

# Green Chemistry for Sustainable Engineering



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Edited by

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## PREFACE

In recent years, the world has witnessed an increasing urgency to address environmental challenges, prompting a fundamental shift in the way we approach chemical processes and engineering practices. As we stand at the intersection of innovation and sustainability, this book aims to serve as a comprehensive guide, navigating the principles, theories, and practical applications of green and sustainable chemistry and engineering.

In this time, we embark on a journey that transcends traditional methodologies, embracing a holistic approach that prioritizes environmental stewardship, human health, and economic viability. By integrating cutting-edge research, case studies, and real-world examples, we delve into the multifaceted realm of green chemistry and engineering, illuminating pathways toward a more sustainable future.

Our exploration begins with an in-depth examination of the foundational principles underlying green chemistry and engineering. We unravel the intricacies of molecular design, catalysis, and process optimization, showcasing how innovation at the molecular level can catalyze transformative change. Drawing upon sustainability principles, we analyze the environmental impact of chemical processes, emphasizing the importance of minimizing waste, conserving resources, and mitigating pollution.

As we navigate through the theoretical underpinnings of green chemistry and engineering, we also embark on a practical journey, exploring the implementation of sustainable practices across diverse industries. From pharmaceuticals to agriculture, energy production to materials science, we uncover the innovative solutions and best practices driving sustainability forward. Through case studies and interdisciplinary perspectives, we demonstrate how collaboration across scientific disciplines can lead to breakthroughs in green technology and engineering.

Furthermore, we recognize the pivotal role of education and outreach in fostering a culture of sustainability. Thus, this book serves not only as a resource for academics, researchers, and industry professionals but also as



a beacon of inspiration for the next generation of scientists and engineers. By empowering individuals with the knowledge and tools to effect positive change, we aim to cultivate a global community committed to advancing the frontiers of green chemistry and engineering.

In conclusion, Green and Sustainable Chemistry and Engineering: Theory & Practice represents a culmination of collective wisdom, innovation, and dedication towards a common goal: to forge a more sustainable future for generations to come. As we embark on this journey together, let us embrace the challenges and opportunities ahead, striving towards a world where chemistry and engineering harmonize with nature, fostering prosperity and well-being for all.

This edited volume begins with an editorial entitled “Green Chemistry and Engineering for Sustainable Future“, that throws light on the future of Green Chemistry and Engineering from the sustainability point of view. The book is divided into four parts. Part I is devoted to the role of Green Chemistry in the future of sustainable engineering and consists of three chapters. Chapter one discusses the use of ethanol as a clean fuel of the future. Chapter two delves into the significance of green designs in sustainable engineering. Chapter three gives an account of green fuels as the fuels of a sustainable future.

Part II is dedicated to the development of methods for the synthesis of materials of different kinds. Part II contains four chapters. Chapter Four Green synthetic pathways for the synthesis of small molecules in general. Chapter five delves into green routes for the extraction of bioactive molecules or phytochemicals. Chapter six presents an overview of green methods adopted for the synthesis of carbon-based quantum dots while chapter seven deliberates on green analytical methods employed for the synthesis of sustainable materials in general.

Part III is confined to the use of green and sustainable materials for industrial applications. Part III comprises of five chapters. Chapter eight sheds light on novel green and sustainable materials and their applications in practical life. Chapter Nine throws light on the application of green and sustainable catalytic materials for industrial use. Chapter ten gives practical insights into the use of green and sustainable solvents in greening processes. Chapter eleven deals with the role of green and sustainable coatings in particular for pharmaceutical applications. Chapter twelve gives insights into the use of vegetable oils as eco-friendly solvents for extracting lipophilic bioactives in pharma and nutraceuticals.

Part IV is dedicated to the adoption of green analytical methods for environmental remediation. Part IV covers four chapters. Chapter thirteen explores the application of green adsorbents for the removal of heavy metals from waste. Chapter fourteen gives an experimental approach to the application of green catalysts for carrying out sustainable synthesis of materials. Chapter fifteen deals with the role of iron oxide nanoparticle synthesis in greening organic reactions while the concluding chapter sixteen gives an overview of green analytical methods, their assessment, limitations, challenges, and opportunities in practical life.

