

AuREUS-Inspired Luminescent Solar Concentrator: Agricultural waste derived Materials, Spectral Conversion and Sustainability Challenges

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Abstract

The growing demand for low-carbon electricity, together with the environmental concerns associated with fossil-fuel use and agricultural-residue management, has stimulated interest in multifunctional solar-energy technologies. Luminescent solar concentrators (LSCs) provide a potential approach by absorbing selected portions of incident solar radiation, re-emitting the energy at longer wavelengths, and guiding the emitted light towards photovoltaic cells through total internal reflection. Within this framework, AuREUS-inspired systems propose the use of luminescent compounds derived from agricultural and biological waste as biomass-based materials for spectral conversion and solar concentration. This review examines the operating principles, material requirements, optical processes, architectural applications, environmental implications, and research challenges associated with AuREUS-type technologies, with particular emphasis on photoluminescence, Stokes shift, spectral conversion, diffuse-light operation, optical losses, photostability, and host-matrix compatibility. Their potential relevance to agrivoltaics and building-integrated photovoltaics is also discussed, particularly the need to balance electricity generation with the transmission of photosynthetically useful radiation and the requirements of plant growth. Agricultural residues may offer renewable feedstocks for luminescent materials; however, their practical suitability depends on pigment composition, extraction efficiency, optical stability, durability, scalability, and life-cycle performance. The review further distinguishes ultraviolet down-conversion from direct electrical power generation and highlights the need for standardised characterisation, long-term testing, techno-economic analysis, and field validation. Overall, AuREUS-type systems represent an emerging research direction in biomass-derived luminescent and spectrally selective solar technologies rather than a commercially validated replacement for conventional photovoltaic modules.

Keywords: AuREUS technology; luminescent solar concentrators; agricultural waste derived materials; spectral conversion; agrivoltaics; sustainability.

1. Introduction

The increasing global demand for energy, coupled with the environmental consequences associated with fossil-fuel consumption, has accelerated the transition toward sustainable and low-carbon energy systems. Among the available renewable-energy technologies, solar photovoltaic (PV) systems have emerged as one of the most promising approaches for large-scale electricity generation because of the abundance of

solar radiation and the continuing development of efficient and economically viable PV technologies [1]. Despite these advantages, the widespread deployment of conventional PV systems presents several challenges, including land requirements, material consumption, thermal management, visual and architectural constraints, and variations in electrical performance under non-uniform or diffuse solar irradiation [2]. These considerations have encouraged the development of alternative approaches that can improve the utilization of incident solar radiation while enabling PV technologies to be integrated into a wider range of environments and applications.

Luminescent solar concentrators (LSCs) represent an important class of optical technologies that can address some of these challenges. An LSC typically consists of a transparent host material containing luminescent species capable of absorbing incident solar radiation at selected wavelengths and subsequently re-emitting it at longer wavelengths. A significant fraction of the emitted radiation can be guided within the host material toward its edges through total internal reflection, where photovoltaic cells can be positioned to convert the concentrated optical radiation into electricity [3,4]. Unlike conventional solar concentrators that generally rely on geometric optics and require direct solar tracking or large optical components, LSCs can operate with both direct and diffuse radiation and can potentially be fabricated in planar, semi-transparent, or geometrically complex forms. These characteristics have generated considerable interest in their application to building-integrated photovoltaics, transparent energy-generating surfaces, windows, façades, and other architectural structures.

The ability of LSCs to manipulate the spectral distribution of incident solar radiation has also opened opportunities beyond conventional electricity generation. In particular, their integration with agricultural environments has attracted increasing research attention. Agricultural photovoltaic systems, commonly referred to as agrivoltaic systems, seek to utilize the same land area for both solar-energy production and agricultural activities. Conventional agrivoltaic configurations, however, require careful management of shading because excessive reduction in the intensity or alteration of the spectral composition of sunlight can influence photosynthesis, plant morphology, crop yield, and microclimatic conditions. LSC-based agrivoltaic systems offer a potentially different approach in which selected portions of the solar spectrum can be redirected toward photovoltaic cells while other wavelengths are transmitted toward crops. Consequently, the optical characteristics of the luminophore, host material, and LSC architecture become important design parameters for simultaneously satisfying the requirements of photovoltaic electricity generation and plant growth [5,6].

