

Energy Balance, Capacity Sizing Verification, and Dioxin Risk Screening of a Titanium Structured Waste-to-Energy Incinerator: A Techno Thermal Case Study of PLTSa 10 MW Cirebon

Safrizal^{1*}, Dias Prihatmoko¹, Agus Siswanto²

^{1,2)} Department of Electrical Engineering, Universitas Islam Nahdlatul Ulama (UNISNU) Jepara, Jepara, Indonesia

²⁾Electrical Engineering Study Program, Faculty of Engineering, Universitas 17 Agustus 1945 Cirebon, West Java, INDONESIA

INFORMASI ARTIKEL

NASKAH DITERIMA : 17 April 2026

DIREVISI : 14 Mei 2026

DISETUJUI : 15 Juni 2026

*KORESPONDENSI PENULIS :

Corresponding author:

Safrizal27@unisnu.ac.id

doi:

<https://doi.org/10.47685/mestro.v8i01.873>

Hal. 37 - 46

Abstract

As Indonesia accelerates its Waste-to-Energy (WtE) program through the Pembangkit Listrik Tenaga Sampah (PLTSa) initiative, independent technical verification of proposed projects is critical to avoid costly design miscalculations. This study presents a techno-thermal simulation and independent verification of a proposed titanium-structured incinerator for the 10 MW, 600 ton/day facility under feasibility study in Cirebon, covering (i) process temperature profiling and dioxin (PCDD/F) formation-risk zoning, (ii) a first-order energy balance from feedstock lower heating value (LHV) to net electrical output, and (iii) post-air-pollution-control (APC) emission compliance. The verification reveals three critical discrepancies. First, the assumed feedstock LHV of 3,363 kcal/kg is 1.5–2.6 times higher than the 1,290–2,270 kcal/kg range typically reported for raw, high-moisture Indonesian municipal solid waste. Second, the combined conversion efficiency of 18% is markedly lower than the 28–35% efficiency reported for modern WtE plants; these two assumptions act in partly offsetting directions, meaning their net effect on the reported 76% capacity mismatch cannot be resolved without plant-specific data. Third, a specific internal inconsistency was identified: the model's net-power formula is not capped at nameplate capacity, producing a physically impossible capacity factor of 135%. Benchmarking against five comparable Indonesian PLTSa projects (Surakarta, Surabaya–Benowo, Semarang, Palembang, and Cirebon itself) shows specific electricity yields of 220–527 kWh per ton of waste, within which the Cirebon plant's planned 10 MW/600 tpd (400 kWh/ton) falls squarely, suggesting the nameplate rating itself is a defensible design choice rather than an undersizing error. Dioxin-risk zoning, using a 400–650 °C de novo formation window, identifies the superheater, economizer, and air-heater zones as high risk; however, the 325 °C APC-inlet zone sits within the 250–350 °C peak de novo window reported in the literature, indicating the model's 400 °C lower bound may understate risk. Emission compliance analysis, cross-checked against the actual Indonesian thermal-waste-treatment standard (Permen LHK No. P.70/2016), shows that the model's sole reported "failure" (particulate matter) does not constitute regulatory non-compliance, as the modeled concentration of 25 mg/Nm³ is well within the national limit of 120 mg/Nm³. Consequently, the reported 76% capacity mismatch, while indicative, is not a validated design flaw. This finding underscores the necessity of grounding screening-level simulations in plant-specific data and verified local regulations to inform sound engineering, policy, and investment decisions in Indonesia's emerging WtE sector.

Keywords: Waste-to-Energy, PLTSa, dioxin/PCDD-F, Energy Balance, Capacity Sizing

I. INTRODUCTION

Indonesia's waste-to-energy (WtE) program, formalized under Presidential Regulation No. 35/2018 (amending No. 18/2016), represents a strategic national initiative to address the twin challenges of mounting municipal solid waste (MSW) generation and

the growing demand for electricity. The regulation designates priority cities for the development of thermal MSW treatment facilities coupled with electricity generation, known locally as *Pembangkit Listrik Tenaga Sampah* (PLTSa) [11, 111]. Public reporting confirms that a 10 MW, 600 ton/day (tpd) PLTSa facility is currently under feasibility study in Kecamatan Gempol, Kabupaten Cirebon, West Java. The project, developed by PT Global Energi Investama, is targeted to begin construction following the completion of the feasibility study [2, 112].

Despite this policy ambition, the gap between planning and implementation remains substantial. As of the second half of 2025, only two Indonesian PLTSa plants were fully operational: the Surabaya–Benowo facility (1,000 tpd, 12 MW, operating since May 2021) and the Surakarta–Putri Cempo facility (545 tpd, 5 MW, operating since 2024) [13, 14]. This limited track record underscores the technical, financial, and regulatory complexities inherent in deploying WtE technology in the Indonesian context, where feedstock characteristics, conversion efficiencies, and emission standards differ markedly from the European and North American contexts in which much of the incineration technology was originally developed.

Two independent technical concerns accompany any WtE incinerator design, and both are particularly salient for emerging markets like Indonesia. The first is combustion-and-energy sizing: the electrical output implied by a plant's feedstock throughput, fuel heating value, and thermodynamic conversion chain must be consistent with its declared nameplate capacity. Where inconsistency exists, the design carries either an underutilized turbine-generator (undersized nameplate) or an over-optimistic energy yield claim (overestimated conversion assumptions) [7, 8, 15]. The second is environmental performance: incomplete combustion and post-combustion cooling through the 250–650 °C range promote unintentional formation of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) via de novo synthesis, independent of the plant's electrical performance [9, 10, 16]. These two concerns are not independent; both are sensitive to the same set of design parameters, including combustion temperature, flue gas residence time, and the effectiveness of air pollution control (APC) systems.