The volume is therefore an invaluable resource to academicians, researchers, students, green chemists, engineers, and practitioners and will enrich the knowledge base of the green chemistry and engineering field.

EDITORIAL:  
GREEN CHEMISTRY AND ENGINEERING  
FOR SUSTAINABLE FUTURE

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In an era where environmental consciousness has become synonymous with progress, the intersection of science and sustainability has never been more critical. Our publication, "Green Chemistry and Engineering: Theory and Practice," emerges as a beacon of knowledge, guiding readers through the transformative landscape of eco-friendly methodologies and innovative technologies. This book stands as a testament to the evolving role of science in creating a harmonious coexistence between industry and the environment.

**Navigating the Landscape of Green Chemistry:** At the heart of this volume lies an exploration of Green Chemistry. This interdisciplinary approach redefines the relationship between chemistry, industry, and the planet. The contributing authors have expertly crafted a narrative that not only elucidates the foundational principles of Green Chemistry but also showcases its real-world applications. From designing sustainable chemical processes to minimizing waste and toxicity, the book provides a comprehensive understanding of how science can be a force for positive change.

In the intricate tapestry of scientific exploration, Green Chemistry emerges as a compass guiding us towards a sustainable and environmentally conscious future. As we navigate this dynamic landscape, it becomes evident that the principles of Green Chemistry go beyond conventional practices, challenging us to rethink and reshape the way we approach chemical processes. Here, we embark on a journey through the key elements that define the landscape of Green Chemistry:

**Principles as North Stars:** At the core of Green Chemistry lie its twelve guiding principles, a set of directives designed to minimize the environmental impact of chemical processes. These principles, ranging from the prevention of waste to the use of safer chemicals, serve as our North Stars, providing a framework for designing sustainable and responsible chemical pathways.

**Atom Economy and Efficiency:** Green Chemistry places a premium on maximizing atom economy—the efficient use of atoms in a chemical transformation. The goal is to minimize waste and optimize resource utilization, steering us away from the traditional "cradle-to-grave" approach and towards a more circular and sustainable model.

**Safer Chemical Synthesis:** A cornerstone of Green Chemistry is the commitment to using inherently safer chemicals. This involves designing processes that prioritize substances with reduced toxicity, ensuring that the environmental and human health impact of chemical products is minimized throughout their life cycle.

**Renewable Feedstocks:** The adoption of renewable feedstocks is a pivotal aspect of navigating the Green Chemistry landscape. By transitioning from fossil fuel-based resources to renewable alternatives, we reduce our dependence on finite resources and contribute to the development of a more sustainable and resilient chemical industry.

**Energy Efficiency:** Green Chemistry encourages the pursuit of energy-efficient processes, advocating for the use of alternative energy sources and the reduction of overall energy consumption. By prioritizing energy efficiency, we not only minimize environmental impact but also contribute to the economic viability of sustainable practices.

**Biocatalysis and Green Technologies:** Embracing nature's toolbox, Green Chemistry incorporates biocatalysis and green technologies. Enzymes and other biological catalysts play a crucial role in enhancing selectivity and reducing the environmental footprint of chemical reactions, exemplifying the marriage of science and sustainability.

**Life Cycle Assessment (LCA):** The journey through Green Chemistry involves a holistic perspective on product life cycles. Life Cycle Assessment (LCA) enables us to evaluate the environmental impact of a product from its inception to its eventual disposal, ensuring that sustainability considerations are integrated into every stage of the chemical production process.

**Education and Advocacy:** Navigating the landscape of Green Chemistry requires a collective effort towards education and advocacy. By fostering awareness and inspiring the next generation of scientists, we empower individuals to champion sustainable practices, fostering a cultural shift towards a greener and more responsible future.

As we traverse the terrain of Green Chemistry, it becomes clear that this discipline is not just a scientific endeavor—it is a philosophy, a commitment to harmonizing human ingenuity with the delicate balance of our planet. Through mindful navigation and a steadfast commitment to these principles, we pave the way towards a future where chemistry and sustainability coalesce seamlessly.

