently more than a disposal activity. It is a service chain extending from waste generation and segregation through packaging, collection, transport, temporary storage, treatment, residue management, and final disposal [2,3,15–18]. Weakness at any

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug780

point in this chain may compromise the effectiveness of the entire system.

Global guidance increasingly places healthcare waste within a wider health-facility environment that also includes water, sanitation, hygiene, electricity, environmental cleaning, occupational safety, and resilient infrastructure [22,23]. The large volumes of waste generated during the COVID-19 response further demonstrated how rapidly weaknesses in segregation, treatment capacity, logistics, and disposal can become health-system risks [25].

Incineration remains one treatment option for selected healthcare waste streams, particularly when non-incineration technologies are unavailable or unsuitable. Appropriate incineration can reduce waste volume and destroy infectious materials, but successful treatment depends strongly on waste characteristics, segregation, equipment design, combustion conditions, operator practices, maintenance, and environmental controls [2,5–9].

Poorly controlled combustion may result in incomplete treatment and emissions of particulate matter, dioxins, furans, heavy metals, and other pollutants [6,8,9,27,30]. Studies of small-scale healthcare waste incinerators have also shown that seemingly minor limitations in installation, operating practice, maintenance, or supporting infrastructure can have substantial effects on treatment and environmental performance [7,26,31,34].

This creates an important distinction from an asset-management perspective.

An incinerator may have been procured, installed, commissioned, and technically capable of combustion without the health system possessing a reliable waste-treatment service. Electricity may be unavailable. Fuel supply may be interrupted. Waste may not reach the treatment site in an appropriate condition. Operators may deviate from required treatment cycles. Preventive maintenance may be absent. Treatment volumes and failures may not be documented. Occupational protection may be incomplete, or environmental safeguards may be insufficient.

The distinction between technical functionality and service performance is therefore fundamental.

ISO 55000:2024 approaches asset management through the realization of value from assets in alignment with organizational objectives and across their life cycles [10]. ISO 55001:2024 further emphasizes planning, lifecycle operations, decision-making, risk and opportunity management, information, knowledge, and continual improvement [11]. ISO 55012:2024 reinforces the importance of people involvement and competence [14], while ISO 55013:2024 addresses the management of data in support of asset-management objectives [12].

Applied to healthcare waste-treatment infrastructure, these principles suggest that asset value should not be assessed primarily through physical presence or the ability of equipment to start. The more relevant question is whether the complete asset system continuously enables a safe, effective, environmentally responsible, and sustainable waste-treatment service.

This issue is particularly relevant where capital investment is supported by time-limited programmes while recurrent requirements—including energy, fuel, operators, maintenance, spare parts, personal protective equipment, supervision, environmental safeguards, and renewal—must subsequently be absorbed by routine institutional financing.

The present study examines healthcare waste-treatment assets from this lifecycle perspective. It does not seek to introduce another comprehensive asset-management framework. Instead, it investigates how installed incineration capacity is translated—or fails to be translated—into operational capacity, effective waste treatment, safe service delivery, and sustainable lifecycle performance.

The objectives were to: (1) examine installed incineration assets from a lifecycle-performance perspective; (2) identify technical, infrastructural, operational, environmental, maintenance, information, and financing factors influencing service performance; (3) distinguish equipment functionality from effective and safe waste-treatment capacity; and (4) derive practical implications for lifecycle optimization of healthcare waste-treatment assets.

II. CONCEPTUAL BACKGROUND

➢ *Healthcare Waste Treatment as an Asset-Service System*

An incinerator is often managed as an individual physical asset. From a service perspective, however, its functional boundary is considerably broader.

Before waste reaches the treatment equipment, segregation, packaging, temporary storage, collection, transportation, and where appropriate quantification must function adequately. At the treatment site, safe operation requires suitable infrastructure, energy, fuel, trained operators, appropriate procedures, occupational protection, and functional combustion systems. Following treatment, residues must be managed safely, activities documented, equipment maintained, and environmental risks appropriately controlled [2,3,5,15,16,21].

Evidence from healthcare facilities in different settings shows that waste segregation and transport practices can remain major weaknesses even where treatment infrastructure exists [17,18,20]. Sustainable healthcare waste management therefore requires coordination between technology, organization, staff behaviour, logistics, financing, and environmental management rather than simply the acquisition of treatment equipment [18,21,32].

The relevant unit of management is consequently not only the incinerator, but an asset-service system:

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug780

Equipment + Infrastructure + Utilities + Waste logistics + People + Processes + Maintenance + Safety + Environmental control + Information + Financing + Governance

This broader boundary is consistent with ISO 55000 and ISO 55001, which relate the management of physical assets to value, organizational objectives, performance, risk, and lifecycle decision-making [10,11].

