

# Smart Campus Waste-to-Energy System Using Incineration and PIC-Based Monitoring

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**Abstract:** *The rapid increase in solid waste generation on educational campuses presents significant environmental and operational challenges, including land scarcity, pollution, and underutilization of recoverable energy. Conventional disposal methods such as landfilling are unsustainable, prompting the need for decentralized and energy-efficient waste management solutions. This study proposes a compact waste-to-energy (WTE) system designed for campus-level implementation. The system utilizes controlled high-temperature incineration to thermally decompose mixed solid waste, achieving up to 90% reduction in waste volume. The heat released during combustion is captured and converted into electrical energy using a thermoelectric generator (Peltier module), enabling small-scale and localized power production. A PIC microcontroller-based control unit regulates voltage, monitors system performance, manages battery charging, and ensures safe operation. The generated electricity is stored in a rechargeable battery and supplied to AC loads through an inverter for on-site utilization. To minimize environmental impact, emission control mechanisms are integrated to reduce harmful gases and particulate matter. Experimental results indicate that 0.6 kg of solid waste produces approximately 45 Wh of electricity, corresponding to an energy yield of about 75 Wh/kg under controlled conditions. These findings demonstrate that integrating incineration with thermoelectric power generation offers a practical, sustainable, and decentralized solution for effective solid waste management and supplementary energy generation in educational institutions.*

**Keywords:** Incineration, Waste-to-Energy, Thermoelectric Generator, Renewable Energy, Campus Solid Waste

## I. INTRODUCTION

Solid waste management and rising energy demand are major challenges in modern educational institutions. Campuses generate large quantities of waste from hostels, canteens, laboratories, and offices, and conventional disposal methods like landfilling cause environmental pollution and greenhouse gas emissions. Simultaneously, increasing electricity consumption raises operational costs and carbon footprints. WTE technology offers a sustainable solution by converting solid waste into useful electrical power. This study proposes a campus-level incineration system integrated with thermoelectric generation and microcontroller-based monitoring to ensure safe, efficient, and decentralized energy production. The approach promotes sustainable development by transforming waste into a valuable renewable energy resource. Kumar et al. reported WTE technologies as sustainable solutions for municipal solid waste (MSW) management, where the study [1] evaluates processes such as incineration, gasification, pyrolysis, and anaerobic digestion in terms of technical, environmental, and economic performance, concluding that integrated WTE systems can significantly reduce landfill dependency while contributing to renewable energy generation, particularly in developing nations. In parallel, research [2] reviews technologies for recovering exhaust heat from internal combustion engines to improve efficiency and reduce fuel consumption, covering thermoelectric generators, organic Rankine cycles, six-stroke engines, and advanced turbocharging systems, and concluding that exhaust heat recovery can



substantially enhance engine performance while lowering greenhouse gas emissions. Expanding on thermoelectric technology, the paper [3] provides a comprehensive reference on thermoelectric principles, materials, devices, and systems, emphasizing advances in nano structuring to enhance efficiency (ZT) from macro to nanoscale applications, while the study [4] further reviews waste heat recovery technologies including heat exchangers, organic Rankine cycles, and thermoelectric generators, highlighting their critical role in improving overall energy efficiency and sustainability.

Moreover, the authors [5] analyse sustainable waste management strategies with a focus on energy recovery, emphasizing the environmental benefits of thermal treatment systems and supporting WTE as a viable alternative to conventional landfilling. Supporting this perspective, the research [6] evaluates modern incineration plants and their energy performance, demonstrating significant waste volume reduction and power generation capability while also discussing emission control strategies. In addition, the study

[7] compares gasification and incineration technologies, explaining process parameters affecting energy recovery efficiency and indicating that incineration is more suitable for mixed municipal waste streams. Similarly, A. Johari et al. [8] analyse waste management issues in developing regions and emphasize the importance of WTE for sustainable urban planning, advocating for decentralized waste-to-energy systems.