Embark on this journey with curiosity, determination, and a vision for a world where chemistry is not just a field of study, but a steward of our planet's well-being.

**Green Engineering a Sustainable Future:** Green Engineering, an integral part of this discourse, takes center stage as we delve into innovative engineering solutions that minimize the environmental impact of technological processes. This book not only acknowledges the challenges posed by conventional engineering practices but also offers viable alternatives that promote efficiency, reduce resource consumption, and foster sustainable development.

In the relentless pursuit of progress and innovation, the engineering landscape finds itself at a crucial crossroads—balancing the imperative for advancement with the pressing need for sustainability. Green Engineering emerges as the visionary path forward, where science, technology, and environmental responsibility converge to engineer a future that is not only efficient and cutting-edge but also harmonious with the ecosystems that sustain us.

**Holistic Design Philosophy:** At the heart of Green Engineering lies a holistic design philosophy that considers the entire life cycle of products and processes. It goes beyond traditional engineering paradigms by prioritizing not only performance and efficiency but also the environmental and social impacts of technological solutions.

**Resource Efficiency and Circular Economy:** Green Engineering champions resource efficiency, aiming to optimize the use of materials and energy throughout a product's life cycle. Embracing the principles of a

circular economy, it strives to minimize waste, promote recycling, and close the loop on resource utilization, thus reducing the burden on finite resources.

**Renewable Energy Integration:** The future envisioned by Green Engineering is one powered by renewable energy sources. From solar and wind to hydropower and beyond, the integration of sustainable energy technologies is not just an option but a necessity. Green Engineers work towards designing systems that harness the power of nature without depleting its finite resources.

**Smart and Sustainable Infrastructure:** Infrastructure development is a cornerstone of societal progress, and Green Engineering transforms this process into an opportunity for sustainable transformation. It involves the creation of smart cities and infrastructure that prioritize energy efficiency, resilience, and environmental compatibility, creating spaces that enhance the quality of life for inhabitants while minimizing ecological impact.

**Innovative Materials and Technologies:** Green Engineering thrives on innovation, pushing the boundaries of materials science and technology. From biodegradable polymers to advanced nanomaterials, sustainable engineering solutions pave the way for a future where materials are not just functional but also environmentally benign, leaving behind a legacy of responsible progress.

**Eco-Friendly Manufacturing Processes:** The manufacturing sector, a traditional bastion of environmental concerns, undergoes a paradigm shift in the realm of Green Engineering. Sustainable manufacturing processes prioritize cleaner production methods, reduced emissions, and the elimination or minimization of hazardous substances, proving that economic growth and environmental stewardship can coexist.

**Collaboration and Interdisciplinary Approaches:** Green Engineering is inherently collaborative, transcending disciplinary boundaries to bring together experts from diverse fields. Engineers collaborate with ecologists, economists, and social scientists to ensure that technological solutions are not only technologically sound but also socially acceptable and environmentally friendly.

**Education and Ethical Responsibility:** The engineers of tomorrow are nurtured with a deep sense of ethical responsibility. Green Engineering education instills a commitment to sustainable practices, fostering a mindset

where environmental and social impacts are considered integral to engineering decision-making.

As we navigate the complexities of the 21st century, Green Engineering emerges as a beacon of hope, offering a blueprint for a future where progress is synonymous with sustainability. It is a call to action for engineers, scientists, policymakers, and citizens alike—a call to collectively engineer a future that thrives on innovation, respects nature, and ensures the well-being of generations to come.

In embracing Green Engineering, we not only revolutionize our approach to technology but also redefine the very essence of progress—a progress that is not measured solely by technological milestones but by the enduring sustainability of our planet. Together, let us engineer a future that is not only smart and efficient but, above all, profoundly green.

**Case Studies in Green Chemistry and Engineering: Realizing the Vision:** The heart of any scientific discourse lies in its application, and "Green Chemistry and Engineering: Theory and Practice" is no exception. Through a series of insightful case studies, readers are transported into real-world scenarios where green methodologies are not just theoretical ideals but proven practices. From large-scale industrial applications to niche sectors like pharmaceuticals, these case studies underscore the tangible impact of embracing sustainability in the scientific realm.

