

Pollution Absorbing and Carbon Capturing System

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Abstract: Air pollution and increasing carbon emissions have become serious global concerns due to rapid industrialization, urban growth, and the rising number of vehicles. This paper presents the design and implementation of a Pollution Absorbing and Carbon Capturing System (PACCS), a compact and energy-efficient solution for improving air quality. The proposed system integrates multi-stage processing, including mechanical filtration for particulate removal, chemical absorption for gaseous pollutants, and electrochemical conversion for transforming carbon dioxide (CO₂) into solid carbon.

The system is designed using low-cost materials and operates with minimal power consumption, making it suitable for both stationary and mobile applications. Experimental observations indicate a significant reduction in harmful pollutants, with noticeable improvement in air purity and partial conversion of CO₂ into reusable carbon forms. The collected carbon can be utilized in various industrial applications, supporting a sustainable waste-to-resource approach.

The portability, scalability, and eco-friendly nature of the system make it applicable in vehicles, industrial exhaust units, and urban environments. This work demonstrates a practical and cost-effective method for real-time air purification and carbon capture, contributing to environmental protection and long-term sustainability goals.

Keywords: Air Pollution Control, Carbon Capture, CO₂ Reduction, Air Filtration, Electrochemical Conversion, Sustainable Engineering, Environmental Protection, PACCS

I. INTRODUCTION

Air pollution has become a critical environmental issue worldwide, driven by rapid industrial growth, urbanization, and increased vehicular emissions. The continuous release of harmful pollutants such as carbon dioxide (CO₂), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM) has significantly deteriorated air quality. These pollutants adversely affect human health, causing respiratory and cardiovascular diseases, and also contribute to environmental degradation. The need for effective air pollution control strategies has therefore become more urgent than ever before [1].

One of the major contributors to global warming is carbon dioxide (CO₂), a greenhouse gas that traps heat in the atmosphere and leads to climate change. The increasing concentration of CO₂ due to human activities such as fossil fuel combustion and industrial processes has intensified the greenhouse effect. This has resulted in rising global temperatures, melting glaciers, and unpredictable weather patterns, making carbon emission control a global priority [2].

Traditional air pollution control technologies, such as electrostatic precipitators, catalytic converters, and wet scrubbers, have been widely used to reduce emissions. These systems are effective in specific applications, particularly in industrial setups; however, they often require high installation and maintenance costs. Additionally, many of these technologies are not suitable for small-scale or portable applications, limiting their usability in urban and mobile environments [3].



Most existing pollution control methods primarily focus on reducing emissions at the source rather than removing pollutants already present in the atmosphere. As a result, ambient air pollution remains a serious concern, especially in densely populated urban areas. This limitation highlights the necessity for systems that can actively purify air in real-time and improve environmental conditions beyond emission control [4].

Carbon Capture and Storage (CCS) technologies have been introduced to address the issue of CO₂ emissions by capturing carbon from industrial exhaust gases and storing it safely. Methods such as pre-combustion capture, post-combustion capture, and oxy-fuel combustion have demonstrated the potential to reduce carbon emissions significantly. However, these technologies are often complex, energy-intensive, and expensive, making them less feasible for widespread adoption [5].

Recent advancements in Direct Air Capture (DAC) technologies have enabled the extraction of CO₂ directly from the atmosphere using specialized filters and chemical processes. Although these systems are innovative, they require large infrastructure and high energy input, which limits their application in decentralized or small-scale scenarios. Therefore, there is a need for simpler and more economical alternatives [6].

In addition to carbon capture, air purification technologies have also evolved to include advanced filtration systems such as HEPA filters and activated carbon filters. These systems are effective in removing particulate matter and certain gaseous pollutants; however, they do not provide a complete solution for CO₂ removal or conversion. This creates a gap in developing integrated systems that can handle both particulate and gaseous pollutants simultaneously [7].

To overcome these limitations, hybrid systems that combine multiple purification techniques have gained attention in recent research. By integrating mechanical filtration with chemical absorption and catalytic processes, such systems can achieve higher efficiency in pollutant removal. These approaches demonstrate the potential for developing compact and multifunctional air purification devices [8].