In practice, feasibility studies for WtE projects in developing economies often rely on screening-level simulations adapted from international models. These simulations, while useful for rapid assessment, are susceptible to compounding errors arising from optimistic or unverified input parameters (e.g., fuel quality assumptions, efficiency curves, emission limits). Without rigorous, independent verification against local data and regulatory frameworks, such models can produce misleading conclusions about technical viability, financial returns, and environmental compliance. This is particularly critical in Indonesia, where the characteristics of MSW—high moisture content, low calorific value, and heterogeneous composition—differ substantially from the feedstock assumptions embedded in many generic WtE models [3]–[6].

This paper provides an independent verification of a screening-level simulation for the proposed titanium-structured Cirebon incinerator, a study that reported three headline findings: (i) a substantial 76% mismatch between the model's thermodynamic gross output (17.6 MW) and the plant's 10 MW nameplate capacity, implying significant energy curtailment (≈ 66.6 GWh/yr); (ii) a dioxin risk-zone classification identifying the superheater–economizer–air-heater train as the dominant formation-risk region; and (iii) a post-APC emission compliance check suggesting that only particulate matter exceeds the regulatory limit. Rather than accepting these headline figures at face value, this study traces each of the model's core assumptions—feedstock lower heating value (LHV), conversion efficiency chain, dioxin-risk temperature thresholds, and regulatory emission limits—back to the primary literature, to publicly available project data, and to the applicable Indonesian national standards. This verification approach is undertaken in direct response to the requirement that all technical claims and citations in the resulting manuscript be independently verifiable.

The specific objectives of this study are fivefold:

1. To reproduce and interrogate the reported energy balance and capacity-mismatch calculation, identifying any internal inconsistencies in the model's formulation;
2. To benchmark the assumed feedstock LHV and conversion efficiency against peer-reviewed Indonesian MSW characterization studies and international WtE efficiency benchmarks;
3. To benchmark the plant's announced 10 MW nameplate capacity against comparable operating and contracted Indonesian PLTSa projects, thereby testing whether the rating is a defensible design choice or an outlier;
4. To re-examine the dioxin risk-zone classification against the de novo synthesis literature, particularly the temperature windows for peak formation reported in experimental and kinetic studies;
5. To verify the emission compliance analysis against the actual Indonesian national standard for thermal waste treatment (Permen LHK No. P.70/MENLHK/SETJEN/KUM.1/8/2016), rather than against the generic or unlabelled limits embedded in the original simulation script.

By undertaking this verification, the paper aims to move beyond a simple acceptance or rejection of the model's headline conclusions. Instead, it seeks to demonstrate *how* screening-level simulation outputs should be critically evaluated, *which* assumptions are most sensitive to local conditions, and *why* independent verification using local benchmarks is an essential step in translating simulation results into sound engineering, policy, and investment decisions for Indonesia's emerging WtE sector.

The remainder of this paper is organized as follows. Section II describes the reference system, the temperature-zone dioxin risk classification, the energy balance model, the emission compliance model, and the verification approach employed. Section III presents the results of the simulation and verification, including the temperature profile and dioxin risk zones, the energy

balance and capacity sizing, and the emission compliance analysis. Section IV discusses each of the model's principal assumptions in light of the verification findings, addressing the feedstock LHV, conversion efficiency, internal consistency of the net-power calculation, benchmarking against comparable projects, dioxin risk classification, and regulatory compliance. Finally, Section V concludes with a summary of the key findings, the limitations of the study, and recommendations for future research and practice.

II. MATERIALS AND METHODS

A. Reference System

The reference system is a 600 tpd moving-grate MSW incinerator with an announced 10 MW nameplate electrical capacity, matching the publicly reported PLTSa Cirebon project specification [2], [12]. The process train (Fig. 1) follows a conventional mass-burn WtE configuration: MSW/coal feeder combustion chamber (850–1,200 °C), superheater and economizer (600–650 °C), air heater (400–450 °C), APC train (≈300–350 °C inlet), stack (≈200 °C) [9], [17]. Cooler structural sections (below ≈600 °C continuous service) are assumed fabricated from, or coated with, Titanium Grade 2 for its corrosion resistance to chloride-bearing flue gas [18], [19].

B. Temperature-Zone Dioxin Risk Classification

Eight process zones (MSW feeder, coal feeder, combustion chamber, superheater, economizer, air heater, APC inlet, stack) were classified into four dioxin-risk categories: Destruction ($T \geq 850$ °C), Transition (650 °C $\leq T < 850$ °C), Formation (400 °C $\leq T < 650$ °C, assigned the highest risk score, reflecting the de novo synthesis window), and Neutral ($T < 400$ °C or $T \geq 850$ °C outside the destruction band).