Further strengthening this argument, the paper [9] reviews thermal waste treatment technologies such as incineration and gasification, comparing efficiency, emissions, and operational parameters, and confirming that incineration remains a reliable and commercially viable WTE method. At the material and device level, the article [10] discusses the practical limitations and efficiency constraints of thermoelectric materials, explaining the figure-of-merit (ZT) concept for evaluating performance and providing essential insight into realistic power output expectations from Peltier modules. Complementarily, the study [11] evaluates the operational efficiency and environmental performance of MSW incineration plants, highlighting energy generation potential and emission reduction benefits, thereby supporting the adoption of incineration for decentralized power systems. Building upon these findings, the review [12] examines recent improvements in MSW incineration efficiency and emission control technologies, particularly advancements in flue gas treatment and energy recovery optimization, and confirms the environmental viability of modern WTE plants. Furthermore, the paper [13] analyzes how operating temperature, waste composition, and moisture content affect incineration performance, showing that optimized combustion significantly improves electrical output and reduces emissions, thereby supporting effective system parameter control in campus-scale WTE systems. In terms of material innovation, the study [14] reviews recent developments in thermoelectric materials for waste heat recovery, discussing efficiency improvements through high-ZT materials and supporting the integration of thermoelectric modules in small-scale energy systems. Finally, the research [15] evaluates small-scale WTE systems in terms of cost, efficiency, and environmental impact, demonstrating that decentralized incineration-based systems are suitable for institutional and community applications and supporting the feasibility of campus-level implementation.

## II. SYSTEM ARCHITECTURE

The proposed WTE system is developed with a comprehensive and integrated architecture that enables efficient conversion of campus solid waste into usable electrical energy. The system primarily consists of an incineration chamber, thermoelectric (Peltier) modules, a voltage sensing unit, a PIC microcontroller, a charging circuit with battery storage, an inverter, and the connected electrical load. Each component plays a vital role in ensuring safe operation, energy conversion, monitoring, and power utilization.

The incineration chamber acts as the core unit of the system, where segregated and pre-treated campus waste is combusted under controlled high-temperature conditions. The combustion process generates a significant amount of thermal energy while simultaneously reducing waste volume and eliminating harmful pathogens. Proper air supply and temperature regulation ensure efficient burning and maximum heat extraction. The heat produced during incineration is transferred to thermoelectric (Peltier) modules placed strategically to create a temperature gradient across their surfaces. Based on the Seebeck effect, these modules directly convert thermal energy into electrical energy without any



moving mechanical parts, making the system compact, reliable, and suitable for small-scale applications. The electrical output generated by the thermoelectric modules is in DC form and varies depending on the temperature difference. To ensure stable system performance, a voltage sensing unit continuously measures the output voltage and sends real-time data to the PIC microcontroller. The microcontroller serves as the control centre of the system, monitoring voltage levels, regulating charging operations, and managing overall system functionality. It ensures protection against overvoltage, overheating, and irregular operating conditions.

The generated electrical energy is then passed through a charging circuit that regulates and stabilizes the output before storing it in a battery. Battery storage allows energy to be utilized even when the incineration process is not active, ensuring continuity of supply. Finally, an inverter converts the stored DC power into AC power, making it compatible with conventional campus electrical loads such as lighting systems, laboratory equipment, and small appliances.

Overall, the integrated architecture ensures efficient waste combustion, effective heat-to-electricity conversion, reliable monitoring, and safe energy utilization, making the system suitable for decentralized campus-level waste-to-energy applications. Fig1. shows the block diagram of the proposed system

After determining the total thermal energy, the next step is to evaluate the useful energy recovered following incineration. Not all the thermal energy generated during combustion is effectively captured due to system losses. Therefore, the useful energy ( $E_{useful}$ ) is obtained by multiplying the total thermal energy ( $E_{th}$ ) by the incineration efficiency ( $\eta_{inc}$ ).

This is expressed as

$$E_{useful} = E_{th} \times \eta_{inc} \quad (2)$$

The incineration efficiency accounts for heat losses in the combustion chamber and heat recovery system.

The useful thermal energy is then converted into electrical energy through a power generation system such as a steam turbine. The electrical energy generated ( $E_{elec}$ ) is calculated by multiplying the useful energy ( $E_{useful}$ ) by the conversion efficiency ( $\eta_{conv}$ ), which represents the efficiency of the energy conversion technology. This relationship is expressed as

$$E_{elec} = E_{useful} \times \eta_{conv} \quad (3)$$

The conversion efficiency reflects thermodynamic limitations and mechanical losses within the power generation unit.