➢ *Functionality, Treatment Capacity, and Service Performance*

Technical functionality remains necessary. A non-functional combustion unit cannot provide its intended treatment service.

Functionality alone, however, does not demonstrate that the service is available.

A technically functional incinerator with an unavailable energy source has little operational capacity. An operational incinerator that cannot complete an appropriate treatment cycle may have limited effective treatment capacity. Equipment capable of processing waste but operating without adequate occupational or environmental safeguards cannot reasonably be considered fully performing. Finally, an installation that performs satisfactorily during an inspection may remain vulnerable if maintenance, financing, competence, or technical support cannot be sustained.

These distinctions imply that performance becomes progressively broader as the analytical boundary moves away from the combustion equipment itself.

➢ *The Distinctive Risk Profile of Incineration Assets*

Waste-treatment assets differ from many other healthcare technologies because their intended function is itself risk reduction.

An unavailable diagnostic system primarily results in lost diagnostic capacity. An unavailable oxygen-production asset primarily results in lost oxygen-service capacity. An inadequately operated healthcare waste-treatment asset can simultaneously result in loss of treatment capacity, accumulation of hazardous waste, occupational exposure, and environmental contamination.

Performance therefore has both a value dimension and a risk-control dimension.

For incineration assets, effective performance should consequently combine:

Appropriate treatment + Safety + Environmental control + Continuity + Lifecycle sustainability

This distinction is important because inappropriate waste streams, inadequate segregation, poor combustion, inappropriate ash management, and poorly maintained incinerators can increase rather than reduce certain occupational and environmental risks [6–9,13,26–31,34].

Lifecycle optimization should therefore never be interpreted as maximizing incinerator utilization. The appropriate objective is to ensure that waste streams for which incineration is justified are treated effectively, safely, and with appropriate environmental control, while prevention, segregation, recycling where appropriate, and alternative technologies remain part of the broader healthcare waste-management strategy [2,5,15,29,32].

III. MATERIALS AND METHODS

➢ *Study Design*

A retrospective multi-site technical assessment was conducted across eight healthcare waste-treatment sites within one health system.

Seven sites had reached the equipment-installation stage at the time of field assessment, while one site remained at an earlier stage of infrastructure preparation and implementation.

The analysis focused on the relationship between planned investment, installed physical capacity, observed operational conditions, service-delivery capability, safety and environmental conditions, and sustainability.

The underlying technical assessment considered installation and commissioning together with functionality, personnel, maintenance, spare parts, waste storage, transport, treatment, and sustainability mechanisms.

For ethical and confidentiality reasons, information capable of identifying the country, healthcare facilities, geographical locations, financing institutions, implementing organizations, contractors, manufacturers, equipment brands, models, and individual respondents was removed.

Sites are therefore identified only as Site A–H.

No patient-level or personal clinical information was used.

➢ *Data Collection*

Evidence was collected from three complementary sources.

First, a documentary review examined available waste-management strategies and operational plans, site studies, technical specifications, procurement and acceptance records, installation and commissioning documentation, training materials, warranty documentation, operating procedures, and other relevant implementation records.

Second, structured interviews were conducted with stakeholders involved in waste management, operation, technical support, supervision, coordination, and facility-level management.

Third, direct site assessment examined the condition and operation of the physical assets and their supporting systems.

The assessment included site organization, waste segregation and flows, temporary storage, internal transport, treatment practices, occupational safety, documentation, maintenance, primary and secondary combustion chambers, chimney condition, fuel and electrical systems, ash and residue management, and operational functionality.

Triangulation was used to compare planned requirements and documentary evidence with the conditions actually observed on site.

➢ *Assessment Domains*

For the present study, observations were reorganized into five interconnected domains:

- Asset and infrastructure readiness — installation completeness, site suitability, utilities, supporting infrastructure, and installed treatment capacity.
- Operational performance — ability to operate reliably and complete appropriate treatment cycles.
- Waste-treatment service delivery — ability to receive, transport, quantify where required, and process intended waste streams.
- Safety and environmental performance — operator protection, operating safety, treatment conditions, ash management, and environmental safeguards.
- Lifecycle sustainability — preventive maintenance, technical competence, documentation, recurrent financing, supervision, and long-term supportability.

➢ *Data Analysis*

Analysis was undertaken in two stages.

First, documentary information, interview findings, and direct observations were triangulated for each installation. Planned specifications and implementation arrangements were compared with installed conditions and observed operational status.

Second, cross-site comparative analysis examined where capacity was lost between investment and sustained service delivery.

Rather than treating each deficiency as an isolated technical finding, observations were interpreted according to their effect on the ability of the asset-service system to fulfil its intended waste-treatment function.