C. Energy Balance Model

Thermal energy input is computed from the feedstock throughput $\dot{W}$ (t day⁻¹) and lower heating value (LHV, kcal kg⁻¹) according to

$$\dot{Q}_{th} = \frac{\dot{W} \cdot LHV}{24 \cdot 860} \quad (\text{MW}) \quad (1)$$

using the standard 860 kcal = 1 kWh conversion, with $\dot{W} = 600$ t/day and LHV = 3,363 kcal/kg. Gross electrical output was obtained by applying a combined boiler turbine generator efficiency chain ($\eta_{\text{boiler}} = 0.80$, $\eta_{\text{turbine}} = 0.25$, $\eta_{\text{generator}} = 0.90$; $\eta_{\text{combined}} = \eta_{\text{boiler}} \cdot \eta_{\text{turbine}} \cdot \eta_{\text{generator}} = 0.18$):

$$\dot{W}_{\text{gross}} = \dot{Q}_{th} \cdot \eta_{\text{combined}} \quad (2)$$

Net electrical output follows after deduction of a 10 % parasitic load and multiplication by the plant availability factor $A = 0.85$:

$$\dot{W}_{\text{net}} = \dot{W}_{\text{gross}} \cdot (1 - f_{\text{parasitic}}) \cdot A. \quad (3)$$

Annual net energy production is then

$$\dot{E}_{\text{annual}} = \dot{W}_{\text{net}} \cdot 365 \cdot 24 \quad (\text{GWh yr}^{-1}) \quad (4)$$

while the gross-to-nameplate capacity mismatch is defined as $\Delta \dot{W} = \dot{W}_{\text{gross}} - \dot{W}_{\text{nameplate}}$. In the original simulation the annualised value of $\Delta \dot{W}$ was labelled “curtailed energy.” Capacity factor was reported as $\dot{W}_{\text{net}}/\dot{W}_{\text{nameplate}}$.

As discussed in Section IV.C, the latter definition is internally inconsistent whenever $\dot{W}_{\text{net}}$ exceeds $\dot{W}_{\text{nameplate}}$, because a turbine-generator set cannot deliver net output above its own nameplate rating. In the present work this discrepancy is retained as a verification finding rather than corrected silently.

D. Emission Compliance Model

Six baseline (pre-APC) pollutant concentrations (dioxin, particulate matter, HCl, SOx, NOx, and a lumped heavy-metal parameter) were each reduced by a uniform assumed APC removal efficiency of 99.5%, representative of a combined activated-carbon-injection/fabric-filter/wet-scrubber/SCR train [20]–[24], and compared against two sets of limits: the limits assumed internally by the simulation script, and the verified Indonesian national standard for thermal waste-treatment emissions, Permen LHK No. P.70/MENLHK/SETJEN/KUM.1/8/2016 [25], [26].

E. Verification Approach

Each of the model's four principal assumptions (feedstock LHV, conversion efficiency chain, nameplate capacity, and emission limits) was independently cross-checked against (i) peer-reviewed Indonesian MSW characterization studies [3]–[6], (ii) published WtE plant efficiency benchmarks [7], [8], (iii) contemporaneous news reporting on the PLTSa Cirebon project and three comparable operating Indonesian PLTSa facilities [2], [12]–[14], and (iv) the primary text of the applicable Indonesian environmental regulation [25].

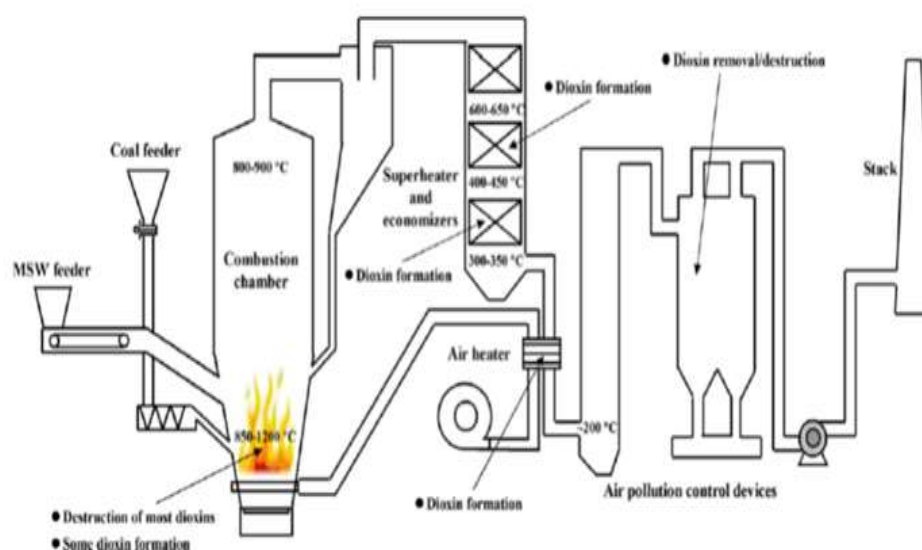


Fig. 1. Process schematic of the MSW/coal-fed incinerator train showing representative zone temperatures and dioxin formation/destruction locations (as provided in the source simulation; a diagram of this general type is consistent with the zone temperatures reported for MSW incinerator boiler trains in the dioxin-formation literature [9], [10]).

III. RESULTS

A. Temperature Profile and Dioxin Risk Zones

Table 1 lists the eight simulated process zones. Three zones superheater, economizer and air heater (625–425 °C), fall in the Formation category and are flagged as high dioxin risk. The combustion chamber and coal feeder (1,050 °C and 850 °C) fall in the Destruction category. The MSW feeder (250 °C), APC inlet (325 °C) and stack (200 °C) are classified Neutral under the model's 400 °C formation-onset threshold.

