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Advancing microalgal biofuel yields through adaptive metabolic engineering

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Microalgae represent one of the most promising renewable feedstocks for next-generation biofuels due to their rapid growth, high lipid content, and limited land-use requirements. However, large-scale deployment is constrained by suboptimal biomass productivity, metabolic bottlenecks, and high cultivation costs. This study introduces an adaptive metabolic engineering framework integrating CRISPR-based gene modulation, dynamic environmental sensing, and automated nutrient optimization to enhance microalgal lipid biosynthesis. Experimental trials across outdoor photobioreactors demonstrated a 42% increase in lipid yield and a 27% improvement in biomass accumulation compared to conventional cultivation. Metabolic flux analysis revealed elevated acetyl-CoA channeling toward triacylglycerol pathways, supported by enhanced expression of key enzymes such as ACCase and DGAT. Additionally, real-time nutrient feedback loops reduced nitrogen waste by 38%, improving cost-efficiency. Downstream transesterification yielded biodiesel with superior oxidative stability and reduced sulfur emissions. Scaling models predict a potential 30% reduction in cost per liter of algal biodiesel when deployed in hybrid photobioreactor–open-pond systems. This work demonstrates that adaptive metabolic engineering, coupled with intelligent process control, offers a transformative pathway toward commercially viable microalgal biofuels. Such integrated bioprocess innovations strengthen the global transition toward sustainable energy systems.

Biography

Elena Vasiliev is a biotechnology researcher at the Technical University of Denmark specializing in metabolic engineering, algal biotechnology, and sustainable biofuel systems. She has led multiple European Horizon-funded projects on renewable energy innovations and has authored more than 60 scientific publications in bioenergy and industrial biotechnology. Her work focuses on integrating biological engineering, computational modeling, and scalable bioprocess design to accelerate the commercialization of next-generation biofuels.

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