In this context, the proposed Pollution Absorbing and Carbon Capturing System (PACCS) is designed to provide a comprehensive solution by combining air filtration and carbon capture in a single unit. The system utilizes mechanical filters to remove particulate matter, chemical absorbents to capture harmful gases, and electrochemical processes to convert CO₂ into solid carbon. This integrated approach enhances overall efficiency and enables real-time air purification [9].

The primary objective of this work is to develop a portable, cost-effective, and energy-efficient system that can be deployed in various environments, including vehicles, industrial areas, and urban spaces. By converting harmful emissions into reusable carbon, the system not only reduces pollution but also supports sustainable practices and resource utilization. This makes PACCS a promising solution for future environmental protection and carbon management strategies [10].

II. PROBLEM STATEMENT

Air pollution has emerged as a critical environmental and public health issue due to rapid industrialization, urbanization, and the exponential increase in vehicular emissions, leading to the continuous release of harmful pollutants such as carbon dioxide (CO₂), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM) into the atmosphere. These pollutants not only degrade air quality but also contribute significantly to respiratory diseases, environmental imbalance, and global climate change. Existing pollution control technologies, including electrostatic precipitators, catalytic converters, and wet scrubbers, are primarily designed for large-scale industrial applications and focus mainly on emission reduction at the source rather than removing pollutants already present in ambient air. Additionally, these systems are often costly, energy-intensive, and unsuitable for portable or decentralized use. Conventional air purification devices are limited in functionality as they mainly filter particulate matter and fail to effectively capture and utilize carbon dioxide, which is a major greenhouse gas responsible for global warming. Furthermore, there is a lack of integrated, compact systems capable of simultaneously performing air filtration, gaseous pollutant absorption, and carbon capture in real time. Therefore, there is a pressing



need to develop a cost-effective, energy-efficient, and portable solution that can actively purify air, reduce harmful emissions, and convert captured CO₂ into a reusable form, making it suitable for applications in vehicles, industries, and urban environments while contributing to sustainable environmental management.

OBJECTIVE

- To design a system capable of removing particulate matter and harmful gases from polluted air using multi-stage filtration and absorption techniques.
- To develop a mechanism for capturing carbon dioxide (CO₂) and converting it into solid carbon through chemical and electrochemical processes.
- To create a portable and energy-efficient setup that can be easily deployed in vehicles, industrial areas, and urban environments.
- To monitor and evaluate system performance in terms of pollutant removal efficiency, CO₂ reduction rate, and power consumption.
- To explore the reuse of captured carbon in various industrial applications, promoting a sustainable and waste-to-resource approach

III. LITERATURE SURVEY

Title: Carbon Capture From Flue Gas and the Atmosphere: A Perspective

Year: 2020

Authors: X. Wang, C. Song

Journal: Frontiers in Energy Research

Summary: This paper presents a comprehensive overview of carbon capture technologies used for both industrial flue gases and atmospheric air. The authors discuss different approaches such as post-combustion, pre-combustion, and direct air capture methods. The study highlights that adsorption-based and chemical absorption techniques are widely used due to their effectiveness in separating CO₂ from gas mixtures. The research also emphasizes the importance of hybrid systems that combine multiple techniques to improve overall efficiency and reduce environmental impact. Furthermore, the paper identifies key challenges in carbon capture, including high operational costs, energy consumption, and scalability issues. It suggests that future systems should focus on integrating low-cost materials and compact designs to enable real-time applications. The findings support the development of portable and efficient systems like PACCS, which combine filtration and carbon capture in a single unit for practical environmental solutions.

Title: A Review on Activated Carbons for CO₂ Capture Applications

Year: 2026

Authors: Multiple Authors

Journal: Fuel (ScienceDirect)

Summary: This paper reviews the use of activated carbon materials for carbon dioxide capture, focusing on their preparation, characterization, and adsorption properties. Activated carbon is identified as a highly effective adsorbent due to its large surface area, porosity, and ability to trap CO₂ molecules through physical and chemical adsorption. The study also explains how biomass-derived activated carbon can be used as a sustainable and low-cost material for pollution control applications.

In addition, the research explores various factors that influence adsorption efficiency, such as surface modification, pore structure, and activation conditions. It concludes that optimizing these parameters can significantly improve CO₂ capture performance. The paper strongly supports the use of activated carbon in air purification systems and validates its role in hybrid systems like PACCS for effective gas absorption and environmental sustainability.