TABLE 1. TEMPERATURE PROFILE AND DIOXIN RISK CLASSIFICATION PER PROCESS ZONE

Zone	Temp. (°C)	Zone type	Risk	Mechanism
MSW Feeder	250	Neutral	Low	No significant reaction
Coal Feeder	850	Destruction	Low	Thermal destruction (>850 °C)
Combustion Chamber	1050	Destruction	Low	Thermal destruction (>850 °C)
Superheater	625	Formation	HIGH	De novo synthesis (400–650 °C)
Economizer	625	Formation	HIGH	De novo synthesis (400–650 °C)
Air Heater	425	Formation	HIGH	De novo synthesis (400–650 °C)
APC Inlet	325	Neutral	Low	No significant reaction (see IV.D)
Stack	200	Neutral	Low	No significant reaction

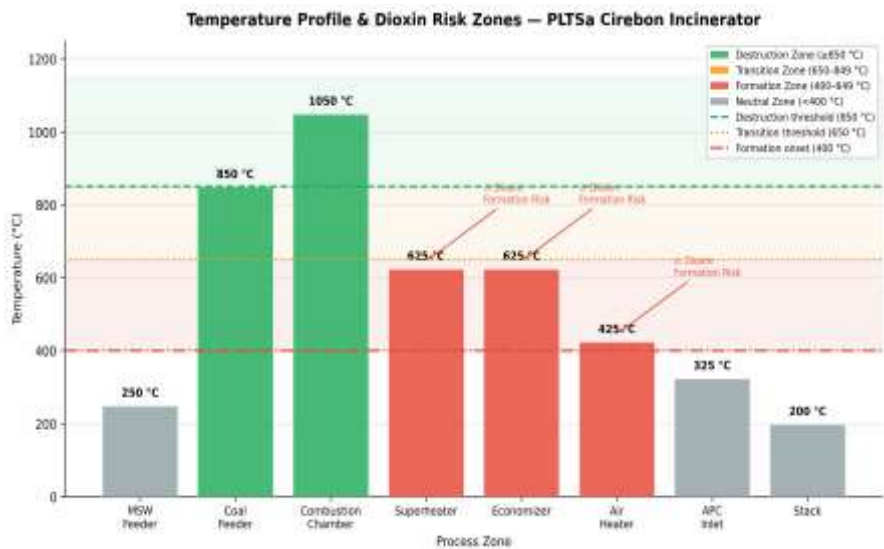


Fig. 2. Simulated temperature profile per process zone relative to the destruction ($\geq 850\text{ }^{\circ}\text{C}$), transition ($650\text{--}849\text{ }^{\circ}\text{C}$) and de novo formation-risk ($400\text{--}649\text{ }^{\circ}\text{C}$) thresholds.

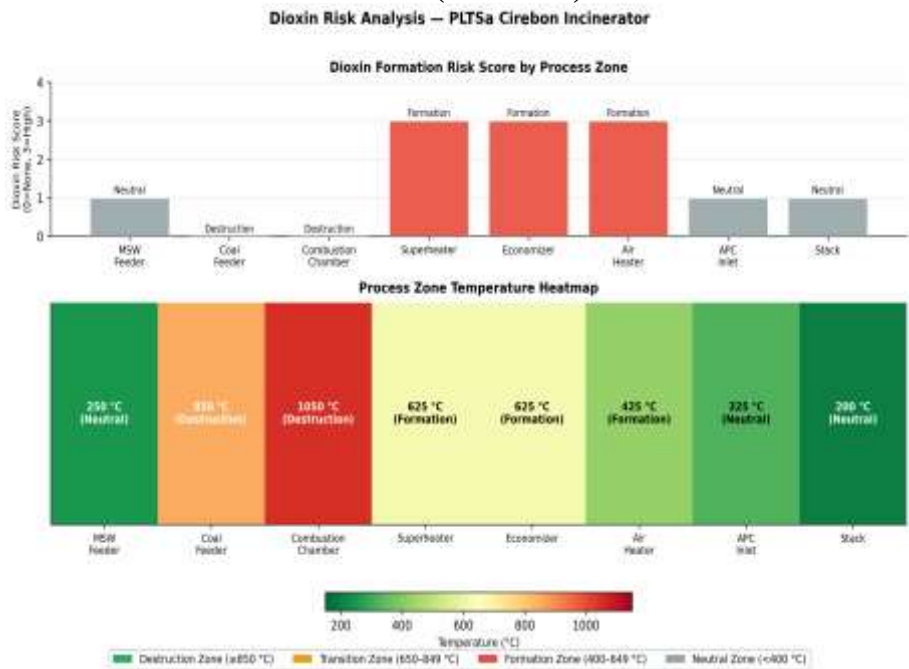


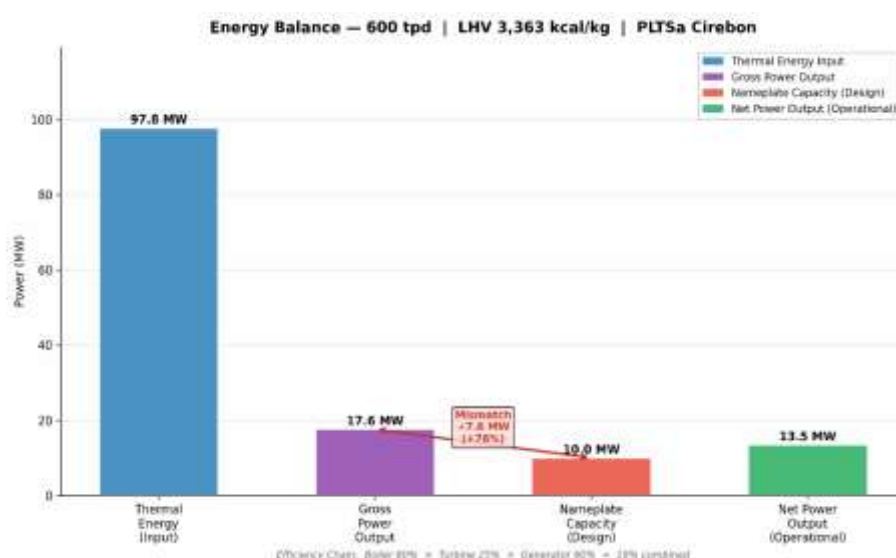
Fig. 3. Dioxin formation risk score (top) and temperature heatmap (bottom) by process zone, highlighting the superheater–economizer–air-heater train as the dominant formation-risk region.