To determine the electrical power output of the system, the generated electrical energy is divided by the operating time ( $t$ ) in hours. The electrical power ( $P$ ), expressed in kilowatts (kW), is therefore calculated as

$$P = E_{elect} \quad (4)$$

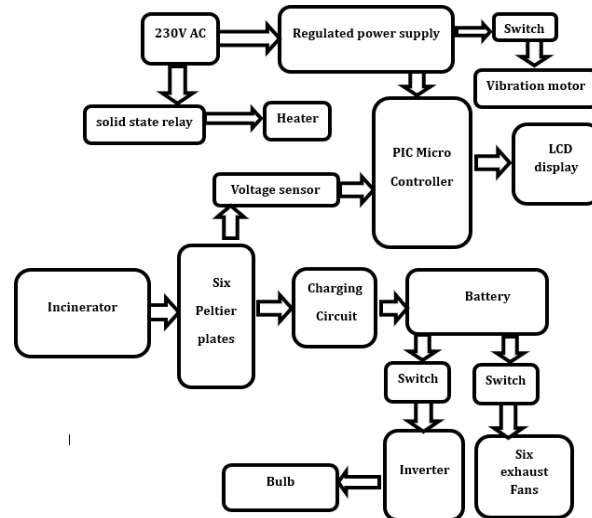


Fig.1 Block Diagram of the Proposed System



### III. MATHEMATICAL MODELLING

The mathematical modelling of the waste-to-energy system begins with estimating the total thermal energy obtainable from the waste material. The thermal energy ( $E_{th}$ ) is calculated as the product of the mass of waste processed ( $M$ ) in kilograms and its calorific value ( $CV$ ) expressed in megajoules per kilogram. Mathematically, this relationship is given as

$$E_{th} = M \times CV \quad (1)$$

This equation represents the total chemical energy stored in the waste that can be released through combustion.

This equation provides the average power output over the specified operating period.

Finally, the efficiency of waste reduction during the incineration process is evaluated using the waste reduction efficiency ( $R$ ). This is calculated by subtracting the mass of residual ash ( $W_{ash}$ ) from the input waste mass ( $W_{in}$ ), dividing by the input waste mass, and multiplying by 100 to express it as a percentage. The formula is given as

$$R = \frac{W_{in} - W_{ash}}{W_{in}} \times 100 \quad (5)$$

This parameter indicates the effectiveness of the incineration process in reducing the volume and mass of solid waste.

### IV. METHODOLOGY

#### A. Waste Collection and Segregation

Waste materials are systematically collected from various campus sources, including classrooms, laboratories, offices. To ensure efficient processing and safe incineration, the collected waste is carefully segregated at the initial stage into combustible and non-combustible categories. Combustible waste typically includes paper and dry waste. The removal of metals, glass, and other non-burnable components is essential to prevent damage to the incinerator, improve combustion efficiency, and reduce the formation of unwanted residues. Proper segregation at this stage enhances the overall performance and environmental sustainability of the system.

#### B. Pre-Treatment

After segregation, the combustible waste undergoes pre-treatment to optimize its suitability for incineration. The first step involves shredding the waste into smaller, uniform pieces. This increases the surface area available for combustion, allowing for more consistent and efficient burning. Following shredding, the waste is subjected to a drying process to reduce its moisture content. High moisture levels can lower combustion temperatures and reduce energy recovery efficiency; therefore, drying improves the calorific value of the waste. Together, shredding and drying ensure stable combustion conditions, minimize smoke production, and enhance overall thermal efficiency.

#### C. Incineration Process

The prepared waste is then fed into the incineration chamber, where it is combusted at high temperatures ranging between 850°C and 1100°C. Maintaining this temperature range is critical to achieving complete oxidation of organic materials and preventing the formation of harmful by-products. High-temperature incineration significantly reduces the volume of waste, often by up to 80–90%, while effectively destroying pathogens, toxic compounds, and hazardous microorganisms. The controlled combustion process ensures that the system operates efficiently and safely, producing a substantial amount of thermal energy for subsequent conversion.

#### D. Energy Conversion

The thermal energy generated during incineration is captured through a heat transfer system integrated within the combustion chamber. This heat is directed to thermoelectric modules, which operate based on the Seebeck effect to directly convert temperature differences into electrical energy. Unlike conventional steam turbine systems, thermoelectric conversion does not require moving mechanical parts, making it relatively compact, low-maintenance, and suitable for small-



to medium-scale applications such as campus waste management. The generated electricity can then be utilized to power campus facilities or stored for later use, contributing to energy sustainability.

### E. Emission Control

To ensure environmental compliance and minimize the impact on air quality, the system incorporates advanced emission control mechanisms. Flue gases produced during incineration pass through pollution control devices such as scrubbers, which remove acidic gases, and high-efficiency filters that capture particulate matter. These components significantly reduce the release of harmful pollutants, including dust, ash, and toxic gases, into the atmosphere. Continuous monitoring of emissions further ensures that the system operates within permissible environmental standards, making the waste-to-energy process both efficient and environmentally responsible. Table-I shows the comparative analysis of the conversion.