Applying Green Chemistry and Engineering principles is not confined to theoretical frameworks; it is a tangible, transformative force reshaping industries, products, and processes. Through a lens focused on real-world applications, this compilation of case studies serves as a testament to the profound impact that embracing sustainable practices can have on diverse sectors.

**Pharmaceutical Innovations: *Green Synthesis of Pharmaceuticals:*** Explore how pharmaceutical companies are adopting environmentally friendly synthesis routes to produce life-saving drugs. Case studies delve into the reduction of waste, the use of bio-catalysis, and the incorporation of green solvents, showcasing a shift towards sustainable drug development.

**Clean Energy Technologies: *Solar Panel Manufacturing:*** Witness the evolution of solar panel production, where Green Engineering principles are harnessed to minimize the environmental footprint of renewable energy technologies. Case studies highlight advancements in material selection,

energy-efficient manufacturing processes, and recycling initiatives within the solar industry.

**Agrochemicals and Crop Protection:** *Sustainable Crop Protection:* Uncover how agrochemical companies are redefining pest control through environmentally benign formulations. Case studies explore the development of bio-based pesticides, precision application technologies, and integrated pest management strategies, emphasizing the role of Green Chemistry in sustainable agriculture.

**Waste Reduction in Manufacturing:** *Zero-Waste Manufacturing:* Examine how industries are striving towards zero-waste production systems. Case studies showcase innovative approaches, such as closed-loop manufacturing processes, recycling streams, and the adoption of circular economy principles, demonstrating the feasibility and benefits of waste reduction in various manufacturing sectors.

**Green Materials in Construction:** *Sustainable Building Materials:* Journey through the construction sector's shift towards eco-friendly materials and practices. Case studies highlight the development of green concrete, recycled building materials, and energy-efficient construction techniques, illustrating how the industry is aligning with sustainable principles.

**Water Treatment and Conservation:** *Greener Solutions for Water Treatment:* Explore case studies in the water treatment industry, where Green Chemistry and Engineering are employed to develop efficient and environmentally friendly methods. From green coagulants to advanced filtration technologies, witness how the sector is addressing water scarcity while minimizing ecological impact.

**Electronics and E-Waste Management:** *Responsible Electronics Manufacturing:* Delve into case studies showcasing how the electronics industry is adopting Green Chemistry and Engineering principles to reduce the environmental impact of electronic devices. From eco-friendly circuit board materials to sustainable end-of-life disposal strategies, witness the industry's commitment to responsible manufacturing.

**Consumer Products Redefined:** *Green Product Design:* Examine how consumer product companies are reimagining their offerings with a focus on sustainability. Case studies showcase innovations in packaging design, biodegradable products, and the incorporation of recycled materials,



illustrating the potential for Green Chemistry and Engineering to redefine the consumer goods landscape.

These case studies collectively paint a vivid picture of a future where sustainable practices are not just a lofty ideal but a practical, achievable reality. By exploring the triumphs and challenges faced by industries in their journey toward sustainability, this compilation aims to inspire and guide practitioners, researchers, and policymakers toward a world where Green Chemistry and Engineering truly realize their transformative vision.

**An Ode to Innovation in Green Chemistry and Engineering:** As the scientific community grapples with global challenges, innovation emerges as the driving force behind progress. The book not only presents the latest developments in Green Chemistry and Engineering but also serves as a platform for discussing emerging trends and the future trajectory of sustainable science. From biodegradable materials to renewable energy solutions, this volume is a testament to the boundless possibilities of a green scientific future.

In the crucible of progress, where scientific inquiry meets the call for environmental stewardship, emerges an ode to innovation—a lyrical celebration of the transformative dance between Green Chemistry and Engineering. This harmony of disciplines, guided by a shared commitment to sustainability, is reshaping industries, challenging paradigms, and illuminating a path toward a greener, more harmonious future.

**Verses of Sustainable Synthesis:** In the laboratory, where molecules dance to the rhythm of discovery, Green Chemistry orchestrates a symphony of sustainable synthesis. Innovations unfold as chemists compose reactions that sing with atom efficiency, minimize waste, and embrace benign solvents. Each breakthrough is a note in the melody of eco-friendly processes, echoing the promise of cleaner, greener chemical transformations.