B. Energy Balance and Capacity Sizing

Table 2 reports the energy balance computed from Eqs. (1)–(3). The 600 tpd feedstock at the assumed 3,363 kcal/kg LHV yields a thermal input of 97.8 MW; after the 18% combined boiler turbine generator efficiency, gross electrical output is 17.6 MW, some 7.6 MW (76%) above the plant’s 10 MW nameplate capacity. Applying the 10% parasitic-load and 85% availability factors gives a nominal net output of 13.5 MW and an annual net energy of 117.9 GWh/yr, with 66.6 GWh/yr nominally "curtailed" relative to the nameplate limit.

TABLE 2. SIMULATED ENERGY BALANCE FOR THE 600 TPD PLTSa CIREBON REFERENCE PLANT

Parameter	Value	Unit
Feedstock throughput	600.0	t/day
Assumed LHV	3,363	kcal/kg
Thermal energy input	97.8	MW(th)
Combined conversion efficiency (80%×25%×90%)	18.0	%
Gross electrical output	17.6	MW(e)
Nameplate capacity (announced, [2],[12])	10.0	MW(e)
Gross–nameplate mismatch	+7.6 (+76%)	MW(e)
Net electrical output (model, uncapped)	13.5	MW(e)
Annual net energy	117.9	GWh/yr
Nominal curtailed energy	66.6	GWh/yr
Reported capacity factor (net/nameplate)	135* (flagged, see IV.C)	%

**Fig. 4.** Energy-balance waterfall from thermal input through gross output, nameplate capacity, and net output, showing the modeled +7.6 MW (+76%) gross-to-nameplate mismatch.

C. Emission Compliance

Table 3 reports post-APC concentrations at a uniform assumed 99.5% removal efficiency, with dioxin expressed in toxic-equivalency (TEQ) units following the WHO 2005 re-evaluation of mammalian and human toxic equivalency factors [29]. Under the script's internal limits, only particulate matter (25 mg/Nm³ against an assumed 10 mg/Nm³ limit) fails; all other parameters (dioxin, HCl, SO_x, NO_x, heavy metal) pass.

TABLE 3. POST-APC EMISSION CONCENTRATIONS VS. SCRIPT-ASSUMED LIMITS AND THE VERIFIED INDONESIAN NATIONAL STANDARD

Parameter	Baseline	After APC (99.5%)	Script limit	Script status	P.70/2016 limit [25]
Dioxin (ng TEQ/Nm ³)	10.0	0.050	0.10	PASS	0.10
Particulate (mg/Nm ³)	5000	25.0	10.0	FAIL	120
HCl (mg/Nm ³)	800	4.0	10.0	PASS	10
SO _x (mg/Nm ³)	400	2.0	50.0	PASS	210
NO _x (mg/Nm ³)	500	2.5	200	PASS	470
Heavy metal (mg/Nm ³)	5.0	0.025	0.05	PASS	n/a*

*Permen LHK P.70/2016 regulates individual heavy metals (e.g., Hg ≤ 3 mg/Nm³) rather than a lumped parameter, so the script's lumped heavy-metal value is not directly comparable to the national standard. Under the verified national limit, the modeled particulate concentration (25 mg/Nm³) is well within the actual 120 mg/Nm³ limit, meaning the sole "failure" identified by the script does not, in fact, indicate non-compliance under Indonesian regulation.

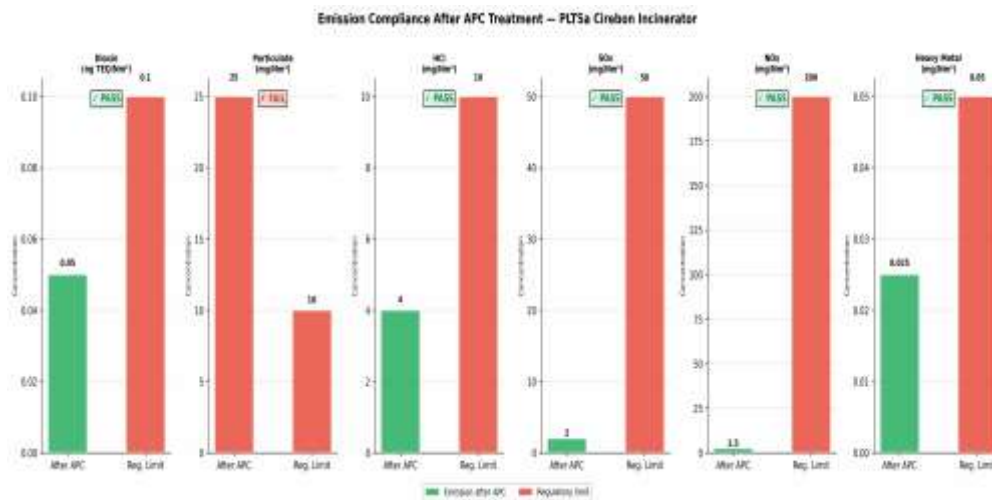


Fig. 5. Post-APC concentrations versus the script-assumed regulatory limit for each pollutant; particulate matter is the only parameter shown failing under the script's internal (non-Indonesian) limit.

