

Environmental Application of Quantum Dots in Photocatalytic Treatment of Urban Waste Water

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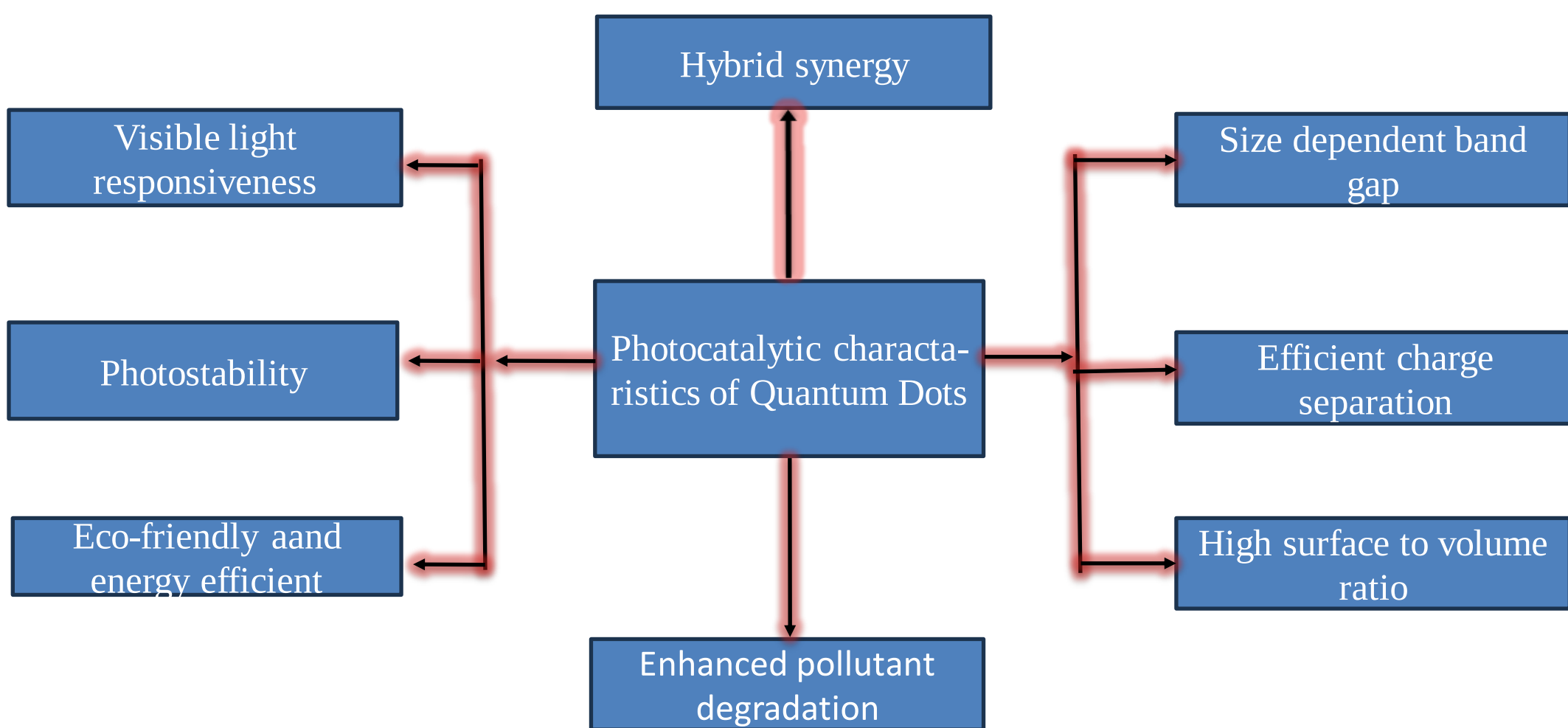
ABSTRACT

