

# Underground Power Vacuum Garbage Collector

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**Abstract**—Rapid urbanization and increasing population have resulted in a significant rise in municipal solid waste generation. Traditional waste collection methods often lead to overflowing bins, traffic congestion, unpleasant odors, and high operational costs. To overcome these challenges, this paper presents an Underground Power-Vacuum Garbage Collector System based on ESP32 and IoT technology. The proposed system utilizes ultrasonic sensors to monitor garbage levels and automatically activates a vacuum pump when the waste reaches a predefined threshold. Waste is transported through underground PVC pipelines to a centralized collection chamber, reducing human intervention and improving hygiene. Experimental testing demonstrated reliable waste-level detection and efficient transportation of lightweight waste materials. The proposed system provides a smart, automated, and environmentally friendly solution for modern urban waste management and smart-city applications.

**Index Terms**—Underground Garbage Collection, Vacuum Waste Collection, Pneumatic Transport System, Smart Waste Management, IoT Sensors, Sustainable Cities, Urban Infrastructure, Automated Waste Collection

## I. INTRODUCTION

The Underground Power-Vacuum Garbage Collector is an innovative waste collection system designed to address the limitations of conventional waste management practices. The system uses electrically powered vacuum technology to transport waste through underground pipelines from disposal points to a centralized collection station. By eliminating the need for frequent garbage truck movements and reducing direct human contact with waste, the system offers a cleaner, safer, and more efficient approach to

waste handling. The underground infrastructure also enhances urban aesthetics by removing visible waste containers

The rapid growth of urban populations and industrial activities has led to a significant increase in municipal solid waste generation worldwide. Traditional waste collection methods, which rely on manual collection and transportation by garbage trucks, often face challenges such as overflowing bins, traffic congestion, high operational costs, unpleasant odors, and environmental pollution. These issues not only affect urban cleanliness but also pose serious risks to public health and sustainable city development. As cities continue to expand, there is a growing need for advanced and efficient waste management systems that can handle increasing waste volumes while minimizing environmental impact.

This research paper focuses on the design, working principle, components, advantages, challenges, and future prospects of the Underground Power-Vacuum Garbage Collector system. The study aims to evaluate its effectiveness as a sustainable waste management solution and explore its potential role in developing cleaner, smarter, and environmentally friendly urban environments. By examining current technologies and implementation strategies, this paper highlights how vacuum-based underground waste collection can contribute to improving public sanitation and enhancing the quality of life in modern cities.

## II. LITERATURE REVIEW

Pneumatic or vacuum-driven urban waste collection systems (often termed Automated Waste Collection Systems — AWCS, or Automated Vacuum Waste

Collection — AVWC) use underground pipelines and suction (vacuum pumps) to transport waste from distributed inlets to a centralized collection station. Interest in AWCS has risen because they can reduce street-level truck traffic, noise, odours and improve urban hygiene particularly attractive for high-density, constrained, or heritage city centres. The most recent comprehensive review synthesizes architectures, case studies and research directions for AWCS

Various cities and districts have implemented industrial systems (Envac and similar providers) demonstrating real-world viability (e.g., Hammarby Sjöstad, Barkarbystaden, Battery Park City/Manhattan feasibility studies, Bergen's expansion). These cases show significant reductions in truck kilometres and improved cleanliness, but also highlight high capital and maintenance costs and energy trade-offs factors that strongly shape feasibility.

Academic and industry LCA and feasibility studies compare AWCS to conventional truck-based collection; results depend heavily on assumptions about energy source, system scale and operational patterns sometimes AWCS shows net environmental benefit, sometimes not. That sensitivity makes energy-use optimization and accurate LCA modelling key research points.

I. Smaller-scale academic work and IOT smart-bin projects provide well-established sensor/control approaches (ultrasonic fill-level sensing, pressure monitoring, microcontroller control and communications) which are directly applicable when building prototype AWCS control systems

### III. PROPOSED SYSTEM

Below are the main technologies, techniques and engineering concerns found in the literature and industry practice with their role for your prototype.

#### A. Hardware Components

The ESP32 microcontroller forms the computational core of the system. Its multiple UART, SPI, I2C, and CAN peripherals accommodate the diverse sensor and communication modules without external bus bridges. Key hardware elements are described below.

