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# From Waste to Watts: A Photovoltaic Approach to Harvesting Flame Energy

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## ABSTRACT

This paper presents a novel approach for energy generation using light emitted from waste combustion. The system utilizes photovoltaic panels to convert flame-generated light into electrical energy. The generated energy is regulated using a DC conversion stage and stored in a rechargeable battery system. The system also demonstrates basic energy monitoring through voltage and current measurement. Although the intensity of flame light is significantly lower than sunlight, the proposed model effectively illustrates the concept of alternative energy generation using waste resources. The project highlights the integration of renewable energy principles with waste management for sustainable applications.

## 1. INTRODUCTION

The continuous growth in global energy demand, coupled with the rapid depletion of fossil fuel reserves and increasing environmental concerns, has driven the need for sustainable and renewable energy solutions. Conventional energy sources such as coal, petroleum, and natural gas not only contribute to environmental pollution but are also limited in availability. As a result, significant research efforts have been directed toward renewable energy technologies, including solar, wind, hydro, and biomass systems. Among these, solar energy stands out as one of the most abundant and widely utilized renewable resources due to its clean nature and the availability of mature photovoltaic conversion technologies.

In parallel with renewable energy development, waste management has become a critical global issue. Large quantities of solid and organic waste are generated daily, and improper disposal leads to environmental degradation. Waste-to-energy (WTE) technologies have emerged as an effective solution to address both waste disposal and energy generation simultaneously. Traditionally, these systems focus on extracting thermal energy from waste through combustion, gasification, or pyrolysis processes. The generated heat is then used to produce steam or drive turbines for electricity generation.

However, during combustion, waste materials not only release heat but also emit visible light energy in the form of flames. This light energy is typically overlooked and dissipated into the environment without any attempt at utilization.

The light emitted from combustion processes contains electromagnetic radiation in the visible and near-infrared spectrum. Although its intensity is lower and more variable compared to sunlight, it still possesses the potential to generate electrical energy when incident on photovoltaic cells. Conventional photovoltaic systems are optimized for solar radiation; however, they can also respond to artificial light sources such as incandescent light, LEDs, and flames. This opens up a unique opportunity to explore the conversion of flame-generated light into electrical energy, especially in small-scale or experimental setups. Such an approach can contribute to enhancing the overall efficiency of waste-to-energy systems by utilizing multiple forms of energy released during combustion.

This project focuses on investigating the feasibility of capturing light emitted from waste combustion using photovoltaic panels and converting it into usable electrical energy. The objective is not to replace conventional solar systems but to demonstrate an alternative and supplementary energy harvesting technique. By placing a solar panel in proximity to a controlled flame source, the system captures light energy and produces a measurable electrical output, which can be analysed for performance and efficiency.

To enhance the functionality and usability of the system, real-time monitoring and data processing capabilities are integrated. The INA219 is used to measure voltage and current accurately, enabling calculation of electrical power generated. Additionally, battery voltage is monitored using a voltage divider connected to the analog-to-digital converter (ADC) of the ESP-12E. The ESP8266 acts as the central

## 2. LITERATURE REVIEW

Previous studies in the field of renewable energy have primarily focused on photovoltaic energy generation using sunlight as the main source. Photovoltaic panels are designed to operate efficiently under solar radiation, converting light energy into electrical energy through the photovoltaic effect. However, several studies have also demonstrated that photovoltaic cells can respond to artificial light sources such as incandescent lamps, LEDs, and flames, although with significantly lower efficiency due to differences in light intensity and spectral distribution. This indicates that while artificial light is not a primary energy source for photovoltaic systems, it can still be utilized for experimental and low-power energy generation applications.

In parallel, research on thermoelectric generators (TEGs) has shown that heat-based energy conversion is often more efficient in combustion systems. TEGs directly convert temperature differences into electrical energy and are widely studied for waste heat recovery in industrial and thermal processes. Since combustion produces a substantial amount of heat, TEG-based systems generally offer higher efficiency compared to light-based conversion methods. However, TEGs require proper thermal gradients, heat sinks, and more complex implementation, whereas light-based systems using photovoltaic panels are simpler, safer, and easier to integrate, especially for small-scale or demonstration setups.