Five progressively broader analytical states emerged:

- Installed capacity — treatment equipment and supporting infrastructure physically available.
- Operational capacity — installed capacity capable of functioning reliably under actual site conditions.
- Effective treatment capacity — operational capacity capable of completing appropriate treatment processes for intended waste streams.
- Safe service capacity — effective treatment delivered while managing occupational and environmental risks.
- Sustainable lifecycle performance — ability to preserve safe service capacity through maintenance, competence, information, financing, supervision, and governance.

These states were not predefined scoring categories. No numerical weighting, composite index, or maturity score was applied.

They were used as analytical performance boundaries to organize patterns emerging from comparison of the eight sites.

IV. RESULTS

➢ *Technical Functionality did Not Consistently Translate into Operational Capacity*

Where installation had been completed, the core combustion equipment was generally technically functional, including primary and secondary combustion components. Basic site infrastructure was also available to varying degrees.

Operational status nevertheless differed substantially between sites.

Supporting energy systems represented one of the clearest constraints. At some installations, inadequate or unavailable power prevented normal operation or interrupted treatment cycles.

At one site, failure of a solar energy system resulted in cessation of incineration activity. Another site experienced insufficient electrical capacity, contributing to incomplete treatment cycles. A separate installation became non-operational following damage to its supporting power system.

These observations demonstrate that the physical condition of the combustion unit alone cannot determine operational capacity.

Installed capacity was not necessarily operational capacity.

Supporting energy infrastructure effectively formed part of the asset-service system, even when physically distinct from the incinerator.

➢ *Operational Capacity did Not Always Represent Effective Treatment Capacity*

A second distinction concerned the completeness and control of the treatment process.

Observed operating practices did not consistently follow the expected sequence of preheating, combustion, and controlled cooling. The assessment identified recurrent deviations in treatment cycles and operating procedures.

At some sites, cycle duration or operating conditions were inconsistent with expected procedures, creating the possibility of incomplete treatment.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug780

This matters because an incinerator can be mechanically operational without consistently achieving the intended waste-treatment process.

The relevant performance question is therefore not simply:

Does the equipment operate? But: Does the installation reliably complete an appropriate treatment cycle under controlled operating conditions?

This distinction separates equipment operation from effective waste treatment.

- *Waste Logistics Influenced Service Capacity*

The ability to treat healthcare waste depended substantially on activities occurring upstream of the incinerator.

Across several sites, recurrent weaknesses included absence of formally defined waste circuits, lack of dedicated transport carts, use of inappropriate containers, and logistical limitations affecting waste movement.

These weaknesses could reduce the ability to connect waste-generation points safely and consistently with available treatment capacity.

This observation broadens the conventional interpretation of asset availability.

A technically available treatment asset generates limited value when waste cannot be segregated, collected, transported, or delivered appropriately.

Waste-treatment capacity should therefore be interpreted across the chain:

Segregation → Collection → Transport → Treatment → Residue management

- *Preventive Maintenance was a Recurrent Lifecycle Weakness*

Maintenance was among the most consistent weaknesses identified across the installed sites.

Preventive maintenance plans were frequently absent or insufficiently structured. Maintenance registers and systematic histories of corrective interventions were also limited.

The underlying assessment associated absence of preventive maintenance with premature deterioration and inadequate maintenance records with poor traceability of repairs and failures.

This creates a lifecycle risk even when equipment currently operates.

Without preventive maintenance, competent technical support, spare parts, maintenance documentation, and adequate financing, minor deterioration can develop into major failure and prolonged service interruption.

The distinction is therefore not only between functional and non-functional equipment but between:

Current functionality and preserved functionality.

- *Operational Information was Insufficient for Performance Management*

Performance information was limited across several installations.

Common deficiencies included the absence or inconsistent use of treatment registers, maintenance registers, activity reports, weighing equipment, and standardized operational records.

Without systematic measurement of waste quantities, actual treatment throughput could not reliably be compared with installed capacity.

Without treatment-cycle records, utilization and continuity were difficult to evaluate.

Without maintenance histories, managers could not readily analyse recurring failures, deterioration trends, or repair response.

These gaps are more than administrative deficiencies.

They constrain evidence-based decisions concerning staffing, fuel planning, maintenance, utilization, cost, rehabilitation, and replacement.

A basic performance dataset could include:

Waste received → Waste treated → Completed cycles → Operating hours → Fuel consumption → Downtime → Failures → Maintenance interventions → Safety incidents → Residue management → Operating cost

This type of information is consistent with ISO 55013:2024, which emphasizes the role of data in supporting asset-management objectives [12].

- *Safety Formed Part of Asset Performance*

Operator protection was incomplete across multiple sites, and electrical or site-related hazards were also identified.

At individual installations, missing protective equipment, exposed electrical risks, unsafe fuel arrangements, or incomplete procedures could create substantial occupational risk.

This is particularly important for healthcare waste-treatment assets because their purpose is to reduce exposure to hazardous waste. Successful treatment should therefore not

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug780

be achieved by transferring risk from waste generators to operators, maintenance personnel, or nearby communities.