**Chorus of Renewable Resources:** Green Engineering takes the lead on the grand stage, directing a chorus of renewable resources. Materials once considered waste find new purpose, and energy derived from the sun and wind powers the crescendo of sustainable progress. Through innovative engineering, industries harmonize with nature, composing a refrain where resource efficiency and circular economy principles create a resilient and regenerative cadence.

**Sonnet of Biocatalysis and Nature's Wisdom:** In the laboratory and beyond, biocatalysis adds a poetic touch, inviting nature's wisdom into the composition. Enzymes and biological catalysts take center stage, guiding chemical transformations with elegance and precision. This sonnet of biocatalysis narrates a tale of harnessing nature's brilliance, where innovation intertwines with the delicate choreography of the biological world.

**Ballad of Circular Economy:** In the realm of manufacturing, the ballad of the circular economy unfolds—a melody of closed loops and sustainable systems. Green Chemistry and Engineering join forces to rewrite the manufacturing score, embracing the concept that waste is but a misplaced resource. The ballad celebrates industries that harmonize production with environmental responsibility, creating a legacy of sustainability.

**Epic of Smart Cities and Sustainable Infrastructure:** An epic unfolds as Green Engineering architects the cities of tomorrow. This narrative transcends the ordinary, weaving a tale of smart cities and sustainable infrastructure. Innovations in energy-efficient buildings, intelligent transportation systems, and green spaces compose a saga where urban landscapes harmonize with the natural world, creating environments that breathe and thrive.

**Harmony in Diversity:** In this symphony of innovation, diversity plays a crucial role. The voices of chemists, engineers, ecologists, and visionaries converge in a harmony that transcends disciplines. Collaboration becomes the linchpin, and the diversity of perspectives adds richness to the melody, echoing the idea that solving complex environmental challenges requires a chorus of minds working in unison.

**Finale: A Sustainable Legacy:** As the final notes of this ode resound, the vision of a sustainable legacy emerges. Green Chemistry and Engineering, hand in hand, have composed a masterpiece—a legacy that transcends the present and resonates through generations. It is an ode to innovation that inspires, a melody that echoes through laboratories, industries, and cities, guiding humanity towards a future where progress is synonymous with sustainability.

In this symphony of innovation, let us all be musicians, playing our part in the transformative dance of Green Chemistry and Engineering. For every discovery, every breakthrough, and every sustainable solution is a note in the composition of a better, greener world—an ode to innovation that

reverberates through time, reminding us that the pursuit of knowledge can be a harmonious journey towards a brighter, more sustainable future.

**A Call to Action in Green Chemistry and Engineering:** In the face of climate change and environmental degradation, this publication serves as more than a repository of knowledge; it is a call to action. By delving into the pages of this book, readers are invited to join the vanguard of change-makers who understand that the future of science lies in its ability to coexist harmoniously with the planet.

**Green Chemistry and Engineering: Shaping a Sustainable Tomorrow:** In the corridors of academia, laboratories of innovation, and the boardrooms of industry, a resounding call reverberates—a call to action in Green Chemistry and Engineering. This is not merely an invitation but an imperative, urging scientists, engineers, policymakers, and global citizens to unite in a collective effort to shape a sustainable tomorrow.

**Redefining Progress:** The first step in answering this call is a paradigm shift—a redefinition of progress. Green Chemistry and Engineering propel us towards a future where success is measured not only in technological advancements but also in the responsible use of resources, the reduction of environmental impact, and the enhancement of societal well-being. It's a call to embrace a new metric, where sustainable practices stand as the hallmark of progress.

**Education as Empowerment:** At the heart of this call is the recognition that knowledge is power. Institutions of learning play a pivotal role in equipping the next generation with the tools and mindset needed to address environmental challenges. A call echoes through lecture halls and laboratories, urging educators to weave Green Chemistry and Engineering into curricula, empowering students to become stewards of a sustainable future.

**Innovation as Catalyst:** In laboratories around the globe, the call to action takes the form of innovation. It challenges researchers to push boundaries, explore unconventional pathways, and pioneer solutions that marry scientific ingenuity with environmental responsibility. The call resonates with entrepreneurs, urging them to see beyond profit margins and embrace innovations that not only drive economic growth but also foster ecological resilience.