Furthermore, recent advancements in IoT technologies have enabled the development of smart energy monitoring systems that allow real-time tracking and analysis of renewable energy performance. Devices such as the ESP-12E have been widely used due to their low cost, built-in WiFi capability, and ease of integration. Sensors like the INA219 are commonly employed to measure electrical parameters such as voltage and current with high accuracy. These systems are often connected to cloud platforms like Blynk IoT, enabling remote monitoring, data visualization, and user interaction.

Overall, existing research highlights that while photovoltaic systems are most effective with solar energy, they can still function with artificial light sources for experimental purposes. At the same time, IoT-based monitoring enhances system usability by providing real-time insights and control. This project builds upon these concepts by combining light-based energy conversion from combustion with IoT-enabled monitoring, offering a novel approach to exploring alternative energy utilization methods.

## 3. METHODOLOGY

The methodology of the proposed system is divided into multiple stages, including energy generation, conversion, storage, and utilization. The system is designed to demonstrate the conversion of light energy obtained from waste combustion into electrical energy using photovoltaic panels.

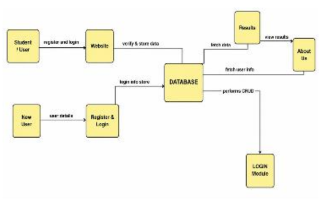


**Figure 1:** Model Architecture of the Proposed System

### A. System Design Approach

The system is based on a hybrid concept of waste management and renewable energy conversion. The design focuses on capturing light emitted during combustion and converting it into electrical energy using photovoltaic cells.

The overall system is divided into the following subsystems:

- Energy generation unit
- Energy conversion unit
- Energy storage unit
- Output and monitoring unit

Each subsystem is designed to ensure proper energy flow and system stability.

### B. Photovoltaic Energy Generation

The energy generation stage utilizes solar panels to convert incident light into electrical energy based on the

**Photovoltaic Effect:** When photons from the flame strike the photovoltaic surface, electrons are excited, generating a direct current (DC). The generated voltage depends on light intensity, while the current depends on both light intensity and panel characteristics. Multiple small solar panels are interconnected to improve overall output. Panels are arranged in a combination of series and parallel configurations to achieve the required voltage and current levels.

### C. Panel Configuration and Optimization

To obtain a usable output, solar panels are arranged in a structured configuration:

- Series connection increases voltage
- Parallel connection increases current

The system uses a mixed configuration (series-parallel) to maintain a balance between voltage and current. Proper wiring and connection techniques are used to minimize losses and ensure maximum power extraction.

### D. Energy Conversion Stage

The output from the solar panels is not stable due to fluctuations in light intensity. Therefore, a voltage regulation stage is required. A Buck Converter Module is used to regulate the varying input voltage to a constant output level.

The buck converter performs the following functions:

- Reduces high input voltage to required level
- Maintains constant output despite fluctuations
- Improves system efficiency

The regulated output is used for charging and powering low-power loads.

### E. Energy Storage Mechanism

The generated electrical energy is stored in rechargeable batteries for later use. Lithium-ion batteries are preferred due to their high energy density and efficiency. A controlled charging mechanism is implemented to ensure safe operation. The charging circuit maintains appropriate voltage and current limits to avoid overcharging and overheating.

### F. DC to AC Conversion Stage

In order to utilize the stored energy for conventional electrical appliances, a DC to AC conversion stage is implemented. The stored DC energy from the battery is converted into alternating current (AC) using an inverter circuit.

An inverter is an electronic device that converts low-voltage DC input (12V) into high-voltage AC output (220V). The inverter circuit consists of switching components and a step-up transformer to generate AC output suitable for powering small AC loads.
The conversion process involves:

- Switching DC using oscillator circuitry
- Generating alternating waveform
- Stepping up voltage using transformer

The AC output is used to operate low-power loads such as LED bulbs.

### G. Load and Utilization

The stored energy is utilized to power small electrical loads such as:

- 3 – 5 Watt AC LED bulb
- Low-power electronic devices
- Monitoring systems

The system demonstrates the practical usability of generated energy in real-time applications

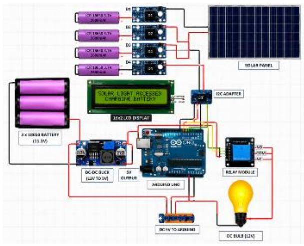

**Figure 2:** Circuit diagram

The designed circuit is a solar-based IoT energy monitoring system that combines power generation, storage, and monitoring in one setup. The system starts with a solar panel, which converts Fire light into electrical energy and supplies DC power to multiple TP4056 modules. These modules safely charge individual 18650 lithium-ion cells, forming a battery that stores energy for later use. The stored energy is then regulated using a buck converter and an AMS1117 to provide stable voltage for the electronic components.