Performance cannot reasonably be considered satisfactory where expected treatment output is obtained under unsafe operating conditions.

Safety should therefore be included within the performance boundary of the asset-service system.

➢ *Environmental Performance could not be Separated from Treatment Performance*

The assessment identified conditions capable of affecting environmental performance, including incomplete treatment cycles, inadequate segregation, challenges related to ash or residue management, and deficiencies in supporting site infrastructure.

The study did not include comprehensive stack-emission measurements or environmental sampling and therefore does not claim to quantify site-specific atmospheric emissions.

Nevertheless, the operational findings are relevant because combustion conditions, waste composition, segregation, equipment characteristics, maintenance, and operating practices influence pollutant generation and residual waste characteristics [6–9,13,26–31,34].

Published evidence has documented particulate matter and heavy-metal emissions from medical waste incineration [27], dioxin-related concerns [9,30], broader environmental impacts of healthcare risk-waste treatment technologies [13], and potential health risks associated with incineration [28,34].

For healthcare waste-treatment assets:

Throughput alone is therefore an inadequate measure of performance.

➢ *Recurrent Financing Represented a Sustainability Constraint*

Capital investment had created physical treatment capacity, but mechanisms for financing recurrent operation were less secure.

Continued performance depended on expenditure for fuel, electricity, operators, maintenance, spare parts, PPE, training, supervision, environmental safeguards, and eventual renewal.

The original assessment identified dependence on project-based financing and uncertainty regarding the integration of operating costs into routine budgets.

This illustrates an important lifecycle principle:

Capital affordability does not necessarily imply lifecycle affordability.

Table 1 Cross-Site Synthesis of Healthcare Waste-Treatment Asset Performance

Site	Asset readiness	Operational status	Dominant performance constraint	Maintenance and information	Lifecycle sustainability
A	Installed	Not consistently available	Supporting infrastructure / site constraint	Weakly structured	At risk
B	Installed	Not operational at assessment	Energy-system failure	Weakly structured	At risk
C	Installed	Partially operational	Energy and treatment-cycle constraints	Relatively stronger documentation	Vulnerable
D	Installed	Partially operational	Utility limitations and incomplete cycles	Weakly structured	At risk
E	Installed	Operational with constraints	Process control and operating practice	Weakly structured	Vulnerable
F	Installed	Operational with constraints	Operating parameters and process compliance	Weakly structured	Vulnerable
G	Installed	Not operational at assessment	Major supporting energy-system failure	Weakly structured	At risk
H	Installation incomplete	Not yet available for routine service	Infrastructure and implementation completion	Not yet fully assessable	Dependent on successful commissioning

- Note: Sites are intentionally anonymized. Categories summarize dominant lifecycle observations and should not be interpreted as a numerical ranking or validated maturity classification.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug780

V. DISCUSSION

➢ *Functionality is Necessary but Insufficient*

The principal finding of this study is that technical functionality represents only one boundary of healthcare waste-treatment performance.

Across the assessed sites, equipment could be installed yet unavailable for service; technically functional yet constrained by utilities; operational yet unable to complete appropriate treatment cycles; capable of treatment yet insufficiently supported by safety, documentation, or maintenance; or functional today while lacking arrangements required to preserve performance over time.

The distinction can be summarized as:

Installed ≠ Operational ≠ Effective treatment ≠ Safe service ≠ Sustainable performance

These states should not be interpreted as successive maturity levels. They represent different boundaries from which the performance of the same asset-service system may be observed.

This distinction matters because conventional investment indicators such as *number procured*, *number installed*, or *number functional* may substantially overestimate the treatment service actually available to the health system.

➢ *The Performance Boundary Extends Beyond the Incinerator*

Many of the most important constraints identified during the assessment were located outside the combustion equipment. Energy, fuel, waste logistics, segregation, procedures, PPE, maintenance, technical support, documentation, and financing all influenced whether installed equipment generated useful service. This means that the asset boundary used for lifecycle management should be broader than the physical equipment boundary.

At the equipment boundary, performance asks whether the incinerator functions.

At the operational boundary, performance asks whether the equipment and its supporting systems can operate reliably.

At the treatment boundary, performance asks whether appropriate waste streams are treated correctly.

At the service boundary, performance incorporates occupational and environmental safeguards.

At the lifecycle boundary, performance concerns whether the complete service can be sustained.

Healthcare waste-treatment performance is therefore partly determined by where the system boundary is drawn.

➢ *Waste-Treatment Performance has a Dual Value–Risk Structure*

Waste-treatment assets present a distinctive relationship between value and risk. Their intended value is the reduction of hazards associated with healthcare waste. Poor performance can therefore generate two consequences simultaneously:

Loss of treatment capacity + creation or redistribution of occupational and environmental risk.