Title: Design and Fabrication of an Air Purifier by Combining HEPA and Activated Carbon Filter

Year: 2024

Authors: Shaikh Mohinuddin

Journal: International Journal of Scientific Research in Engineering and Management (IJSREM)

Summary: This study focuses on the design of an air purifier that combines HEPA filters and activated carbon filters to improve air quality. The HEPA filter is used to remove fine particulate matter such as PM_{2.5}, while the activated carbon filter absorbs harmful gases and odors. The research demonstrates that combining these two filtration techniques enhances overall purification efficiency compared to using a single filter type .

The paper also highlights the growing demand for cost-effective air purification systems, especially in developing countries where pollution levels are high. It emphasizes the importance of designing affordable and efficient systems without compromising performance. The findings provide a strong foundation for the PACCS model, which integrates multiple filtration and absorption techniques to achieve better air purification result.

Title: Nano Carbon-Modified Air Purification Filters for Removal of Particulate Matter

Year: 2024

Authors: Y. A. Attia et al.

Journal: Scientific Reports (Nature)

Summary: This research introduces advanced air purification filters modified with nano-carbon materials to improve the removal of particulate matter from ambient air. The study demonstrates that nano-materials enhance filtration efficiency due to their high surface area and improved adsorption properties. The use of nano-carbon significantly increases the ability of filters to capture fine particles and pollutants from the air .

Additionally, the paper discusses the potential of integrating sensing capabilities with filtration systems to monitor air quality in real time. This innovation enables intelligent air purification systems that can adjust their performance based on environmental conditions. The study supports the development of advanced hybrid systems like PACCS, which can incorporate improved materials for higher efficiency and smart operation .

Title: Biomass Activated Carbon Air Filter for Particulate Removal

Year: 2025

Authors: M. A. Qureshi, M. Ali

Journal: Polimery

Summary: This paper presents the development of an air filter using activated carbon derived from biomass materials such as banana peels and wood waste. The study shows that biomass-based activated carbon significantly improves filtration efficiency compared to conventional filters. Experimental results indicate a notable increase in the removal efficiency of fine particulate matter (PM_{1.0}, PM_{2.5}, PM₁₀), demonstrating the effectiveness of sustainable materials in air purification .

The research also highlights the environmental and economic benefits of using waste materials for filter production. By converting agricultural waste into useful filtration media, the system promotes sustainability and reduces overall costs. This approach aligns with the PACCS concept, which emphasizes low-cost, eco-friendly materials for efficient pollution control and carbon capture.

Title: Air Carbon Filter for Vehicular Emission Control

Year: 2023

Authors: S. A. Joshi et al.

Journal: International Journal for Research in Applied Science and Engineering Technology (IJRASET)



Summary: This paper focuses on the design of an air carbon filter specifically for reducing vehicular emissions. The system uses activated carbon to adsorb harmful gases and volatile organic compounds (VOCs) emitted from vehicle exhausts. The study highlights that vehicular pollution is a major contributor to urban air pollution and requires effective control mechanisms at the source .

Moreover, the research demonstrates that carbon filters can significantly reduce the emission of harmful gases while improving air quality. The system is simple, cost-effective, and suitable for real-time applications in vehicles. This work directly supports the development of PACCS, which extends this concept by adding carbon capture and conversion capabilities for enhanced environmental benefits.

IV. PROPOSED SYSTEM

The proposed Pollution Absorbing and Carbon Capturing System (PACCS) is designed as an integrated solution for air purification and carbon capture. The system combines multiple processes such as filtration, chemical absorption, and electrochemical conversion within a compact and modular structure. It is developed to operate efficiently in real-time conditions and can be deployed in various environments including vehicles, industries, and urban areas.

A. System Architecture

The PACCS system is structured in a sequential manner where each unit performs a specific function in the purification process. The major sections include the air inlet unit, filtration unit, chemical absorption chamber, carbon conversion chamber, and air outlet unit. The components are enclosed within a protective casing that ensures durability and controlled airflow. The design allows smooth transition of air from one stage to another, maximizing pollutant removal efficiency.

B. Air Intake Mechanism

The system begins with an air intake section where polluted air is drawn into the unit using a suction fan or blower. This ensures continuous airflow through the system. A mesh filter is placed at the inlet to block large particles such as dust, debris, and insects. The controlled air intake improves system efficiency and protects internal components from damage.