Within this broader framework of spectral management and multifunctional solar-energy systems, the AuREUS technology concept has attracted attention because it proposes the utilization of biological and agricultural residues as a source of luminescent materials. The underlying concept involves extracting or processing naturally occurring organic compounds from biological waste and incorporating the resulting luminescent particles into a suitable transparent or semi-transparent matrix. The resulting material is intended to function as a luminescent solar-concentrating medium capable of converting incident solar radiation into guided optical energy that can subsequently be utilized for electricity generation. The concept therefore establishes a connection between solar-energy conversion and the valorization of biomass-derived resources.

Despite the growing interest in luminescent solar concentration, agrivoltaic systems, and biomass-derived functional materials, a comprehensive assessment of their convergence in the context of AuREUS remains important. In particular, systematic consideration is required of the physical operating principles of AuREUS-type LSCs, the suitability of agricultural and biological residues as sources of luminescent

compounds, the influence of luminophore properties on optical and photovoltaic performance, and the challenges associated with scaling and practical deployment. It is also necessary to distinguish experimentally demonstrated characteristics from proposed mechanisms and prospective applications so that the technological potential of the concept can be assessed on an appropriate scientific basis.

Accordingly, this article provides a comprehensive review of the AuREUS technology concept and its relevance to sustainable solar-energy conversion. The review first examines the fundamental operating principles of luminescent solar concentrators and the physical mechanisms governing spectral conversion and light guidance. It subsequently evaluates the potential of agricultural and biological residues

2. Importance And Principle Of Aureus Technology

2.1. Significance

The potential significance of AuREUS extends beyond the optical conversion mechanism itself. Agricultural residues are generated in substantial quantities worldwide, and their conventional disposal or open burning can contribute to environmental pollution and greenhouse-gas emissions. Converting selected components of such residues into functional luminescent materials could provide an additional pathway for resource recovery and waste valorization. From this perspective, AuREUS can be considered within the broader framework of a circular approach to renewable-energy technology, in which an agricultural by-product is transformed into a functional material for energy-related applications. Furthermore, the possibility of incorporating luminescent materials into transparent panels, façades, windows, or other architectural elements may facilitate solar-energy generation without necessarily requiring additional land solely for PV deployment (Figure 1).