IV. DISCUSSION

A. Verifying the Feedstock LHV Assumption

The assumed LHV of 3,363 kcal/kg (≈ 14.1 MJ/kg) is substantially higher than the 5.4–9.5 MJ/kg ($\approx 1,290$ –2,270 kcal/kg) range reported across independent Indonesian MSW characterization studies, which consistently attribute the low heating value to high moisture content (30–57%) in mixed, un-pretreated waste [3]–[6]. A calculated wet-basis LHV of 8.6 MJ/kg has been reported for MSW sampled across several Indonesian cities [4], and 9.5 MJ/kg for a broader multi-city survey [5], both well below the assumed value. The 14.1 MJ/kg figure used in the simulation is more consistent with a dried, pre-treated, or coal-blended fuel stream plausible given that the process schematic (Fig. 1) explicitly shows co-fed coal and MSW streams but this blending assumption is not stated explicitly in the simulation and should be reported quantitatively (e.g., as a percentage coal co-firing ratio) in any engineering-grade version of the model, since the thermal input, and therefore every downstream energy figure in Table 2, scales linearly with the assumed LHV.

B. Verifying the Conversion Efficiency Chain

The assumed combined efficiency of 18% ($0.80 \times 0.25 \times 0.90$) is below the 28–35% electrical efficiency reported for modern, typically larger-scale European WtE plants without heat off-take [7], [8]. This is not necessarily an error: smaller-scale plants such as the 600 tpd Cirebon facility are subject to unfavorable economies of scale in steam-cycle efficiency, and a conservative combined efficiency near 18–20% is plausible for a small single-line grate incinerator without advanced heat-recovery stages. However, because the LHV assumption (Section IV.A) is itself likely overestimated relative to raw Indonesian MSW, and the efficiency assumption is conservative relative to modern large-plant benchmarks, these two deviations act in partly offsetting directions on the gross-power estimate; their net effect on the reported 76% capacity mismatch cannot be resolved without plant-specific fuel-sampling and turbine-selection data, and the mismatch figure should therefore be treated as indicative rather than as a validated design deficiency.

C. Internal Consistency of the Net-Power and Capacity-Factor Calculation

A specific internal inconsistency was identified in the energy balance model: net power is computed as gross power reduced only by parasitic load and availability factors (Eq. 3), without capping the result at the plant's nameplate rating. Because the modeled gross output (17.6 MW) already exceeds the nameplate capacity (10 MW), the resulting "net" output (13.5 MW) remains above nameplate, yielding a reported capacity factor of 135%, which is definitionally impossible—a capacity factor is bounded at 100% by the installed nameplate rating in any real plant, since a turbine-generator set physically cannot export more power than it is rated for; any thermal energy in excess of what the turbine-generator can absorb must instead be dissipated (e.g., via steam-dump/bypass to the condenser) rather than delivered to the grid. This finding does not invalidate the underlying observation that the thermodynamically implied gross output exceeds the nameplate rating which remains a legitimate design question but it does mean that the specific "net power" and "curtailed energy" figures reported by the model (13.5 MW and 66.6 GWh/yr) are not physically meaningful as stated and should be recalculated with net output capped at the nameplate rating before being used for any techno-economic conclusion.

D. Benchmarking Nameplate Capacity Against Comparable Indonesian Projects

Contemporaneous project reporting provides an independent check on whether 10 MW is a reasonable nameplate rating for 600 tpd of feedstock. The Surakarta PLTSa (Putri Cempo), operating since 2024, processes 545 tpd for 5 MW (≈ 220 kWh/ton);

the Surabaya–Benowo PLTSA, operating since May 2021, processes 1,000 tpd for 12 MW (≈ 288 kWh/ton); the planned Semarang PLTSA is designed to process approximately 910 tpd (70% of the city's 1,300 tpd waste stream) for 20 MW (≈ 527 kWh/ton) [30]; and the Chinese-financed Palembang WtE project is designed for 1,000 tpd and 20 MW (≈ 480 kWh/ton) [2], [13], [14]. The Cirebon project's own announced parameters 600 tpd for 10 MW (≈ 400 kWh/ton) fall within this 220–527 kWh/ton range observed across five real, financed or operating Indonesian WtE projects [2], [12]. This is a materially different conclusion from the simulation's implied 17.6 MW gross figure (≈ 704 kWh/ton before parasitic and availability losses), which sits above the entire observed range. Taken together with Sections IV.A and IV.B, this comparison suggests that the reported "critical sizing mismatch" more likely reflects compounding optimistic assumptions in the screening-level thermal model (LHV, efficiency chain) than an actual design flaw in the announced 10 MW nameplate rating, which is broadly consistent with comparable, independently reported Indonesian WtE project economics.

E. Dioxin Risk Zone Classification

The model's 400–650 °C "Formation" window correctly captures the superheater, economizer and air-heater zones (625–425 °C) as high-risk, consistent with the de novo synthesis mechanism described by Stanmore [9] and McKay [10]. However, published de novo synthesis kinetics generally place the maximum formation rate near 250–350 °C rather than uniformly across 400–650 °C [9], [27], meaning the APC-inlet zone at 325 °C, classified "Neutral/Low" under the model's 400 °C formation-onset threshold, sits inside, rather than outside, the reported peak de novo window. This suggests the 400 °C lower bound used for the Formation category in this version of the model is a conservative simplification that may understate risk at the APC inlet, and a more literature-consistent threshold (e.g., 200–400 °C peak, with a broader 200–650 °C "at-risk" band, as used in this group's earlier kinetic analysis of the same facility [28]) is recommended for future iterations.

