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Perspective

Gasoline Biodegradation and Biotechnological Innovations

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DESCRIPTION

Gasoline is widely used as a fuel worldwide, but its extraction, transportation and usage pose significant environmental challenges due to hydrocarbon emissions, soil contamination and groundwater pollution. Environmental biotechnology offers promising solutions by employing microorganisms and enzymes capable of degrading gasoline components and converting them into non-toxic byproducts. Understanding and harnessing these biological pathways not only mitigates pollution but also opens avenues for the biotransformation of gasoline into value-added products.

Microbial degradation of gasoline primarily targets alkanes, cycloalkanes and aromatic compounds. Species such as Pseudomonas putida, Rhodococcus and Mycobacterium are known for their ability to metabolize linear and branched alkanes, transforming them into fatty acids that enter the central metabolic cycle. Aromatic hydrocarbons such as toluene, xylene and benzene are degraded via dioxygenase-mediated pathways, forming catechols and other intermediates that are further metabolized into CO_2 and water. These processes form the foundation for bioremediation strategies applied to gasoline-contaminated soils and water systems.

Enzymes play a central role in gasoline biodegradation. Alkane hydroxylases catalyze the initial oxidation of alkanes to alcohols, which are further converted to aldehydes and carboxylic acids. Monooxygenases and dioxygenases target aromatic hydrocarbons, introducing hydroxyl groups to break the stability of the aromatic ring. Genetic engineering of these enzymes enhances their substrate range, turnover rate and tolerance to hydrocarbon toxicity, improving overall biodegradation efficiency.

Gasoline biodegradation can be applied through in situ or ex situ strategies. In situ bioremediation involves stimulating indigenous microbial populations by adding nutrients, oxygen, or surfactants to enhance hydrocarbon degradation in contaminated soils and aquifers. Ex situ techniques, such as bioreactors, composting and bioaugmented soil treatment, allow controlled conditions for higher degradation rates. Integration with biogas production or bio-based chemical synthesis further converts gasoline contaminants into renewable energy or industrially relevant products, exemplifying circular bioeconomy principles.

Emerging research in microbial consortia and synthetic biology is expanding the potential of gasoline biotransformation. Co-cultivation of complementary microbial species improves pathway efficiency, ensures metabolic stability and allows simultaneous degradation of multiple gasoline components. Engineered microbial strains can convert hydrocarbons into biofuels, organic acids and polymer precursors, providing economic incentives alongside environmental remediation. Additionally, monitoring tools such as metagenomics, proteomics and biosensors enhance understanding of microbial community dynamics and optimize biodegradation processes.

Challenges in gasoline biotechnology include the complex composition of gasoline, toxicity of hydrocarbons to microbes and limited bioavailability of hydrophobic compounds. Advances in bioreactor design, surfactant-assisted bioremediation and two-phase partitioning systems enhance microbial access to hydrocarbons, improving process efficiency. Economic feasibility, scalability and regulatory considerations remain critical for large-scale deployment.

Microbial gasoline degradation is initiated by enzymes such as alkane hydroxylases, monooxygenases and dioxygenases, which catalyze the oxidation of alkanes and aromatics into alcohols, aldehydes and organic acids. Linear and branched alkanes are oxidized to fatty acids and subsequently enter central metabolic pathways, while aromatic hydrocarbons such as toluene, xylene and benzene are transformed into catechols, which undergo ring cleavage and mineralization to CO_2 and water. Bacteria including Pseudomonas putida, Rhodococcus and Mycobacterium are well-studied for their ability to degrade diverse gasoline components, making them ideal candidates for bioremediation applications.

Biotechnological applications of gasoline biodegradation include *in situ* and *ex situ* remediation. *In situ* bioremediation enhances

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native microbial populations through nutrient addition, oxygenation, or surfactant treatment, facilitating hydrocarbon degradation in contaminated soils and aquifers. *Ex situ* strategies, such as composting, bioreactors and bioaugmentation, provide controlled environments for accelerated and high-efficiency gasoline removal. Hybrid processes integrate microbial degradation with biofuel or chemical production, enabling valorization of gasoline-derived intermediates and promoting circular bioeconomy principles.

CONCLUSION

Biotechnology enables effective degradation and biotransformation of gasoline, offering sustainable solutions for pollution mitigation and resource recovery. Microbial and enzymatic strategies convert hydrocarbons into non-toxic products and value-added chemicals, supporting environmental protection and circular bioeconomy principles. Continued research in synthetic biology, microbial consortia and bioprocess optimization is essential for advancing practical and scalable gasoline biotechnology.