For monitoring, the circuit uses an INA219 sensor to measure voltage and current from the source. A voltage divider is used to reduce the battery voltage so it can be read safely by the ADC of the ESP-12E. The ESP8266 processes all the data, calculates power and estimated runtime, and sends the information to the cloud. The results are shown on a 16x2 LCD for local viewing and also sent to the Blynk IoT for remote monitoring. The stored DC energy can also be converted into AC using an inverter to run devices like a bulb. Overall, this system helps monitor energy usage, battery condition, and runtime in a simple and smart way.

*H. System Operation*

The complete operation of the system can be described in the following steps:

- Waste materials are burned in a controlled environment
- Flame emits light energy
- Light falls on solar panels
- Panels generate DC voltage
- Voltage is regulated using buck converter
- Energy is stored in battery
- The stored DC energy is converted into AC using an inverter circuit
- The generated AC output powers low-power AC loads such as LED bulb

*I. . Mathematical Representation*

The output power generated by the photovoltaic system can be expressed as:

$$P = V \times I$$

Where:

- P= Output power (Watt)
- V= Output voltage (Volt)
- I= Output current (Ampere)

The efficiency of the system depends on light intensity and conversion efficiency of the photovoltaic panel.

*J. System Limitations Consideration*

During the design process, the following limitations are considered:

- Low intensity of flame light
- Fluctuating input conditions
- Limited current output
- Conversion losses

Appropriate design adjustments are made to ensure stable demonstration despite these limitations.

## 4. RESULTS AND DISCUSSION

The system successfully demonstrates voltage generation from flame light. However, due to low intensity of the light source, the output power is limited. Voltage generation is observed, but current output is significantly lower compared to standard solar conditions.

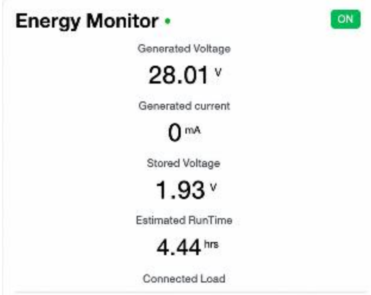


**Figure 3:** Performance analysis

The developed system is an IoT-based energy monitoring system that shows real-time electrical values and also predicts battery performance and runtime. The INA219 sensor is used to measure the generated voltage and current from the power source, so the input energy can be monitored continuously. At the same time, the battery voltage is measured using a voltage divider connected to the ADC of the ESP-12E, which helps in understanding the battery condition and available energy. The system also takes load power input from the Blynk IoT, and based on this, it calculates how long the battery can run the load.

Some important calculations used in the program include power and runtime estimation. Power is calculated using the formula P=V×I, where voltage and current are measured by the sensor. The battery energy is calculated using Energy=Voltage× Capacity (Ah). Using this energy, the runtime is estimated as

Runtime = (Energy ×Efficiency) /Load

Where Load is User Input and efficiency is taken 80 % accounts for losses in the inverter. All the results, including voltage, current, and runtime, are displayed on a 16x2 LCD and also sent to the cloud for remote monitoring. The user can change the load value from the mobile app, and the system updates the results accordingly. An LED is used to indicate internet connection status. Overall, the system not only shows real-time data but also provides useful calculations to understand energy usage and battery backup in a simple way.

The system is effective for

- Concept demonstration
- Educational purposes

Limitations include

- Low efficiency
- Dependency on light intensity

Advantages

- Utilizes waste materials
- Eco-friendly approach
- Simple and low-cost system
- Demonstrates renewable energy concept

Limitations

- Low power output
- Not suitable for large-scale applications
- Flame light intensity is insufficient
- Efficiency is very low

## CONCLUSION

The project demonstrates a novel method of generating electrical energy from waste combustion light using photovoltaic panels. Although the efficiency is low, the system effectively illustrates the concept of alternative energy utilization. This approach can be further enhanced by integrating heat-based energy conversion methods or improving light intensity capture mechanisms. light using photovoltaic panels. Although the efficiency is low, the system effectively illustrates the concept of alternative energy utilization. This approach can be further enhanced by integrating heat-based energy conversion methods or improving light intensity capture mechanisms.

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