Quantum dots (QDs) have drawn a lot of attention as photocatalytic materials due to the growing need for environmentally friendly wastewater treatment technologies. Among these, carbon-based QDs, including graphene oxide quantum dots (GOQDs), graphitic carbon nitride (g-C₃N₄), and carbon quantum dots (CQDs), have exceptional optical, electronic, and surface characteristics that increase their suitability for degrading pollutants when exposed to sunlight or visible light. These composites are better, and breaking down pollutants. In terms of environment, QDs are a promising way to clean up urban wastewater in a way that will last. They follow eco-friendly and energy-efficient treatment principles because they can use solar energy, work in mild conditions, and break things down quickly. Metal-based QDs like ZnO and CdS also have strong photocatalytic activity, but their sustainability remains a concern due to the potential release of toxic ions when they corrode in light. The green synthesis approach addresses these challenges. Using natural extracts, like polyphenols from tea leaves, to biofunctionalize surfaces has been shown to reduce toxicity and improve photocatalytic performance. Green synthesis using renewable precursors solves problems with toxicity, resource depletion, and environmental pollution, which supports a low-impact and circular technological approach. QDs are a strong type of nanomaterial for cleaning up the environment, but there are still problems with making them bigger, cheaper, and more stable and with getting them approved by the government. This study examines recent developments in the making, modifying, and use of QD-based photocatalysts in the environment, with a focus on CQD/g-C₃N₄ hybrid systems. Future research should focus on making green, non-toxic, regenerable, and highly active carbon-based QDs for safe large-scale water treatment.

INTRODUCTION

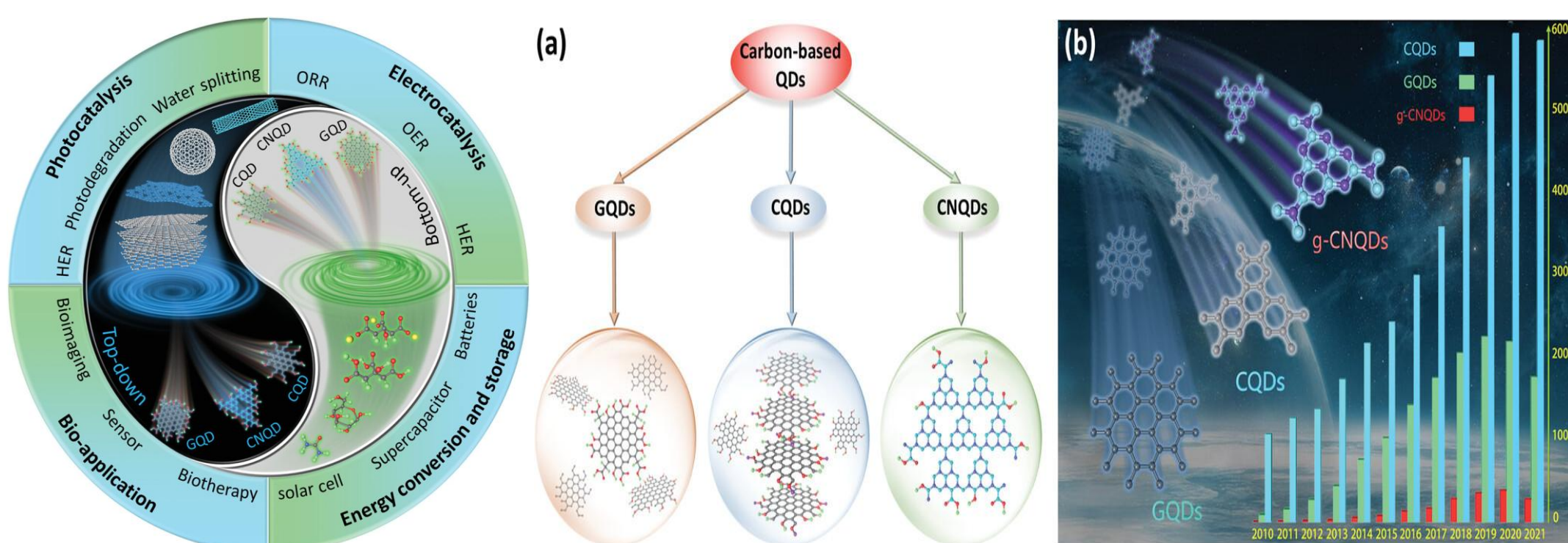
The critical need for sustainable water purification technologies has accelerated development of advanced photocatalytic systems. Carbon-based quantum dots (CQDs) represent a promising class of nanomaterials that address fundamental limitations of conventional semiconductor photocatalysts. Their distinctive quantum confinement characteristics and tunable electronic structures enable superior visible-light absorption and charge carrier dynamics. Furthermore, CQDs offer significant advantages in environmental compatibility and cost-effectiveness through sustainable synthesis pathways. Strategic fabrication of CQD-based heterostructures enhances photocatalytic performance while ensuring operational stability in complex aqueous environments. These engineered systems demonstrate remarkable efficiency in degrading diverse organic contaminants and inactivating pathogenic microorganisms. This review comprehensively examines recent advances in CQD photocatalyst design, synthesis methodologies, and applications for sustainable water remediation.