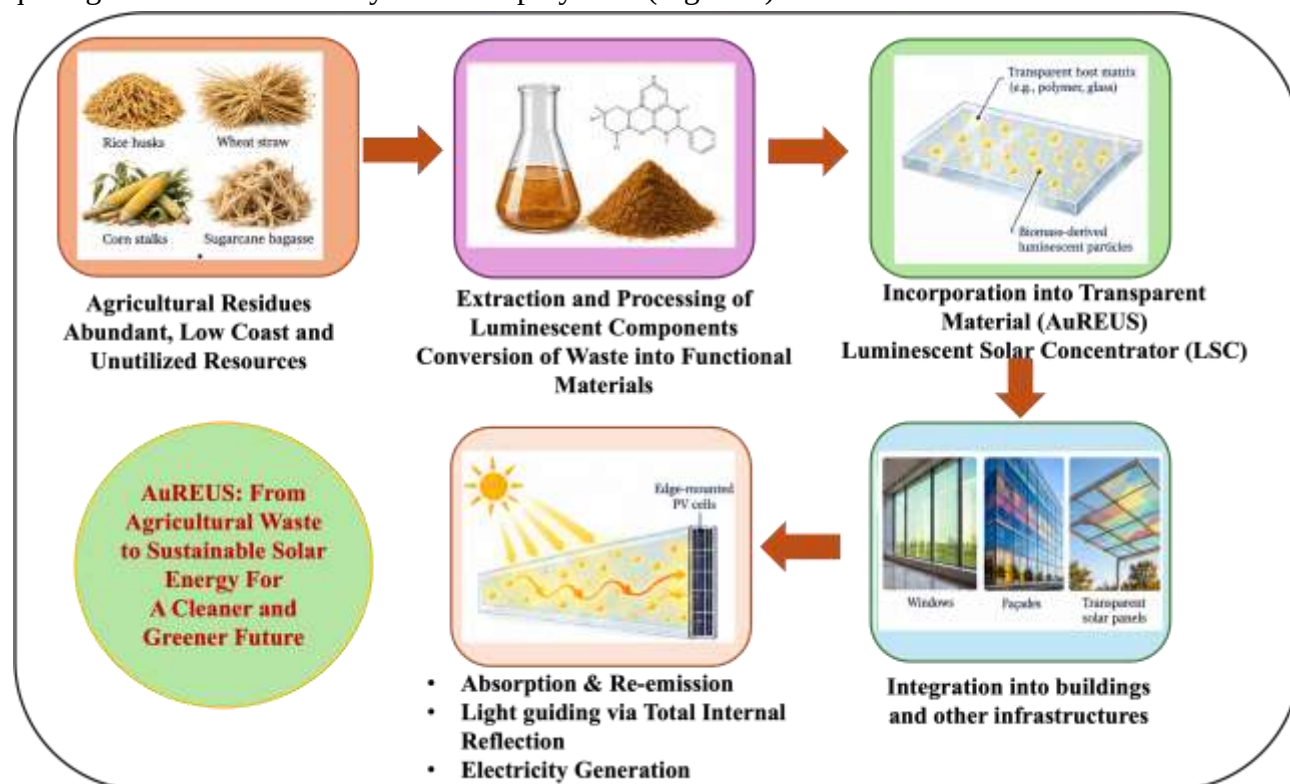


Figure 1: Basic Principle of AuREUS Technology

2.2. Principle Of Aureus Technology

2.2.1. Integrated Solar-Energy Conversion

AuREUS technology is based on the integration of photoluminescence, spectral conversion, luminescent solar concentration and biomass-resource utilisation within a transparent or semi-transparent structure. In an AuREUS-type system, luminescent compounds obtained from biological or agricultural residues are incorporated into a suitable transparent host matrix. These compounds absorb selected wavelengths of incident solar radiation and re-emit the absorbed energy at longer wavelengths.

2.2.2. Light Absorption and Spectral Conversion

When sunlight enters the panel, the biomass-derived luminophores absorb photons within their characteristic absorption bands. The absorbed energy excites the luminophores, which subsequently return to a lower-energy state by emitting photons of lower energy and longer wavelength. This process, known as photoluminescence, modifies the spectral distribution of sunlight. A sufficiently large Stokes shift between the absorption and emission bands is desirable because it reduces reabsorption losses within the panel.

2.2.3. Light Guidance and Photovoltaic Conversion

A substantial fraction of the emitted photons is confined within the transparent host by total internal reflection. The host matrix consequently functions as an optical waveguide, directing the converted light towards photovoltaic cells positioned along one or more edges of the panel. The edge-mounted cells convert the guided optical radiation into electrical energy. Thus, the large surface area of the panel acts simultaneously as a solar collector, spectral converter and waveguide, while only a relatively small photovoltaic area is required.

2.2.4. Biomass Waste Valorisation

The distinctive feature of AuREUS is its proposed use of agricultural and biological residues as sources of functional luminescent materials. Residues such as crop stalks, husks, leaves, fruit peels and other plant-derived materials may contain naturally occurring chromophores or carbon-rich constituents. These can potentially be processed through extraction, chemical modification, pyrolysis, hydrothermal treatment or carbon-dot synthesis to produce luminescent compounds. The approach therefore creates a proposed waste-to-energy pathway in which agricultural by-products are converted into value-added optical materials.