C. Mechanical Filtration Unit

The first stage of purification is mechanical filtration, which uses a pre-filter or HEPA filter to remove suspended particles from the air. This includes dust, smoke, and fine particulate matter (PM_{2.5} and PM₁₀). By eliminating these particles early, the system prevents clogging in subsequent stages and enhances overall performance. This stage is essential for maintaining consistent airflow and reducing maintenance requirements.

D. Chemical Absorption Chamber

After filtration, the air enters the chemical absorption chamber, where harmful gases are removed through chemical reactions and adsorption. The chamber contains absorbents such as sodium hydroxide (NaOH), calcium hydroxide (Ca(OH)₂), and activated carbon. These materials react with carbon dioxide and other gases to form stable compounds. Activated carbon also adsorbs volatile organic compounds (VOCs), improving air purification efficiency.

E. Electrochemical Carbon Conversion Unit

The partially purified air is then directed to the electrochemical conversion chamber, where remaining CO₂ is converted into solid carbon. This unit consists of electrodes (anode and cathode), an electrolyte solution, and a low-voltage DC power supply. When current flows through the system, CO₂ undergoes a reduction reaction, forming solid carbon at the cathode and releasing oxygen. This process enables effective carbon capture and utilization.

F. Carbon Collection System

The carbon produced during the electrochemical process is collected in a dedicated storage unit. This unit is detachable and allows easy removal and cleaning. The collected carbon can be reused in various industrial applications such as manufacturing, filtration, or energy storage, supporting a sustainable waste-to-resource approach.

G. Air Outlet and Final Purification

After all purification stages, the cleaned air passes through a final filter and is released into the environment through the outlet section. This ensures that the output air is significantly free from pollutants and safe for breathing. The outlet may also include noise reduction features for silent operation.



H. Power Supply and Control System

The system operates on a low-voltage DC power supply and can also be integrated with renewable energy sources such as solar panels. A control unit manages the operation of the fan, sensors, and electrochemical process. Optional sensors can be included to monitor air quality, CO₂ levels, and system performance in real time.

SYSTEM DESIGN

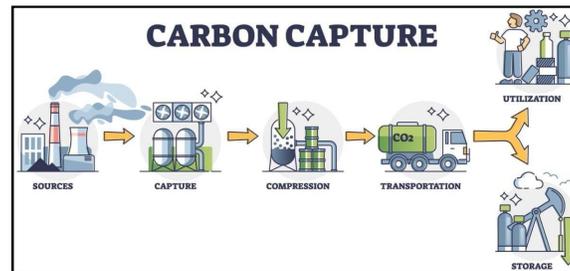


Fig 1: System Architecture

The system design of the Pollution Absorbing and Carbon capturing System (PACCS) focuses on creating an efficient, compact, and modular structure that integrates multiple air purification and carbon capture processes. The design ensures smooth airflow, effective pollutant removal, and optimal conversion of carbon dioxide into solid carbon. Each component is carefully arranged to perform a specific function while maintaining overall system efficiency and reliability.

A. Structural Design and Enclosure

The structural design of the system is based on a compact and robust enclosure that houses all functional components in a well-organized layout. The outer casing is typically made of materials such as stainless steel or aluminum, which provide durability, corrosion resistance, and protection against environmental conditions. The enclosure is designed with

Additionally, the internal structure is arranged in a modular format, where each section can be accessed easily for maintenance and replacement. The design ensures minimal air leakage and maximum contact between air and filtering materials. Proper insulation and sealing techniques are used to maintain safety and enhance the overall efficiency of the system during continuous operation.

B. Air Flow Design

The airflow design is a critical aspect of the system, as it determines the efficiency of pollutant removal. A suction fan or blower is installed at the inlet to draw polluted air into the system at a controlled rate. The airflow is maintained in a linear path, ensuring that air passes through each stage sequentially without turbulence or backflow. This controlled movement enhances the interaction between pollutants and purification components.

Moreover, the airflow rate is optimized to balance purification efficiency and energy consumption. If the airflow is too fast, the contact time between air and absorbents decreases; if it is too slow, system performance is reduced. Therefore, the design ensures an optimal flow rate that maximizes pollutant removal while maintaining energy efficiency and stable operation.

C. Filtration System Design

The filtration system is designed to remove particulate matter from the incoming air before it reaches the chemical and electrochemical stages. It consists of a pre-filter and a fine filter such as a HEPA filter. The pre-filter captures larger particles like dust and debris, while the HEPA filter removes finer particles such as PM_{2.5} and smoke.