**Policy for Progress:** Policymakers, positioned at the intersection of science and governance, hear a distinct call—a call to enact and enforce regulations that incentivize sustainable practices. It is a summons to create a legislative symphony that harmonizes economic goals with environmental well-being, ensuring that the legal framework propels societies towards a greener, more sustainable equilibrium.

**Collaboration as Catalyst for Change:** The call is not exclusive to any single discipline; it is a collective summons for collaboration. Scientists and engineers must join hands with policymakers, businesses, and communities. It is an invitation to transcend silos, share knowledge, and co-create solutions that address global challenges collaboratively. Together, we can amplify the impact of Green Chemistry and Engineering, creating a transformative ripple effect across industries and societies.

**Investment in Sustainability:** Economies are urged to heed the call by redirecting financial resources towards sustainability. Investors are challenged to consider not only returns on investment but also the ecological and societal dividends that sustainable initiatives yield. The call resonates in boardrooms, urging businesses to recognize that long-term viability is intrinsically linked to responsible, sustainable practices.

**Consumer Empowerment:** In the marketplace, consumers hear the call—a call to be discerning, conscious, and demanding of sustainability. As stewards of purchasing power, individuals are empowered to choose products and services that align with Green Chemistry and Engineering principles. The call resonates in every purchase, encouraging consumers to be catalysts for change through their choices.

**Global Citizenship:** Ultimately, the call to action transcends borders. It is a global imperative, a recognition that the challenges we face—climate change, pollution, resource depletion—are shared burdens. Nations must unite, fostering international collaboration and knowledge exchange. The call inspires a sense of global citizenship, urging us to recognize our interconnectedness and work collectively towards a sustainable, shared future.

In the chorus of this call to action, every voice matters. Whether you are a scientist in a laboratory, an educator shaping minds, a policymaker crafting regulations, a business leader steering corporate strategies, or a citizen making everyday choices—heed the call. Green Chemistry and Engineering beckon us to be architects of change, forging a sustainable legacy for

generations to come. The time to act is now, and the call is a melody of hope, resilience, and the promise of a brighter, greener future. Will you

**Conclusion:** "Green Chemistry and Engineering: Theory and Practice" is not merely a book; it is a roadmap toward a sustainable and responsible future. We extend our gratitude to the dedicated authors who have contributed their expertise to this endeavor. May this book inspire a new generation of scientists, engineers, and advocates to champion the cause of green chemistry and engineering, and may their efforts propel us towards a brighter and greener tomorrow.



## **PART I**

# **GREEN, CHEMISTRY FOR SUSTAINABLE ENGINEERING FUTURE**

# USE OF ETHANOL AS A FUEL FOR THE SUSTAINABLE FUTURE

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## **Abstract**

Bio-ethanol is a renewable and eco-friendly fuel produced through the fermentation of sugars and starch components in plants, such as sugarcane, grains, corn, rice, beetroot, and wheat. It is considered a clean and cost-effective fuel because it reduces greenhouse gas emissions and can be produced from various sources like sugar cane, sugar beet, corn, and lignocellulosic biomass. The production process of bio-ethanol involves four main steps: pretreatment, hydrolysis, fermentation, and separation.

## **Problems Identified**

The depletion of petroleum supplies and the harmful effects that exhaust fumes from fossil fuels have on the environment have spurred research on ecologically friendly and renewable fuels in recent years. The high cost of oil has made other renewable energy sources increasingly appealing. Numerous technologies are environmentally sustainable. Other options to ethanol include biodiesel, which is produced from leftover cooking oil or agricultural crops and combined with diesel; and gas-to-liquids (GTL), which is produced from the abundance of biomass, coal, and natural gas. However, despite these apparent benefits, limited manufacturing efficiency of biodiesels prevents their usage in internal combustion engines.

In this chapter, we will focus on recent developments in the manufacturing of green fuels such cellulosic ethanol and biodiesel.