2.2.5. Conceptual Process Flow

The conceptual flow of the process has been represented in the flowchart shown in figure 2. The effectiveness of the technology depends on the luminophore's absorption range, photoluminescence quantum yield, Stokes shift, stability and compatibility with the host matrix, as well as on the panel's geometry and optical design.

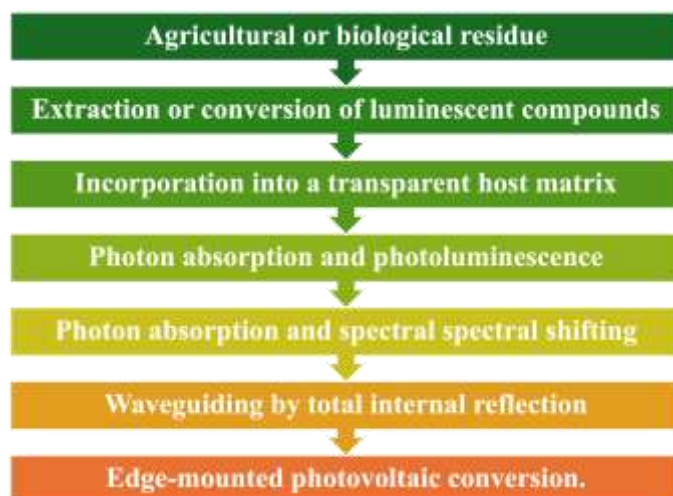


Figure 2: Process for AuREUS Technology

3. Potential Luminescent Materials for LSCs

A wide range of luminophores has been investigated for LSC applications. Their suitability depends on the required absorption range, emission wavelength, photoluminescence quantum yield, Stokes shift, stability, cost, toxicity, and compatibility with the host matrix. Major classes include organic dyes, inorganic quantum dots, rare-earth-based luminophores, perovskite nanocrystals, and carbon-based nanomaterials.

Table 1: Potential Materials for Luminescent Solar Concentration

Luminescent Materials		Advantages	Limitations	Reference
Organic dyes	Rhodamine derivatives, coumarins, fluorescein derivatives, BODIPY-type dyes	High absorption coefficients, tunable emission, relatively simple processing	Photobleaching, reabsorption, limited long-term stability	[7]
Rare-earth complexes/ions	Eu ³⁺ , Tb ³⁺ , Er ³⁺ , Yb ³⁺ systems	Large Stokes shifts, narrow emission bands, high photophysical stability in suitable hosts	Cost, processing complexity, limited broadband absorption	[8]
Semiconductor quantum dots	CdSe/CdS, InP, PbS, AgInS ₂	Tunable absorption/emission, high PLQY [#] , broad spectral engineering	Toxicity concerns for some compositions, synthesis complexity	[9]
Carbon quantum dots	Biomass-derived CQDs/GQDs	Potentially low-cost, tunable fluorescence, biomass compatibility, relatively benign compositions	Variable composition, excitation-dependent emission, reproducibility and stability issues	[10]

Perovskite nanocrystals	Lead-halide and lead-free perovskites	High PLQY [#] and tunable emission	Moisture/thermal stability and toxicity concerns for Pb-based systems	[11]
Natural/biomass-derived chromophores	Pigments, polyphenols and other plant-derived compounds	Renewable feedstock, potentially low environmental burden	Photostability, extraction variability, spectral instability	[12]

PLQY is Photoluminescence Quantum Yield

Organic dyes and quantum dots remain extensively investigated because of their tunable optical properties, while rare-earth complexes can provide large Stokes shifts and high photoluminescence efficiencies. Carbon dots are particularly relevant to the AuREUS concept because they can be synthesized from carbon-rich agricultural and food residues and can exhibit tunable photoluminescence.