F. Emission Compliance and Regulatory Citation

As in the companion kinetic analysis of this facility [28], the emission limits embedded in the simulation script are only partially aligned with the actual Indonesian national standard for thermal waste treatment, Permen LHK No. P.70/MENLHK/SETJEN/KUM.1/8/2016 [25], [26]. The dioxin (0.10 ng TEQ/Nm³) and HCl (10 mg/Nm³) limits used in the script match the national standard exactly, but the particulate limit (10 mg/Nm³) used in the script is twelve times stricter than the actual national limit (120 mg/Nm³). Consequently, the sole compliance failure reported by the model, particulate matter at 25 mg/Nm³, does not represent an actual regulatory non-compliance under Indonesian law; the modeled particulate concentration remains well within the 120 mg/Nm³ national limit. This finding reinforces the general recommendation, consistent with the companion analysis of this facility [28], that emission-limit values used in screening models be sourced and cited directly from the applicable national regulation rather than from unlabelled or generic "Indonesia/EU" assumptions.

V. Conclusion

An independent verification of a screening-level energy, dioxin-risk and emission-compliance simulation for the proposed 10 MW/600 tpd titanium-structured PLTSA Cirebon incinerator finds that its headline conclusion — a 76% mismatch between thermodynamically implied gross power (17.6 MW) and nameplate capacity (10 MW) — rests on a feedstock LHV assumption (3,363 kcal/kg) that is 1.5–2.6 times higher than typical raw Indonesian MSW values reported in the literature, combined with a conservative 18% conversion-efficiency chain well below the 28–35% typical of modern large-scale WtE plants; these assumptions act in partly offsetting directions and the net effect on the mismatch figure cannot be resolved without plant-specific data. Benchmarking against five comparable Indonesian PLTSA projects shows the Cirebon plant's announced 10 MW/600 tpd rating (400 kWh/ton) is consistent with real project specific yields of 220–527 kWh/ton, suggesting the nameplate rating itself is defensible. A specific model inconsistency net electrical output not capped at nameplate capacity, producing a 135% capacity factor was identified and should be corrected before any techno-economic conclusion is drawn from the model's curtailment estimate. Dioxin risk-zone classification correctly identifies the superheater economizer air-heater train as the dominant formation-risk region, though the 400 °C formation-onset threshold used may understate risk at the 325 °C APC-inlet zone relative to the 250–350 °C peak de novo window reported in the literature. Finally, cross-verification against the actual Indonesian thermal-waste-treatment emission standard (Permen LHK No. P.70/2016) shows that the model's sole reported compliance failure (particulate matter) is not an actual regulatory non-compliance, underscoring the importance of citing verified national regulatory limits rather than generic or unlabelled benchmarks in engineering and policy-facing simulation studies of Indonesian WtE facilities.

REFERENCES

- [1] Presiden Republik Indonesia, Peraturan Presiden No. 35 Tahun 2018 tentang Percepatan Pembangunan Instalasi Pengolah Sampah Menjadi Energi Listrik Berbasis Teknologi Ramah Lingkungan, 2018. [Online]. Available: <https://waste4change.com/blog/pros-cons-of-accelerating-waste-to-energy-plt-sa-development-in-indonesia/>
- [2] "PLTSA yang akan Dibangun di Cirebon Berkapasitas 10 Megawatt," *Bisnis.com*, Jul. 17, 2025. [Online]. Available: <https://bandung.bisnis.com/read/20250717/550/1894048/plt-sa-yang-akan-dibangun-di-cirebon-berkapasitas-10-megawatt>
- [3] T. H. Nufus et al., "Analyzing the Lower Heating Value (LHV) in Urban Waste Management: Optimizing Energy Efficiency in Urban Areas," *IOP Conference Series: Earth and Environmental Science*, vol. 1504, art. 012015, 2025, doi: 10.1088/1755-1315/1504/1/012015.

