Bioenergy and the energy transition: Pathways to a low-carbon future.

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As the world grapples with the dual challenges of climate change and energy security, the transition to low-carbon energy sources has become an imperative. Among the array of renewable energy options, bioenergy stands out for its versatility and potential to contribute significantly to a sustainable energy future [1, 2].

Bioenergy is derived from biomass, which includes organic materials such as plants, agricultural residues, and waste. It can be converted into various forms of energy, including heat, electricity, and biofuels. Unlike fossil fuels, which release carbon that has been stored for millions of years, bioenergy can be part of a closed carbon cycle. When managed sustainably, the carbon dioxide (CO2) released during the combustion of biomass is offset by the CO2 absorbed during the growth of new biomass, making it a potentially carbon-neutral energy source [3].

Traditional biomass power plants convert organic materials into electricity and heat. Advanced technologies, such as co-firing biomass with coal, can help reduce emissions from existing coal-fired power plants. Liquid biofuels, such as bioethanol and biodiesel, are essential for reducing the carbon footprint of the transportation sector. Advanced biofuels, derived from non-food biomass, offer a sustainable alternative to fossil fuels. Anaerobic digestion of organic waste produces biogas, which can be used for heating, electricity generation, or upgraded to bio-methane for use in natural gas grids and as a vehicle fuel. CHP systems use biomass to generate both electricity and heat, maximizing energy efficiency and reducing waste [4, 5].

Bioenergy has the potential to significantly reduce greenhouse gas emissions, particularly when replacing fossil fuels in electricity generation and transportation. By diversifying the energy mix and utilizing local resources, bioenergy can enhance energy security and reduce dependence on imported fossil fuels. The bioenergy sector can create jobs and stimulate economic growth, particularly in rural areas where biomass resources are abundant. Utilizing agricultural and municipal waste for energy production can help address waste management challenges and reduce landfill use [6, 7].

Ensuring that biomass is sourced sustainably is crucial to avoid negative impacts on land use, food security, and biodiversity. Certification schemes and sustainability criteria are essential to address these concerns. Continued research and development are needed to improve the efficiency and cost-effectiveness of bioenergy technologies, particularly advanced biofuels and biomass conversion processes. Supportive policies and incentives are necessary to encourage investment in bioenergy. Governments must provide clear and stable regulatory frameworks to attract private sector participation. Raising awareness about the benefits of bioenergy and addressing public concerns about its environmental impact is vital for gaining broader acceptance [8, 9].

Bioenergy has a crucial role to play in the global energy transition. Its integration into the energy mix can provide a reliable, renewable, and sustainable source of power, heat, and fuels. However, realizing the full potential of bioenergy requires concerted efforts from policymakers, industry stakeholders, and researchers. By addressing sustainability concerns, investing in technological advancements, and fostering supportive policies, bioenergy can become a cornerstone of a low-carbon future, helping to mitigate climate change and build a resilient energy system. Bioenergy represents a promising pathway to a low-carbon future. Its diverse applications and potential for carbon neutrality make it an essential component of the global strategy to transition away from fossil fuels. With the right investments and policy frameworks, bioenergy can help achieve a sustainable, secure, and low-carbon energy future for all [10].

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