PHOTOCATALYTIC CHARACTERISTICS OF QDs



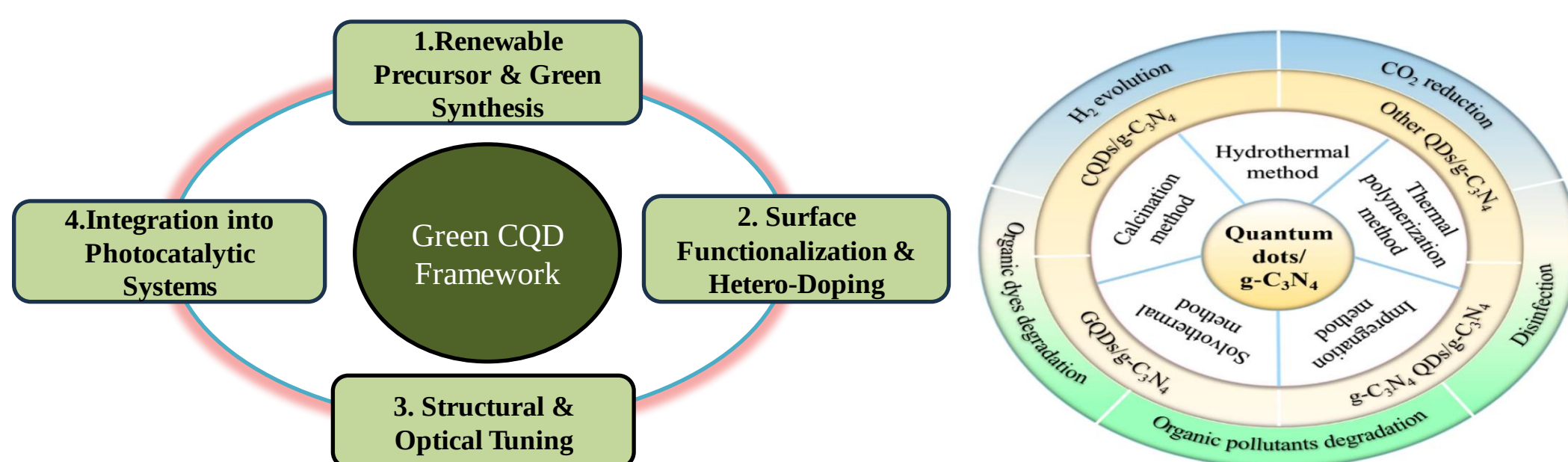
CARBON-BASED QDs AS GREEN PHOTOCATALYSTS

Carbon-based quantum dots (CQDs, GQDs, and g-CNQDs) have emerged as a new class of sustainable photocatalytic materials owing to their remarkable quantum confinement effects, tunable bandgap, and efficient charge transfer characteristics. These properties enable enhanced light absorption and superior photocatalytic performance compared to conventional metal-based quantum dots. In addition, their intrinsic advantages—such as non-toxicity, high chemical stability, cost-effectiveness, and facile synthesis—make them highly attractive for environmentally benign photocatalytic systems. The distinctive optical behavior, versatile surface functionalization, and up conversion emission of carbon-based QDs further promote efficient solar energy harvesting, pollutant degradation, and energy conversion. Collectively, these features position carbon-based quantum dots as promising candidates for the development of next-generation green and sustainable photocatalysts