### **Advantages of bio-ethanol:**

Reduced greenhouse gas emissions

Environmental benefits

Energy security

**Case study:**

40% of the world's population gets most of their nutrition from rice. India manufactures 130 million tons of straw annually. Majority of the straw is used to make animal feed. The majority of the energy in the straw is lost when the remainder is burned, mainly in the fields. This also releases carbonaceous particles into the atmosphere, which can lead to a number of lung ailments. Despite the fact that rice straw is produced in large quantities, farmers in this nation must understand the value of agro-waste and how to convert rice straw into bioethanol in order to use it as a substitute for the source of befouled production.

The current case study with its numerous advantages challenges and cost effectiveness will be discussed with authentic statistics in the chapter.

**Keywords:** Bio-ethanol, biomass, fuel cell technology, pre-treatment, fermentation, recovery, lignocellulose biomass (LCB) advantages, challenges.

## 1.1 Introduction

### 1.1.1 Defining Ethanol: A Sustainable Energy Elixir

Ethanol, chemically known as ethyl alcohol, stands as a renewable, bio-based fuel derived from organic matter. Its production predominantly involves the fermentation of sugars found in various biomass sources, ranging from crops like corn and sugarcane to agricultural residues and even algae. This versatile alcohol holds immense promise as an eco-friendly alternative to conventional fossil fuels due to its renewable nature and lower environmental impact.[1]

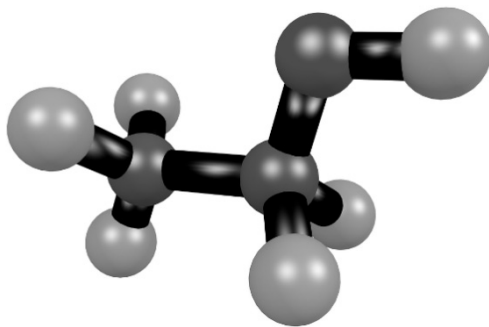


Fig 1/1. Ethanol

### **1.1.2 Ethanol's Role in Fuel: A Powerful Combination**

When blended with gasoline, ethanol forms a potent fuel commonly known as E10 (containing 10% ethanol) or higher blends like E15 and E85. This blending not only reduces the reliance on non-renewable resources but also enhances the octane rating of the fuel, leading to cleaner combustion and reduced emissions. [2]

### **1.1.3 The Evolution of Ethanol in the Energy Landscape**

Ethanol's usage in fuel applications has undergone a remarkable evolution. Initially employed for lighting and medicinal purposes in ancient civilizations, its contemporary significance as a sustainable fuel source gained prominence in the late 20th century. Today, it stands as a pivotal component in global efforts to transition towards cleaner energy alternatives. [3]

This chapter embarks on an exploration of ethanol's potential to drive a sustainable energy future, examining its production, environmental impact, economic viability, and future prospects, thereby envisioning a world powered by eco-friendly fuel alternatives.

### **1.1.4 Historical background of ethanol as a biofuel**

The roots of ethanol as a biofuel can be traced back to ancient civilizations where it found varied applications. Historical records indicate its use in activities like lighting, medicinal preparations, and even religious rituals. Early societies discovered its combustible nature and harnessed it for practical purposes long before its formal identification as a potential fuel source.

### **1.1.5 Industrial Revolution to the 20th Century: Ethanol's Emergence as Fuel**

During the Industrial Revolution, ethanol gained recognition as a viable fuel alternative. Its usage expanded into powering lamps and engines in the late 19th century. However, its widespread adoption as a biofuel commenced in the 20th century when technological advancements in distillation and engine design facilitated its use as a motor fuel.

### **1.1.6 Prohibition Era: Ethanol's Transition to Fuel Additive**

The Prohibition era in the US (1920-1933) led to a change in ethanol's perception and usage. With alcohol production legalized for industrial purposes, ethanol emerged as a fuel additive. Its blending with gasoline in various proportions gained attention due to its octane-enhancing properties and as a means to reduce engine knocking.

### **1.1.7 Modern Era: Ethanol as a Renewable Fuel Source**

The latter part of the 20th century witnessed significant strides in ethanol production methods, particularly with the introduction of bioethanol from crops like corn and sugarcane. Governments worldwide started promoting biofuels, including ethanol, as a means to reduce dependence on fossil fuels and address environmental concerns, further advancing its role in the energy sector.