TABLE-I: COMPARATIVE ANALYSIS

Parameter	Incineration	Anaerobic Digestion	Gasification	Landfilling
Waste Type	Mixed MSW	Biodegradable	Dry high-calorific	All waste
Volume Reduction	70–90%	30–40%	60–80%	<20%
Energy Output	High	Medium	High	Very Low
Space Requirement	Low	Medium	Medium	Very High
Suitability for Campus	High	Medium	Medium	Low

### V. RESULTS

The prototype was tested under continuous operation for a duration of one hour to evaluate its electrical performance and fuel efficiency. During the test, the system maintained a stable output voltage of 15 V while supplying a load current of 3 A. Using the standard electrical power relation

$$P=V \times I \quad (3)$$

the output power was calculated

$$P=15 \times 3=45 \text{ W} \quad (4)$$

This indicates that the prototype consistently delivered 45 watts of electrical power throughout the testing period.

The total energy generated during the one-hour operation was determined using the relation

$$E=P \times t \quad (5)$$

Substituting the measured values, the energy output was  $E=45 \times 1=45 \text{ Wh} = 162 \text{ J}$  (6)

For standard energy unit comparison, this value was converted into joules. Therefore, the system generated 45 Wh (162 kJ) of electrical energy during the test period.

Fuel consumption was also measured to evaluate the energy yield of the system. Over the one-hour test duration, the prototype consumed 0.6 kg of fuel. Based on the total energy produced (45 Wh), the specific energy yield of the system was calculated as

$$\text{Energy Yield} = 45 \text{ Wh} / 0.6 \text{ Kg} = 75 \text{ Wh/Kg} \quad (7)$$

This means that for every kilogram of fuel consumed, approximately 75 Wh of electrical energy was generated.

Overall, the results demonstrate that the prototype operated steadily under load conditions, delivering a consistent 45 W output power with an energy yield of approximately 75 Wh per kilogram of fuel during the one-hour evaluation period.

Fig.2 shows the hardware model of WTE Conversion System and Fig.3 shows control and power generation circuit setup with PIC Microcontroller and load output.



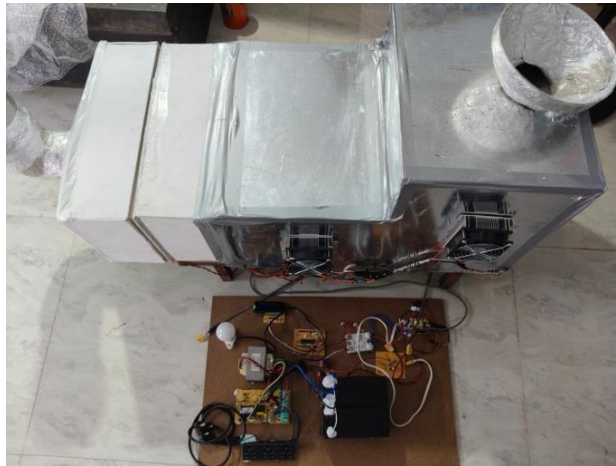


Fig.2. Hardware Model of WTE Conversion System



Fig.3. Control and Power Generation Circuit Setup with PIC Microcontroller and Load Output.

## VI. CONCLUSION

The proposed incineration-based WTE system successfully demonstrates a practical and innovative approach to converting campus solid waste into electrical energy. The system effectively addresses two major challenges faced by educational institutions: increasing solid waste generation and rising energy demand. By utilizing controlled high-temperature incineration, the volume of waste is significantly reduced up to 70–90%, while simultaneously recovering valuable thermal energy. This process not only minimizes the burden on landfills but also reduces environmental pollution and improves overall campus cleanliness.

The incorporation of thermoelectric (Peltier) modules enables the direct conversion of heat energy into electrical power, providing a compact and efficient energy recovery method suitable for small-scale applications. Furthermore, the integration of a PIC microcontroller-based monitoring and control system enhances operational safety, reliability, and efficiency. Continuous monitoring of voltage, temperature, and power output ensures stable system performance, while battery storage and inverter arrangements allow effective energy utilization for campus loads.

Experimental results indicate that the system is capable of generating measurable electrical output from a relatively small quantity of campus solid waste, demonstrating its feasibility for localized energy production. In addition to energy generation, the system promotes sustainable waste management practices, supports environmental conservation, and contributes to circular economy principles.



Overall, the project offers an eco-friendly, cost-effective, and scalable solution that can be implemented in educational campuses and small communities. With further improvements in thermoelectric efficiency, emission control mechanisms, and automation, the system has strong potential for future expansion and real-world application in sustainable waste-to-energy management.

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