CHEMEDGE

PRESENTED BY THE DEPARTMENT OF CHEMICAL ENGINEERING

Heritage Institute of Technology

DECEMBER 2024

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VOL.

FEATURING

CHEMCON 2023
CHEMSPARK 2024
ICRESS 2024
TECHNICAL ESSAYS
CREATIVE WRITING
SHUTTER STOCK
ARTISTIC CANVAS
CLASS PHOTOGRAPH

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Principal Sir Speaks

I am delighted to know that students of the Department of Chemical Engineering of HITK are set to publish Chemedge, a departmental publication. Chemedge will contain contributions of teachers and students of the department on subjects of Chemical Engineering. Any branch of engineering today goes through rapid changes. Problems are more interdisciplinary in nature and subjects need continuous upgradation. Students have to understand and continuously strive to learn newer subjects and approaches. Chemedge goes beyond curricula and informs all the stakeholders the trajectories of change. I congratulate all concerned for making such a brilliant effort to bring out this publication. My good wishes to all.

PROF.(DR.) BASAB CHAUDHURI
PRINCIPAL
HERITAGE INSTITUTE OF TECHNNOLOGY

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HOD Ma'am Speaks

I feel proud to share the winter edition of Chemedge 2024. One full year has rolled by and the editorial team has changed hands to make way for the new. I see new faces, bright as they were last year, eager to take on responsibility, very optimistic. Chemedge is as much of a technical journey as a creative one. And definitely a documentary of HIT Chemical Engineering Department's enlarging pool of alumni. Each version gets better in content and creative effort. I thank all everyone who contributed to this effort. I sincerely appreciate the team effort as I see that every version of Chemedge outbeats its previous one.

PROF.(DR.) SULAGNA CHATTERJEE
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From Mentor's Desk

We are pleased to announce the publication of December 2024 issue of CHEMEDGE.
As teachers, we have had the privilege of witnessing the remarkable growth and transformation of many young minds within our department. Our journey in the realm of chemical engineering is not just about equations, reactions, and lab experiments; it is about unlocking the mysteries of the natural world, shaping our environment, and harnessing science to improve the lives of countless individuals.The pages of CHEMEDGE have always been a canvas where our students showcase their passion, creativity, and dedication to the field.

Chemical engineering is a field of innovation, constantly evolving to address global challenges. It is here, in these pages, that we get a glimpse of the future. The future engineers, researchers, and leaders who will tackle pressing issues such as sustainable energy, clean water, pharmaceutical advancements, and more.
The dedication of the editorial team and contributors of CHEMEDGE to bring the latest developments and insights in chemical engineering to our readers is commendable. Likewise in earlier year, we have presented a brief overview of CHEMCON 2023, an International Conference organized by Indian Institute of Chemical Engineers (IIChE) wherein the departmental faculty and staff and student members actively involved to make the event a grand success. Snapshots of other departmental students' event CHEMSPARK 2023 and CHEMSPARK 2024 have also been added in the magazine alongwith industrial tour organized for departmental students. A brief note on ICRESS '24, (International Conference on Renewable Energy with Sustainable Solutions, 2024), organized by the department has also been included in the Magazine.

We extend our heartfelt gratitude to all who contribute to making CHEMEDGE journey a success.We eagerly look forward to reading the articles and discoveries that will grace the pages of this magazine in the future.
Wishing you all continued success in your academic endeavors and a future filled with innovation and impact.
Warm regards,

Diptendu Datta

Dr. Diptendu Datta
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Heritage Institute of Technology

Message From The Editorial Board

We, the students of the Department of Chemical Engineering at Heritage Institute of Technology, Kolkata, take great pride in presenting the winter edition of ChemEdge 2024, our biannual departmental magazine. The Editorial Board, composed of dedicated student editors and our PR team, extends its heartfelt gratitude to our mentors, Professor Diptendu Dutta and Professor Sangita Bhattacharjee. Their guidance and unwavering support have been instrumental in the successful publication of this edition.

This issue features a captivating array of technical articles contributed by students within our department. Much like its predecessor, this edition boasts a creative section replete with imaginative literature, photography, and artwork.

We sincerely hope that our readers will derive as much enjoyment from exploring this magazine as we have experienced in its creation.

Thanking You,
Student Editorial and PR Team

TABLE OF CONTENTS

1 TECHNICAL ESSAY › 5

2 DEPARTMENTAL EVENTS › 65

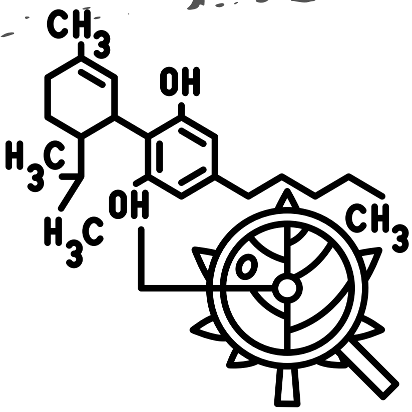
3 ARTISTIC CANVAS › 76

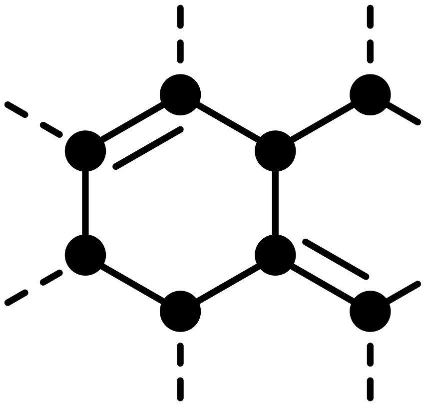
4 SHUTTER STOCK › 82

5 CREATIVE WRITTING › 87

6 CLASS PHOTOGRAPHS › 94

7 TEAM CHEMEDGE › 97





TECHNICAL ESSAYS

Battery Technology & Energy storage

Battery Technology and Energy Storage: Key Drivers for a Sustainable Energy Future