3.1. Agricultural Waste Derived Luminescent Materials

Agricultural residues represent an abundant and renewable source of carbonaceous precursors for the synthesis of luminescent materials. Wastes such as rice husk, crop stalks, bamboo leaves, fruit peels, sugarcane bagasse, and other lignocellulosic biomass can be converted into carbon dots (CDs), carbon quantum dots (CQDs), and graphene quantum dots (GQDs) through hydrothermal, microwave-assisted, pyrolysis, and other relatively simple processes. These biomass-derived materials can exhibit strong and tunable photoluminescence because of their quantum-confinement effects, surface functional groups, defect states, and heteroatom-containing structures. Their renewable origin, low-cost feedstock, and potentially low environmental impact make them attractive candidates for sustainable optoelectronic applications.

Table 2: Agricultural Waste derived Luminescent Materials for Solar Concentration

Agricultural Waste	Luminescent Material	Important Characteristics	Potential application in AuREUS/LSCs	References
Rice husk	Carbon dots/CQDs	Photoluminescence; oxygen-containing surface groups	Solar-spectrum conversion and LSCs	[13]
Sugarcane bagasse	Carbon dots/CQDs	Biomass-derived fluorescent carbon nanomaterials	Luminescent layers and photovoltaic applications	[14]
Fruit peels	Carbon quantum dots	Strong and tunable fluorescence; surface functionalization	Potential wavelength-conversion material	[15]
Bamboo leaves	Carbon dots	Fluorescence and abundant biomass precursor	Potential LSC luminescent layer	[16]
Crop residues/stalks	CDs/CQDs/GQDs	Carbon-rich precursor; emission can be	Potential solar-energy conversion	[17]

		modified by synthesis conditions		
Lignocellulosic agricultural waste	CDs/GQDs	Tunable optical properties and functional surface groups	Potential sustainable luminescent materials	[13]

The use of agricultural waste as a precursor for luminescent materials offers an important opportunity for AuREUS technology, particularly because the conventional synthesis of luminescent compounds may involve expensive or non-renewable chemical precursors. Biomass-derived carbon dots are attractive because their optical properties can be tailored through precursor selection, reaction temperature, reaction time, pH, surface passivation, and heteroatom doping. For an AuREUS-type LSC, the most important parameters would be the absorption spectrum, photoluminescence quantum yield, emission wavelength, Stokes shift, photostability, and compatibility with the polymeric panel matrix. A sufficiently large Stokes shift is particularly desirable because it can reduce re-absorption of emitted photons within the panel and thereby improve the transport of luminescent light toward the edges.

3.2. Suitability of Biomass-Derived Luminescent Materials For Aureus Technology

Biomass-derived luminescent materials, particularly CDs, CQDs, and GQDs, have considerable potential for integration into AuREUS technology because they can combine renewable feedstocks with tunable optical properties. Agricultural residues such as rice husk, sugarcane bagasse, fruit peels, crop stalks, and leaves can provide carbon-rich precursors for producing luminescent materials with adjustable absorption and emission characteristics. Their suitability for AuREUS-type luminescent solar concentrators depends primarily on high photoluminescence quantum yield, broad solar absorption, suitable emission wavelengths, large Stokes shift, low self-absorption, high photostability, and compatibility with transparent polymer matrices. In addition, their low-cost and potentially scalable production from agricultural waste could reduce dependence on synthetic luminescent materials and contribute to a circular bioeconomy. However, the suitability of these materials for practical AuREUS applications cannot be established solely from their fluorescence properties; systematic studies of photon-conversion efficiency, optical losses, long-term stability, matrix compatibility, and photovoltaic output are required. Therefore, biomass-derived luminescent materials should currently be regarded as promising candidates for next-generation AuREUS panels, with further experimental validation needed to demonstrate their effectiveness in complete LSC systems.