The appropriate objective is consequently not maximum incinerator utilization or maximum throughput. Rather, it is the: Appropriate, controlled, safe, and environmentally responsible treatment of waste streams for which the technology is suitable.

This interpretation is consistent with wider healthcare waste-management literature, which increasingly considers segregation, treatment selection, environmental burden, occupational protection, organizational practice, and sustainability as interconnected dimensions [15–18,21,29,32].

The distinction is particularly important because environmentally sustainable healthcare waste management may sometimes favour non-incineration alternatives, depending on waste type, local infrastructure, technical supportability, lifecycle cost, and environmental requirements [5,29,32].

Lifecycle optimization should therefore concern the waste-treatment service, not simply maximization of the use of a particular technology.

➢ *Maintenance Preserves Capital Value*

The recurrent weakness of preventive maintenance provides an important lifecycle insight. Procurement creates potential value; Installation makes capacity physically available; Operation realizes value through service delivery.

- *Maintenance Preserves that Value Over Time*

Without maintenance planning, technical competence, spare parts, records, and financing, the probability that current functionality will persist decreases.

Maintenance expenditure should therefore not be interpreted only as an operating expense. Properly designed maintenance is also an investment in preservation of existing capital value, reduction of lifecycle risk, and continuity of service [10,11].

➢ *Performance Information Closes the Lifecycle Loop*

The absence of consistent treatment and maintenance data restricts the health system's ability to learn from operational experience.

An organization may know the nominal capacity of an incinerator without knowing with similar confidence its actual throughput, downtime, failure frequency, fuel consumption, operating cost, or maintenance burden. Data

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug780

therefore connect day-to-day operation to future asset decisions. ISO 55013:2024 explicitly positions data management as supporting asset-management and organizational objectives [12].

For healthcare waste-treatment assets, relatively simple standardized records could materially improve maintenance planning, budgeting, capacity assessment, failure management, and renewal decisions.

➢ *People and Competence are Lifecycle Resources*

Initial operator training had been provided, but observed deviations from expected operating procedures indicate that completion of training should not be equated with durable operational competence.

Competence must be maintained through practical supervision, refresher training, access to procedures, learning from failures and incidents, and adaptation to staff turnover.

ISO 55012:2024 similarly emphasizes people involvement and competence within asset-management activities [14].

This dimension is particularly important for incineration because operator practice influences treatment effectiveness, occupational safety, equipment deterioration, fuel consumption, and environmental performance.

➢ *Sustainability Begins before Procurement*

Dependence on temporary external financing highlights a recurrent weakness in healthcare infrastructure investment. Sustainability is sometimes addressed only after procurement and commissioning. By that point, however, many lifecycle costs have already been determined through decisions concerning treatment technology, installed capacity, energy requirements, site design, staffing, maintenance model, spare parts, monitoring, and environmental safeguards. Lifecycle sustainability should therefore be designed before acquisition.

A credible investment decision should consider not only whether an organization can afford to acquire the asset, but whether it can support its total service requirement throughout its useful life.

Life-cycle and cost analyses have shown that healthcare waste-treatment alternatives can have substantially different environmental and economic profiles [33]. Technology selection should therefore consider capital cost together with recurring expenditure, waste composition, utilization, environmental burden, maintenance supportability, local skills, and expected asset life.

➢ *Incinerator Asset-to-Service Performance Pathway*

The empirical findings can be summarized through the following performance pathway:

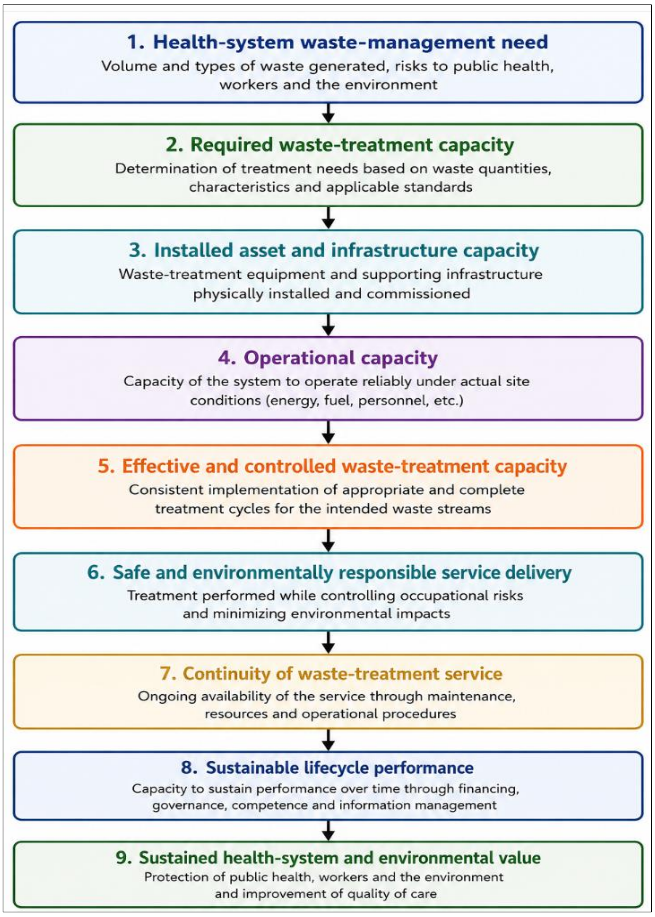

Fig 1 Incinerator Asset-to-Service Performance Pathway

The pathway is not proposed as a new comprehensive asset-management framework or formal maturity model. It is an analytical representation of how installed treatment capacity is progressively translated into service value.

The transitions are conditional.

Installed capacity → Operational capacity depends particularly on site infrastructure, utilities, energy, commissioning, fuel, and technical readiness.

Operational capacity → Effective treatment capacity depends on operator competence, appropriate operating cycles, suitable waste streams, procedures, and process control.

Effective treatment → Safe and environmentally responsible service depends on segregation, occupational protection, combustion quality, residue management, safe infrastructure, and environmental safeguards.

Service delivery → Continuity depends on preventive and corrective maintenance, spare parts, logistics, technical response, and stable operational resources.

Continuity → Sustainable lifecycle performance depends on recurrent financing, governance, performance information, competence retention, supervision, and renewal planning.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug780

VI. IMPLICATIONS FOR LIFECYCLE OPTIMIZATION AND PERFORMANCE MEASUREMENT

The findings suggest that healthcare waste-treatment programmes should move beyond binary *functional/non-functional* indicators.

Five complementary performance boundaries may provide more meaningful information.

Installed capacity asks whether the required physical equipment and supporting infrastructure are available.

Operational capacity asks whether the system can function reliably under actual site conditions.

Effective treatment capacity asks whether intended waste streams can be processed according to appropriate operating requirements.

Safe service capacity asks whether treatment is delivered while controlling occupational and environmental risks.

Sustainable lifecycle performance asks whether this service can be preserved over time.

These distinctions provide a basis for performance monitoring without requiring a composite score.

For asset condition and reliability, useful indicators may include availability, completed operating cycles, downtime, failure frequency, preventive-maintenance compliance, repair time, and critical spare-parts availability.

For treatment performance, indicators may include waste received, waste treated, cycle completion, relevant operating parameters, and untreated backlog.

For occupational and environmental performance, indicators may include waste-segregation compliance, PPE availability and use, safety incidents, ash and residue management, site-safety conditions, and environmental monitoring where required.

For lifecycle sustainability, monitoring may include maintenance financing, recurrent operating budget, technical-support availability, operator competence, fuel security, completeness of performance records, supervision, and renewal planning.

Where treatment alternatives are available, lifecycle optimization should also periodically reconsider whether the installed technology remains appropriate in relation to changing waste characteristics, environmental performance, technical supportability, regulatory expectations, and total cost of ownership [5,29,32,33].

Keeping these dimensions separate may be more useful than combining them prematurely into a single numerical score because the location and nature of the performance constraint remain visible.

VII. SCIENTIFIC CONTRIBUTION

The contribution of this study lies less in proposing another healthcare waste-management framework than in reconsidering where the performance boundary of a healthcare physical asset should be drawn.

The same incinerator may appear to perform differently depending on whether assessment stops at technical functionality, extends to operational reliability, examines treatment effectiveness, incorporates occupational and environmental safeguards, or considers the ability to sustain the service over its lifecycle.

For healthcare waste-treatment technologies, value realization cannot therefore be defined solely through service output.

Performance must simultaneously consider the risks that the treatment process is intended to control and the new risks that inadequate operation may create.

The distinction:

Installed capacity → Operational capacity → Effective treatment capacity → Safe service capacity → Sustainable lifecycle performance

Provides a means of identifying where asset value is preserved, constrained, or lost without requiring a separate comprehensive management framework for the technology.

More broadly, the findings support the proposition that common asset-management principles—value, lifecycle, risk, performance, decision-making, competence, information, and continual improvement—can remain relatively stable across healthcare technologies [10–14], while the determinants through which those principles are expressed remain asset-specific.

For healthcare waste-treatment assets, the distinctive contribution is the explicit incorporation of occupational and environmental risk within the definition of asset performance itself.

VIII. STUDY LIMITATIONS

Several limitations should be considered when interpreting the findings.

First, the study represents a cross-sectional assessment conducted during a defined period and therefore does not provide longitudinal reliability evidence across the entire asset lifecycle.