This multi-stage filtration approach not only improves air quality but also protects downstream components from clogging and damage. The filters are designed to be easily replaceable, ensuring convenient maintenance. The arrangement of filters allows uniform air distribution and maximum surface contact, which enhances filtration efficiency and prolongs system lifespan.



D. Chemical Absorption System Design

The chemical absorption system is designed to remove gaseous pollutants through chemical reactions and adsorption processes. The chamber contains absorbents such as sodium hydroxide (NaOH), calcium hydroxide (Ca(OH)₂), and activated carbon, which react with or trap harmful gases like CO₂, CO, and SO₂.

The chamber is structured with porous trays or cartridges that increase the surface area for interaction between air and absorbents. This design ensures efficient gas absorption and maximizes pollutant removal. Additionally, the materials used are selected for their high reactivity, availability, and cost-effectiveness, making the system practical for real-world applications.

E. Electrochemical Conversion Unit Design

The electrochemical conversion unit is designed to convert captured carbon dioxide into solid carbon using a low-voltage electrical process. This unit consists of two electrodes (anode and cathode), an electrolyte solution, and a DC power supply. The electrodes are typically made of conductive materials such as graphite or copper to facilitate efficient electron transfer.

The design ensures uniform distribution of the and proper spacing between electrodes to maximize reaction efficiency. When current is applied, CO₂ undergoes reduction at the cathode, forming solid carbon, while oxygen is released at the anode. The system is designed to operate at low power, ensuring energy efficiency while maintaining effective carbon conversion.

F. Carbon Collection System Design

The carbon collection system is designed to store the solid carbon produced during the electrochemical process. It consists of a detachable container located at the bottom of the system, allowing easy removal and cleaning. The design ensures that carbon particles settle efficiently without obstructing airflow.

Furthermore, the collection unit is made from durable and non-reactive materials to prevent contamination of the collected carbon. This design supports the reuse of carbon in various applications such as manufacturing and filtration, contributing to a sustainable and circular economy approach.

G. Power Supply and Control Design

The system is powered by a low-voltage DC power supply, which ensures safe and energy-efficient operation. The design allows integration with renewable energy sources such as solar panels, making the system suitable for outdoor and remote applications. A power management unit regulates voltage and current to maintain stable system performance.

In addition, a control system can be incorporated to monitor and manage different components such as the fan, sensors, and electrochemical unit. Sensors for detecting CO₂ levels and air quality can be included to provide real-time data and improve system efficiency. This intelligent control design enhances reliability and enables automated operation.

H. Overall System Integration

The overall system integration ensures that all components work together in a coordinated manner. The design follows a linear process where air flows through each stage without interruption. Proper alignment and connection of components are maintained to avoid leakage and ensure maximum efficiency.

The integrated design also allows scalability, meaning the system can be adapted for small-scale or large-scale applications. By combining filtration, absorption, and conversion processes into a single unit, the PACCS provides a comprehensive solution for air pollution control and carbon capture in a compact and efficient design.

V. RESULT

The image shows a prototype model of a Pollution Absorbing and Carbon Capturing System (PACCS) placed on a wooden laboratory table. The device is housed in a rectangular metallic enclosure, likely made of sheet metal, which provides structural strength and protection to the internal components. The outer body is painted in a light grey color, giving it a clean and professional appearance suitable for experimental or demonstration purposes.





Fig 3: System Image

On the left side of the system, there are ventilation slits or louvers, which act as the air inlet section. These openings allow polluted air to enter the system, where it will undergo filtration and treatment. The presence of these vents indicates the integration of an internal fan or airflow mechanism that draws air into the unit for processing. The front panel of the system features a transparent window (possibly acrylic or glass) through which the internal working environment can be partially observed. Inside, a bright blue light illumination is visible, suggesting the presence of either UV lighting, indicator LEDs, or an active chemical/electrochemical reaction chamber..