The historical journey of ethanol as a bio-fuel showcases its gradual evolution from ancient applications to its current standing as a prominent renewable energy source, reflecting human endeavors to harness nature's resources for sustainable energy solutions.

## **1.2. Environmental Advantages**

### **1.2.1 Reduced Greenhouse Gas Emissions**

Comparing bioethanol to conventional energy sources like gasoline, there is a significant decrease in emissions of greenhouse gases. Its production from biomass leads to a closed carbon cycle, minimizing net carbon dioxide emissions. It emits fewer greenhouse gases compared to fossil fuels when burned. The entire life cycle of bio-ethanol, from growth to combustion, results in a net reduction in CO<sub>2</sub> emissions.

### **1.2.2 Bioethanol's Carbon Footprint**

Bioethanol's lifecycle results in lower net CO<sub>2</sub> emissions comparable to conventional fossil fuels. The carbon released during ethanol combustion is balanced by the CO<sub>2</sub> absorbed during biomass growth.

## **1.2.3 Contribution to Climate Change Mitigation**

### **1.2.3.1 Mitigating Climate Impact**

Bioethanol's use helps mitigate climate change by reducing CO<sub>2</sub> emissions. Its renewable nature supports a closed carbon cycle, maintaining equilibrium and reducing the overall impact on the environment.[11]

### **1.2.3.2 Dependency on Fossil Fuels**

#### **Energy Independence**

Bioethanol minimizes reliance on limited fossil fuel reserves, contributing to greater energy security and independence. Its production from renewable biomass sources offers an alternative to conventional, non-renewable energy sources.[12]

#### **Renewable Resource Utilization**

Derived from organic matter such as sugarcane, corn, or cellulose, bioethanol serves as a renewable energy source. This reliance on biomass helps reduce dependency on finite fossil fuel resources. Bioethanol is derived from organic materials like crops or agricultural residues, making it a renewable and sustainable energy source compared to finite fossil fuels.

#### **Diversification of Energy Sources**

Bioethanol offers an alternative to conventional fuels, decreasing reliance on imported oil and enhancing energy independence within nations.

## **1.2.4 Rural Development Opportunities**

The cultivation of feedstocks for bioethanol production can generate economic opportunities in rural areas, fostering growth in farming, processing, and related sectors.

## **1.2.5 Utilization of Agricultural Surplus and Waste**

Bioethanol production often involves utilizing surplus agricultural products or waste biomass, potentially reducing waste and optimizing resource utilization.

### 1.3. Technological Innovation and Sustainability

#### 1.3.1 Research and Development Incentives

The pursuit of bioethanol encourages advancements in biotechnology, agricultural practices, and engineering, fostering innovation in renewable energy technologies. Continual advancements in conversion technologies, such as enzymatic hydrolysis and fermentation techniques, enhance bioethanol production efficiency. These innovations aim to improve yields, reduce processing costs, and optimize the utilization of diverse feedstocks.

#### 1.3.2 Promotion of Sustainable Practices

Bioethanol production can adhere to sustainable agricultural practices, minimizing environmental impact and promoting eco-friendly farming techniques. [7]

#### 1.3.3 Biorefinery Concepts

Integration of biorefinery concepts allows for the extraction of multiple products from biomass, diversifying revenue streams and enhancing the overall efficiency and sustainability of bioethanol production.

### 1.4. Production

#### 1.4.1 Sources

**Sugar Crops:** (Sugar Cane, Sugar Beet): Extracting fermentable sugars from crops rich in sucrose, such as sugar cane and sugar beet, is a common method for bioethanol production.

**Starch Crops:** (Corn, Wheat, Cassava): These crops are processed to break down starch into fermentable sugars, primarily using enzymes, and then fermented to produce ethanol.

**Cellulosic Biomass:** (Agricultural Residues, Forestry Residues, Energy Crops): Utilizing cellulose and hemicellulose from non-food crops or agricultural and forestry residues involves more complex processes, including pretreatment, enzymatic hydrolysis, and fermentation.