Second, historical information on treatment volumes, operating cycles, downtime, failures, fuel consumption, and maintenance was incomplete across several installations. This

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug780

limited quantitative comparison between nominal and realized performance.

Third, one site had not reached the same implementation stage as the installed sites and therefore could not be evaluated across all operational domains.

Fourth, the study did not include comprehensive quantitative stack-emission monitoring or environmental sampling. Environmental findings therefore concern observed operating conditions and risk-control arrangements rather than directly measured emissions.

Fifth, the analytical performance boundaries were derived from comparative interpretation of the assessed sites and have not been validated as a maturity model or standardized measurement instrument.

Finally, anonymization intentionally removes contextual information that could identify individual facilities, organizations, suppliers, financing mechanisms, or jurisdictions. This protects confidentiality but limits explanation of certain site-specific determinants.

Future studies should examine healthcare waste-treatment performance longitudinally and link treatment throughput, operating parameters, downtime, maintenance expenditure, fuel consumption, occupational incidents, environmental monitoring, and lifecycle costs. Comparative research across incineration and non-incineration technologies could also help determine how performance boundaries vary according to treatment technology.

IX. CONCLUSION

Healthcare waste-treatment investments cannot be adequately evaluated through procurement, installation, or technical functionality alone.

The assessed installations demonstrate that substantial value can be lost between the presence of physical treatment capacity and the provision of a reliable waste-management service.

Infrastructure, energy, fuel, waste logistics, operator competence, operating procedures, maintenance, occupational protection, environmental safeguards, information, financing, and governance all influence whether an installed incinerator ultimately fulfils its intended health-system function.

The central distinction emerging from this study is therefore:

Installed ≠ Operational ≠ Effective treatment ≠ Safe service ≠ Sustainable performance

These are not proposed as maturity levels. They represent progressively broader performance boundaries through which the same asset-service system can be examined.

For healthcare waste-treatment technologies, this distinction is particularly important because performance includes not only the delivery of a treatment service but also control of the occupational and environmental risks associated with that service.

The relevant unit of performance is consequently not the incinerator alone, but the safe and sustainable waste-treatment service enabled by the complete asset system.

Lifecycle optimization should therefore seek to minimize the loss of value between installed treatment capacity and sustained health-system and environmental value.

For healthcare asset managers, the practical question should no longer be simply:

Does the incinerator work? *But rather:* Does the complete asset system continue to deliver the safe, effective, and environmentally responsible waste-treatment service for which the health system invested in it?

REFERENCES

[1]. World Health Organization. *Health-care waste*. Geneva: World Health Organization; updated 24 October 2024.

[2]. World Health Organization. *Safe management of wastes from health-care activities*. 2nd ed. Geneva: World Health Organization; 2014. ISBN 978-92-4-154856-4.

[3]. World Health Organization. *Safe management of wastes from health-care activities: a summary*. Geneva: World Health Organization; 2017.

[4]. Cook E, Woolridge A, Stapp P, Edmondson S, Velis CA. Medical and healthcare waste generation, storage, treatment and disposal: a systematic scoping review of risks to occupational and public health. *Critical Reviews in Environmental Science and Technology*. 2023;53(15):1452–1477. doi:10.1080/10643389.2022.2150495.

[5]. World Health Organization. *Overview of technologies for the treatment of infectious and sharp waste from health care facilities*. Geneva: World Health Organization; 2019. ISBN 978-92-4-151622-8.

[6]. Alvim-Ferraz MCM, Afonso SAV. Incineration of healthcare wastes: management of atmospheric emissions through waste segregation. *Waste Management*. 2005;25(6):638–648. doi:10.1016/j.wasman.2004.07.017.

[7]. Rogers DEC, Brent AC. Small-scale medical waste incinerators—experiences and trials in South Africa. *Waste Management*. 2006;26(11):1229–1236. doi:10.1016/j.wasman.2005.08.007.

[8]. Ibáñez R, Andrés A, Viguri JR, Ortiz I, Irabien JA. Characterisation and management of incinerator wastes. *Journal of Hazardous Materials*. 2000;79(3):215–227. doi:10.1016/S0304-3894(00)00268-5.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug780

[9]. Ajay SV, Prathish KP. Dioxins emissions from bio-medical waste incineration: a systematic review on emission factors, inventories, trends and health risk studies. *Journal of Hazardous Materials*. 2024;465:133384. doi:10.1016/j.jhazmat.2023.133384.

[10]. International Organization for Standardization. *ISO 55000:2024 Asset management — Vocabulary, overview and principles*. Geneva: ISO; 2024.

[11]. International Organization for Standardization. *ISO 55001:2024 Asset management — Asset management system — Requirements*. Geneva: ISO; 2024.

[12]. International Organization for Standardization. *ISO 55013:2024 Asset management — Guidance on the management of data assets*. Geneva: ISO; 2024.