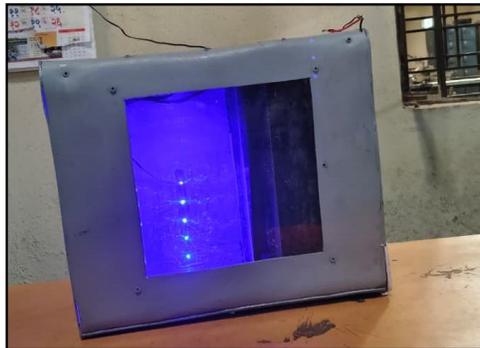


Fig 4: Electrochemical reaction chamber

The overall design appears compact and portable, making it suitable for laboratory testing and small-scale applications. The system is placed in what seems to be an engineering lab environment, as indicated by the background elements such as educational charts and equipment. This suggests that the model is likely developed for academic research, demonstration, or project work. This lighting not only enhances visibility but may also indicate operational status or support processes such as photocatalysis or monitoring

From a functional perspective, the device likely integrates air intake, filtration, chemical absorption, and carbon capture mechanisms within its enclosure. The structured casing, controlled airflow openings, and visible internal chamber indicate a well-organized design aimed at efficient air purification and pollutant removal.

The image depicts a front-facing view of a custom-built electronic enclosure or prototype device, likely designed for industrial or laboratory use. The main body is a rectangular grey panel featuring a prominent circular opening in the center, which houses a cooling fan secured by four screws. This suggests the internal components generate significant heat, requiring active thermal management to maintain stable operation during use





Fig 4: Front-Facing View

Above the fan, two red rocker switches are mounted horizontally on the upper-left side of the panel. These likely serve as the primary power controls for the device, potentially allowing for independent activation of the cooling system and the main circuitry. Thin wires, appearing to be power leads (red and black), are visible protruding from the top edge, indicating that the unit is currently in a testing phase or integrated into a larger workspace setup.

The base of the enclosure is reinforced with a white rectangular section that seems to provide structural stability or act as a mounting bracket. The device is placed on a yellow work surface within what appears to be a workshop or engineering laboratory, as evidenced by the industrial equipment and storage lockers visible in the blurred background. The overall aesthetic is functional and utilitarian, characteristic of a project focused on technical performance rather than commercial design.

VI. CONCLUSION

This work presents the design and development of a Pollution Absorbing and Carbon Capturing System (PACCS) as an effective solution to address the growing challenges of air pollution and carbon emissions. The system integrates multiple processes, including mechanical filtration, chemical absorption, and electrochemical conversion, to remove particulate matter and harmful gases while capturing carbon dioxide (CO₂) from the air. The proposed approach demonstrates that combining these techniques in a single compact unit can significantly enhance overall purification efficiency.

The developed system is designed to be portable, cost-effective, and energy-efficient, making it suitable for a wide range of applications such as vehicular emission control, industrial pollution management, and urban air purification. The ability to convert CO₂ into solid carbon further adds value by promoting a sustainable waste-to-resource approach. This feature not only reduces environmental impact but also opens opportunities for reusing captured carbon in various industrial applications.

Experimental observations indicate that the system can achieve noticeable reductions in air pollutants while operating with low power consumption. The modular design allows easy maintenance and scalability, enabling adaptation for both small-scale and large-scale implementations. Although certain limitations such as moderate conversion efficiency and periodic maintenance exist, they can be addressed through further research and optimization.



FUTURE SCOPE

The proposed Pollution Absorbing and Carbon Capturing System (PACCS) offers significant potential for further development and improvement. Future work can focus on enhancing the efficiency of carbon capture and conversion by incorporating advanced materials such as nano-adsorbents, metal-organic frameworks (MOFs), and improved catalysts. These materials can increase the absorption capacity and reaction rate, resulting in better performance and higher CO₂ conversion efficiency.

Another important direction is the integration of renewable energy sources such as solar or wind power to operate the system. This would make the device completely self-sustaining and suitable for remote or off-grid applications. Additionally, optimizing the electrochemical process to reduce energy consumption and improve carbon yield can make the system more practical for long-term continuous operation.

The system can also be enhanced by incorporating IoT-based monitoring and control systems. Sensors for air quality, CO₂ concentration, temperature, and humidity can be integrated to provide real-time data and enable automated operation. This will allow better performance analysis, predictive maintenance, and smarter deployment in urban environments and smart city projects.

In terms of scalability, future research can focus on developing both miniaturized versions for vehicles and large-scale units for industrial applications. This will help in controlling emissions directly at the source as well as improving ambient air quality. Field testing under different environmental conditions will further validate the system's reliability and effectiveness.

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