4. Challenges

The development of AuREUS technology using agricultural waste presents several interconnected scientific, environmental, manufacturing and economic challenges, despite its considerable sustainability potential. The optical properties of biomass-derived luminophores may vary with the type, geographical origin and seasonal availability of the agricultural residue, as well as with extraction methods, chemical composition, processing conditions and interaction with the host matrix. Such variations can affect the photoluminescence quantum yield, emission spectrum, absorption coefficient, Stokes shift, photostability, reabsorption, scattering and concentration-quenching behaviour of the material, thereby influencing the efficiency and durability of the luminescent solar concentrator. Natural origin alone does not ensure environmental safety, since extraction solvents, additives, polymer matrices, degradation products and

photovoltaic components may generate toxicity or disposal concerns; consequently, material-safety assessment, life-cycle analysis and a clearly defined end-of-life strategy are essential. Large-scale implementation would also require reliable collection, storage and preservation of geographically dispersed and seasonally variable agricultural waste, together with standardised extraction, quality control and efficient transport infrastructure. During the manufacture of large-area panels, maintaining uniform luminophore dispersion and transparency may be difficult because of aggregation, non-uniform concentration, optical scattering, defects, bubbles and variations in mechanical integrity, while integration with edge-mounted photovoltaic cells may increase fabrication and installation costs. A comprehensive techno-economic assessment must therefore consider feedstock and processing costs, extraction yield, energy consumption, panel fabrication, maintenance, replacement frequency, service life and lifetime electricity generation. In agrivoltaic applications, the system must additionally balance electricity production with the transmission of photosynthetically useful radiation, since changes in spectral distribution, light intensity and photoperiod can influence crop growth and productivity. Nevertheless, by converting locally available agricultural residues into value-added luminescent materials, AuREUS technology could support waste valorisation, reduce dependence on non-renewable feedstocks, promote resource efficiency and contribute to more circular and sustainable energy systems, provided that its environmental benefits are demonstrated through standardised performance testing and whole-life evaluation.

5. Future Scope

The future scope of AuREUS technology using agricultural waste is promising because it can transform abundant agricultural residues into valuable luminescent materials for sustainable energy applications. Agricultural wastes such as crop stalks, husks, leaves, fruit peels, and other biomass residues contain naturally occurring or chemically transformable luminescent compounds that can potentially be extracted and incorporated into LSCs. Further research can focus on optimizing the extraction, purification, and modification of biomass-derived luminescent compounds to improve their photoluminescence efficiency, photostability, and spectral response. The development of durable, low-cost, and environmentally friendly AuREUS panels could enable their integration into building façades, windows, greenhouses, and agrivoltaic systems, allowing agricultural productivity and solar-energy generation to coexist. Future work should also investigate large-scale processing of agricultural waste, standardized material formulations, panel durability, recycling, life-cycle assessment, and techno-economic feasibility. Thus, AuREUS technology could contribute to a circular bioeconomy by converting agricultural waste into functional optoelectronic materials while reducing waste-management problems and supporting decentralized renewable-energy generation.

6. Conclusion

AuREUS-inspired luminescent solar technologies combine spectral management, luminescent solar concentration and agricultural-waste-derived materials. These systems absorb sunlight, re-emit it at longer wavelengths and direct it to edge-mounted photovoltaic cells, enabling potential use in buildings, greenhouses and agrivoltaic structures. Agricultural residues such as rice husk, crop stalks, leaves, fruit peels and sugarcane bagasse can serve as feedstocks for carbon dots and other luminophores. However, variations in biomass composition and processing can affect their optical performance, stability and environmental suitability. In agrivoltaic applications, system design must balance electricity generation

with light transmission and crop requirements. Before commercial adoption, challenges including material consistency, optical losses, durability, panel uniformity, recycling and economic feasibility must be addressed through standardised testing and long-term evaluation. Overall, AuREUS-inspired technology is a promising research direction rather than a commercially established alternative to conventional photovoltaics. Its success will depend on achieving reliable performance, durability, environmental benefits and competitive lifetime energy generation.

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