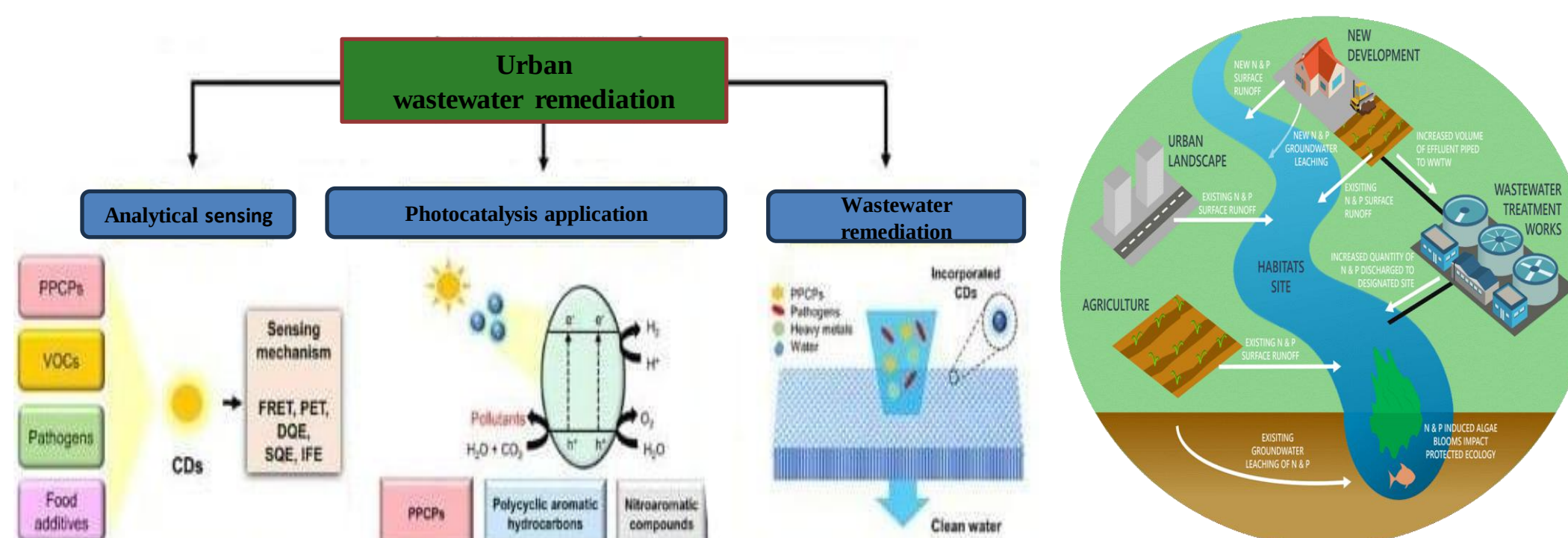
GREEN-FUNCTIONALIZED of CQDs

STAGES	PROCESS
1. Selection of Renewable Precursors and Green Synthesis	Utilization of biomass-derived materials (e.g., plant extracts, sugars, amino acids) as carbon sources. Employing eco-friendly synthesis methods such as hydrothermal, microwave-assisted, or ultrasonic techniques.
2. Surface Functionalization and Heteroatom Doping	Functionalization and doping alter electronic structures, introducing surface states and active sites that enhance charge transfer and light absorption.
3. Structural and Optical Tuning	Quantum confinement effects and surface state modulation influence the bandgap, absorption, and emission properties of CQDs.
4. Integration into Photocatalytic Systems	CQDs serve as photosensitizers, electron mediators, or active catalytic sites, facilitating efficient electron-hole separation and transfer.



ENHANCED URBAN WASTEWATER REMEDIATION

Carbon quantum dots demonstrate efficient photocatalytic degradation of urban wastewater contaminants under visible light irradiation. Their functionalized surfaces enable concurrent adsorption and oxidative removal of organic pollutants and heavy metals. Sustainable synthesis from biomass precursors yields heterojunctions that improve charge separation efficiency while avoiding metallic toxicity. These nanostructures retain photocatalytic performance through successive treatment cycles in complex aqueous environments. This validated system provides an environmentally sound, scalable methodology for sustainable water remediation applications.



CONCLUSION

Carbon quantum dots are successfully integrated into composite nanofibers using a synergistic electrospinning-hydrothermal approach. This incorporation significantly enhanced the photocatalytic performance under visible light illumination compared to the base material. The modified architecture demonstrated remarkable efficiency in degrading organic pollutants and achieving complete microbial elimination. These findings establish a foundation for developing economically viable and environmentally sustainable photocatalytic systems for advanced water purification.

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