- [4] "Experimental study on characteristics of municipal solid waste (MSW) in typical cities of Indonesia," 2020. [Online]. Available: <https://www.researchgate.net/publication/341875775>
- [5] "Overview of Municipal Solid Waste Generation and Energy Utilization Potential in Major Cities of Indonesia," IOP Conference Series: Earth and Environmental Science, vol. 1858, art. 012064, 2021, doi: 10.1088/1742-6596/1858/1/012064.
- [6] D. M. Novita and E. Damanhuri, "Heating value based on composition and characteristics of municipal solid waste in Indonesia in waste to energy concept," Jurnal Teknik Lingkungan, cited in: A. B. D. Nandiyanto et al., "Life cycle environmental benefit and waste-to-energy potential of municipal solid waste management scenarios in Indonesia," Journal of Material Cycles and Waste Management, 2022, doi: 10.1007/s10163-022-01441-6.
- [7] "Waste-to-energy plants: Key issues that impact electrical efficiency," NS Energy Business, Aug. 10, 2022. [Online]. Available: <https://www.nsenergybusiness.com/analysis/waste-to-energy-plants-key-issues-that-impact-electrical-efficiency/>
- [8] "How to reduce energy consumption in waste incineration plants," Explosion Power, 2025. [Online]. Available: <https://www.explosionpower.ch/en/artikel/how-can-the-electrical-energy-consumption-of-a-waste-incineration-plant-be-reduced/>
- [9] B. R. Stanmore, "The formation of dioxins in combustion systems," Combustion and Flame, vol. 136, no. 3, pp. 398–427, Feb. 2004, doi: 10.1016/j.combustflame.2003.11.004.
- [10] G. McKay, "Dioxin characterisation, formation and minimisation during municipal solid waste (MSW) incineration: review," Chemical Engineering Journal, vol. 86, no. 3, pp. 343–368, Apr. 2002, doi: 10.1016/S1385-8947(01)00228-5.
- [11] Presiden Republik Indonesia, Peraturan Presiden No. 18 Tahun 2016 tentang Percepatan Pembangunan Instalasi Pengolah Sampah Menjadi Energi Listrik Berbasis Teknologi Ramah Lingkungan, 2016. [Online]. Available: <https://sw-indo.com/perpres-pembangkit-listrik-tenaga-sampah-pltsa/>
- [12] "Pemkab Cirebon memproyeksikan PLTSa olah 600 ton sampah per hari," ANTARA News Jawa Barat, Jul. 16, 2025. [Online]. Available: <https://jabar.antaranews.com/berita/627881/>
- [13] "Daftar 15 Proyek Pembangkit Sampah di RI dan Pengembangnya," Bisnis.com, Sep. 30, 2025. [Online]. Available: <https://hijau.bisnis.com/read/20250930/652/1916064/daftar-15-proyek-pembangkit-sampah-di-ri-dan-pengembangnya>
- [14] International Energy Agency, "Case 7. Palembang waste-to-energy plant," China's Official Energy Finance in Emerging and Developing Economies. [Online]. Available: <https://www.iea.org/reports/chinas-official-energy-finance-in-emerging-and-developing-economies/case-7-palembang-waste-to-energy-plant>
- [15] A. B. D. Nandiyanto et al., "Life cycle environmental benefit and waste-to-energy potential of municipal solid waste management scenarios in Indonesia," Journal of Material Cycles and Waste Management, 2022, doi: 10.1007/s10163-022-01441-6.
- [16] Y. Zhou et al., "Analysis and discussion on formation and control of dioxins generated from municipal solid waste incineration process," Journal of the Air & Waste Management Association, vol. 72, no. 10, 2022, doi: 10.1080/10962247.2022.2100843.
- [17] European Commission, "Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (Recast)," Official Journal of the European Union, 2010. [Online]. Available: <https://eur-lex.europa.eu/eli/dir/2010/75/oj/eng>
- [18] Corrosion Materials, "Titanium Grade 2," technical datasheet. [Online]. Available: <https://corrosionmaterials.com/alloys/titanium-grade-2/>
- [19] UPMET, "Titanium Grade 2, Sheet, Bar, Plate, AMS 4902 (CP Grade 2) – UNS R50400," technical datasheet. [Online]. Available: <https://www.upmet.com/products/titanium/cp-grade-2>
- [20] "Activated carbon treatment of municipal solid waste incineration flue gas," conference paper. [Online]. Available: <https://www.academia.edu/33227315/>
- [21] "Minimum feeding rate of activated carbon to control dioxin emissions from a large-scale municipal solid waste incinerator," Journal of Hazardous Materials, 2008. [Online]. Available: <https://www.sciencedirect.com/science/article/abs/pii/S0304389408006651>
- [22] "Effects of injected activated carbon and solidification treatment on the leachability of polychlorinated dibenzo-p-dioxins and dibenzofurans from air pollution control residues of municipal waste incineration," Chemosphere, 2006. [Online]. Available: <https://www.sciencedirect.com/science/article/abs/pii/S0045653506013452>
- [23] National Research Council (US), "Incineration Processes and Environmental Releases," in Waste Incineration & Public Health, Washington, DC: National Academies Press. [Online]. Available: <https://www.ncbi.nlm.nih.gov/books/NBK233627/>
- [24] "Partitioning and removal of dioxin-like congeners in flue gases treated with activated carbon adsorption," PubMed ID 16488462. [Online]. Available: <https://pubmed.ncbi.nlm.nih.gov/16488462/>
- [25] Ministry of Environment and Forestry of the Republic of Indonesia, Peraturan Menteri Lingkungan Hidup dan Kehutanan No. P.70/MENLHK/SETJEN/KUM.1/8/2016 tentang Baku Mutu Emisi Usaha dan/atau Kegiatan Pengolahan Sampah Secara Termal, 2016. [Online]. Available: <https://jdih.kemenkoinfra.go.id/cfind/source/files/permen-lhk/p.70-2.pdf>

- [26] Citarum Harum Jabar Prov, "Membakar Sampah dalam Insinerator Tidak Boleh Sembarangan," 2025. [Online]. Available: <https://citarumharum.jabarprov.go.id/membakar-sampah-dalam-insinerator-tidak-boleh-sembarangan/>
- [27] "A model for de novo synthesis and decomposition rates of dioxins and furans in municipal waste incinerators," *Chemosphere*. [Online]. Available: <https://www.sciencedirect.com/science/article/abs/pii/004896979190006Z>
- [28] Safrizal, M. Khairudin, and R. Asnawi, "Titanium-Based Incinerator Design for Dioxin Neutralization in Municipal Solid Waste-to-Energy Plants: A Thermal–Kinetic and Techno-Economic Simulation Study of PLTSa Cirebon," unpublished manuscript, companion analysis of the same facility, 2026.
- [29] M. Van den Berg et al., "The 2005 World Health Organization Reevaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-Like Compounds," *Toxicological Sciences*, vol. 93, no. 2, pp. 223–241, Oct. 2006, doi: 10.1093/toxsci/kfl055.
- [30] "The development of waste to energy in Semarang, Indonesia," *IOP Conference Series: Earth and Environmental Science*, 2021. [Online]. Available: <https://www.researchgate.net/publication/356178230>