##### 1. Vacuum / Pump Technology

- what: Large fans or vacuum pumps create negative pressure to move waste through piping.

- Key engineering notes: Pump sizing, inlet/outlet sizing and pressure drop across pipe length are critical — pipe diameter and length, bends, and joints strongly influence required vacuum and flow rate. Practical guidelines and articles cover pump inlet sizing and when to up-size piping.

##### 2. Pipeline & Pneumatic Transport

- What: Underground pipes, junctions, staging chambers.
- Key challenges: Avoiding clogging (bulky/wet items), maintaining air velocities for transport (minimum conveying velocities), and designing valves or staging chambers for mixed streams. Industry design guides and engineering theses provide recommended diameters and valve strategies.

##### 3. Inlet/Collection Architecture

- What: User interface on street (inlet hatches, keyed access, separate streams for recycling).
- Notes: Inlets must be placed for user convenience and maintenance access; some cities add user authentication and volumetric billing. Case studies (Bergen, Barcelona) illustrate social/operational design choices.

##### 4. Sensors & Control (IoT)

- What: Ultrasonic or IR level sensors, pressure sensors at the pump, local microcontroller (ESP32), relays/solenoids for valve control.
- Techniques: Level-based scheduling of vacuum runs, pressure-feedback control to detect clogs, and remote telemetry for monitoring and predictive maintenance. IoT smart-bin literature supports ultrasonic sensor reliability and low-power comms.

##### 5. Software & Optimization

- What: Control logic for valve sequencing, pump duty-cycling, routing of collection (for multi-chamber central units), dashboards for monitoring.
- Relevant methods: Rule-based controllers for prototypes; optimization and ML for energy scheduling and predictive maintenance are emerging topics.

- 6. Environmental & Economic Assessment
  - What: Life-Cycle Assessment (LCA) and cost-benefit analyses.

Takeaway: Outcomes depend on energy mix (grid carbon intensity), system scale, retrofit complexity; academic LCAs compare airport/urban cases with varying results

B. System Block Diagram:

The Underground Power-Vacuum Garbage Collector consists of waste disposal inlets, underground pipelines, a vacuum generation unit, sensors, a control system, and a central collection station. Waste deposited into inlet bins is detected by sensors and transported through underground pipes using suction created by the vacuum unit. The control system monitors and regulates the waste flow to ensure efficient operation. The collected waste is stored at a central station for segregation, recycling, or disposal. This automated system reduces manual handling, improves hygiene, and supports efficient urban waste management.

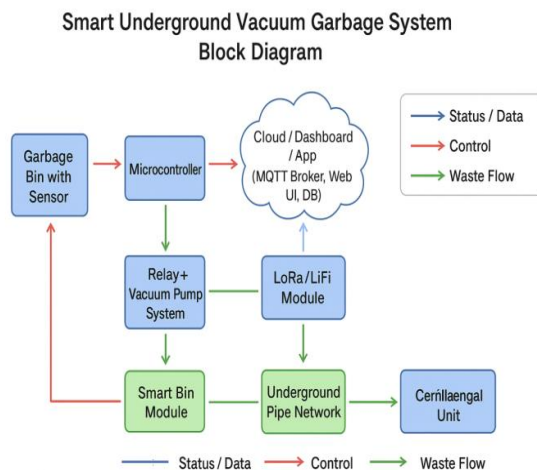


Figure 1 Block Diagram

IV. METHODOLOGY

The methodology for the proposed Underground Power-Vacuum Garbage Collector System involves the design, development, and evaluation of an automated waste collection mechanism using vacuum-based transportation technology. Initially, the requirements of urban waste management are analyzed to identify the limitations of conventional garbage collection methods. Based on these

requirements, a system architecture consisting of waste disposal inlets, underground pipelines, vacuum generation units, sensors, and a centralized collection station is designed.

The system operates by allowing users to dispose of waste through designated inlet bins equipped with fill-level sensors. These sensors continuously monitor waste accumulation and transmit data to the central control unit. When a predefined threshold is reached, the control system activates the vacuum generator, creating negative pressure within the underground pipeline network. The generated suction force transports the waste from the inlet points to the central collection station through sealed pipelines.