[13]. Zikhathile T, Atagana H, Bwapwa J, Sawtell D. A review of the impact that healthcare risk waste treatment technologies have on the environment. *International Journal of Environmental Research and Public Health*. 2022;19(19):11967.

[14]. International Organization for Standardization. *ISO 55012:2024 Asset management — Guidance on people involvement and competence*. Geneva: ISO; 2024.

[15]. Kenny C, Priyadarshini A. Review of current healthcare waste management methods and their effect on global health. *Healthcare*. 2021;9(3):284. doi:10.3390/healthcare9030284.

[16]. Windfeld ES, Brooks MSL. Medical waste management—A review. *Journal of Environmental Management*. 2015;163:98–108. doi:10.1016/j.jenvman.2015.08.013.

[17]. Khan BA, Cheng L, Khan AA, Ahmed H. Healthcare waste management in Asian developing countries: a mini review. *Waste Management & Research*. 2019;37(9):863–875. doi:10.1177/0734242X19857470.

[18]. Chisholm JM, Zamani R, Negm AM, Said N, Abdel Daiem MM, Dibaj M, Akrami M. Sustainable waste management of medical waste in African developing countries: a narrative review. *Waste Management & Research*. 2021;39(9):1149–1163. doi:10.1177/0734242X211029175.

[19]. Padmanabhan KK, Barik D. Health hazards of medical waste and its disposal. In: Barik D, ed. *Energy from Toxic Organic Waste for Heat and Power Generation*. Woodhead Publishing; 2019:99–118. doi:10.1016/B978-0-08-102528-4.00008-0.

[20]. Adu RO, Gyasi SF, Essumang DK, Otabil KB. Medical waste-sorting and management practices in five hospitals in Ghana. *Journal of Environmental and Public Health*. 2020;2020:2934296. doi:10.1155/2020/2934296.

[21]. Janik-Karpinska E, Brancaleoni R, Niemcewicz M, et al. Healthcare waste—A serious problem for global health. *Healthcare*. 2023;11(2):242.

[22]. World Health Organization, United Nations Children's Fund. *Universal water, sanitation, hygiene, waste and electricity services in all health care facilities to achieve quality care: Global framework for action 2024–2030*. Geneva/New York: WHO/UNICEF; 2024.

[23]. World Health Organization, United Nations Children's Fund. *Water, sanitation, hygiene, environmental cleaning and waste management in health care facilities: 2023 data update and special focus on primary health care*. Geneva/New York: WHO/UNICEF; 2024.

[24]. World Health Organization. *Safe management of pharmaceutical waste from health care facilities: global best practices*. Geneva: World Health Organization; 2025.

[25]. World Health Organization. *Global analysis of health care waste in the context of COVID-19: status, impacts and recommendations*. Geneva: World Health Organization; 2022. ISBN 978-92-4-003961-2.

[26]. Batterman S. *Findings on an Assessment of Small-scale Incinerators for Health-care Waste*. Geneva: World Health Organization; 2004.

[27]. Alvim-Ferraz MCM, Afonso SAV. Incineration of different types of medical wastes: emission factors for particulate matter and heavy metals. *Environmental Science & Technology*. 2003;37(14):3152–3157. doi:10.1021/es026209p.

[28]. Tait PW, Brew J, Che A, et al. The health impacts of waste incineration: a systematic review. *Australian and New Zealand Journal of Public Health*. 2020;44(1):40–48. doi:10.1111/1753-6405.12939.

[29]. Fadaei A. Comparison of medical waste management methods in different countries: a systematic review. *Reviews on Environmental Health*. 2023;38(2):339–348. doi:10.1515/reveh-2021-0170.

[30]. World Health Organization. *Dioxins and their effects on human health*. Geneva: World Health Organization; current fact sheet.

[31]. United Nations Environment Programme. *Minimum Specifications for Health Care Waste Incineration*. Nairobi: UNEP; 2012.

[32]. Lattanzio S, Stefanizzi P, D'Ambrosio M, Cuscianna E, Riformato G, Migliore G, Tafuri S, Bianchi FP. Waste management and the perspective of a green hospital—A systematic narrative review. *International Journal of Environmental Research and Public Health*. 2022;19(23):15812. doi:10.3390/ijerph192315812.

[33]. Soares SR, Finotti AR, da Silva VP, Alvarenga RAF. Applications of life cycle assessment and cost analysis in health care waste management. *Waste Management*. 2013;33(1):175–183. doi:10.1016/j.wasman.2012.09.021.

[34]. Njagi NA, Oloo MA, Kithinji J, Kithinji MJ. Health-Care Waste Incineration and Related Dangers to Public Health: Case Study of the Two Teaching and Referral Hospitals in Kenya. *Journal of Community Health*. 2012;37(6):1168–1171. doi:10.1007/s10900-012-9578-4.