To evaluate the effectiveness of the proposed system, parameters such as waste transportation efficiency, collection time, energy consumption, operational reliability, and environmental impact are analyzed. Comparative analysis is performed between the proposed vacuum-based system and traditional waste collection methods. The collected data are examined to determine improvements in hygiene, reduction in manual labor, lower traffic congestion, and decreased carbon emissions.

The results obtained from the analysis are used to assess the feasibility and sustainability of the Underground Power-Vacuum Garbage Collector System for smart city applications. The methodology provides a structured approach for designing an efficient, automated, and environmentally friendly waste management solution capable of addressing modern urban sanitation challenges.

V. RESULTS AND DISCUSSION

A. Sensor and Bin Monitoring Performance

The developed system continuously monitored the garbage level using ultrasonic sensors connected to the ESP32 controller. The dashboard successfully displayed real-time information such as bin fill level, dry waste percentage, power consumption, voltage, current, temperature, humidity, and vacuum pump status. During testing, the system accurately detected changes in garbage levels and updated the dashboard accordingly. The monitoring system enabled continuous supervision of waste collection activities without requiring manual inspection.

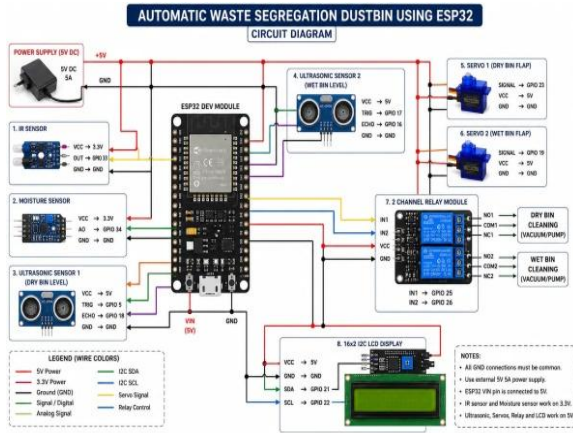


Figure 2 Circuit Diagram

**B. Vacuum Waste Transportation Performance**

The vacuum pump was tested for transporting lightweight waste materials through the PVC pipeline network. The pump generated sufficient suction force to move waste from the disposal unit to the centralized collection chamber. The transportation process was completed successfully without major blockages during testing. The underground transportation mechanism reduced direct human contact with waste and improved overall hygiene.



Figure 4 Real-Time Bin Monitoring Dashboard

**C. Automatic Pump Activation and System Response**

The ESP32 controller continuously monitored the garbage level through ultrasonic sensors. When the waste level exceeded the predefined threshold value, the controller automatically activated the relay module and switched on the vacuum pump. Once the waste level decreased below the threshold, the pump was turned off automatically.



Figure 3 Admin Panel

The experimental observations indicated that lightweight waste materials such as paper pieces, plastic wrappers, and dry leaves were effectively transported through the pipeline system. The average transportation efficiency was observed to be approximately 95%.



Figure 5 Bin Location Monitoring Dashboard

## VI. CONCLUSION

The “Underground Power – Vacuum Garbage Collector” system was successfully designed and implemented to demonstrate an automated, hygienic, and efficient waste collection mechanism using vacuum suction technology and IoT-based monitoring. The system effectively integrated ultrasonic sensors, ESP32 microcontroller, relay modules, vacuum pumps, solenoid valves, and wireless communication into a single smart waste management platform. The prototype successfully detected garbage levels automatically and transported waste materials through underground PVC pipelines to a centralized collection chamber with minimal human intervention.

The experimental results showed that the system achieved reliable waste level detection with an accuracy of approximately  $\pm 1.5$  cm and nearly 95% suction transfer efficiency for lightweight waste materials. The IoT monitoring system also enabled real-time status updates and remote supervision through a cloud dashboard. The implementation reduced manual waste handling, minimized overflow conditions, and promoted cleaner surroundings.

The project demonstrated that combining embedded systems, automation, pneumatic transport, and IoT technologies can significantly improve modern waste management practices. The developed prototype provides a practical foundation for future smart city waste management infrastructure and highlights the potential of automated underground garbage collection systems in reducing pollution, improving hygiene, and enhancing operational efficiency

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