Battery technology and energy storage systems are at the forefront of the transition to a sustainable, low-carbon energy future. As the world moves toward more renewable energy sources like wind and solar, efficient and reliable energy storage solutions are essential to overcome the intermittent nature of these power sources. Battery storage is not only crucial for renewable energy integration but also plays a significant role in various other sectors, including electric vehicles (EVs), portable electronics, and grid stabilization. This essay explores the advancements in battery technology, the importance of energy storage, and the challenges and opportunities facing the industry.

The Importance of Energy Storage

Energy storage refers to the capture of energy produced at one time for use at a later time. It is an essential part of modern energy systems, enabling the efficient distribution of energy according to demand and supply fluctuations. In particular, energy storage addresses several key challenges:

Intermittency of Renewable Energy: Renewable energy sources like solar and wind are inherently intermittent. Solar power generation is only possible during daylight hours, and wind power generation is dependent on wind conditions. Energy storage technologies, such as batteries, can store excess energy produced during peak production periods and release it when demand is higher or when generation is low.

Grid Stability and Load Balancing: Energy storage systems can help stabilize electrical grids by providing backup power during peak demand, reducing the need for costly peaking power plants, and supporting grid frequency regulation. This is especially important for grids with a high penetration of renewable energy, as they are less predictable than traditional fossil-fuel-based power plants.

Electrification of Transport: With the growing demand for electric vehicles (EVs), advanced battery technology has become a key enabler of the shift toward cleaner transportation. Batteries store the energy required to power EVs, and improvements in energy density and charging times are making EVs more viable for everyday use.
Decentralized Power Generation: As more consumers opt for decentralized energy sources, such as rooftop solar panels, the ability to store surplus energy for later use is becoming increasingly important. Battery storage solutions at the residential and commercial levels can improve energy autonomy and reduce dependence on the grid.

Types of Battery Technologies

The battery industry has seen rapid advances in various technologies, each with its own set of advantages and challenges. The main types of batteries used for energy storage are:

Lithium-Ion Batteries (Li-ion): Lithium-ion batteries are the most widely used battery technology today, powering everything from smartphones to electric vehicles. Li-ion batteries are favored for their high energy density, long cycle life, and relatively fast charging times. They are lightweight, have a high round-trip efficiency (the ratio of energy retrieved from a battery to the energy put into it), and have become increasingly cost-effective due to economies of scale and improvements in manufacturing processes.

Li-ion batteries are a dominant choice for both grid storage and electric vehicles, but they have some limitations, such as relatively high production costs, safety concerns related to overheating (thermal runaway), and limited raw material availability. The mining of lithium, cobalt, and other essential materials has raised environmental and ethical concerns, prompting the industry to explore alternatives.

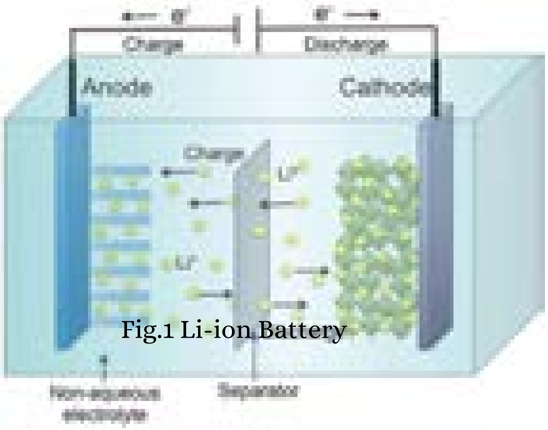


Fig.1 Li-ion Battery

Sodium-Ion Batteries (Na-ion): Sodium-ion batteries are an emerging alternative to lithium-ion technology. Sodium is abundant, cost-effective, and environmentally friendly compared to lithium, making it an attractive option for large-scale energy storage applications. Although sodium-ion batteries currently have a lower energy density than lithium-ion batteries, advances in material science are improving their performance, and they are seen as a promising solution for stationary energy storage systems.

Sodium-ion batteries are being tested in grid-scale storage applications, where their lower energy density is less of a concern compared to consumer electronics or EVs. The development of sodium-ion technology may help alleviate some of the supply chain issues associated with lithium-ion batteries.

Fig.2 Na-ion battery and it's applicable

Solid-State Batteries: Solid-state batteries use a solid electrolyte instead of the liquid or gel electrolytes found in traditional lithium-ion batteries. These batteries promise to deliver higher energy densities, improved safety (as there is less risk of leakage or fire), and a longer cycle life. Solid-state batteries are often seen as a "holy grail" for energy storage due to their potential to surpass the performance of current liquid-based batteries.

However, the technology faces challenges in terms of manufacturing scale, cost, and the development of solid electrolytes that are both conductive and stable. Research and development in this area are ongoing, and commercial solid-state batteries are expected to become a reality in the coming decades.

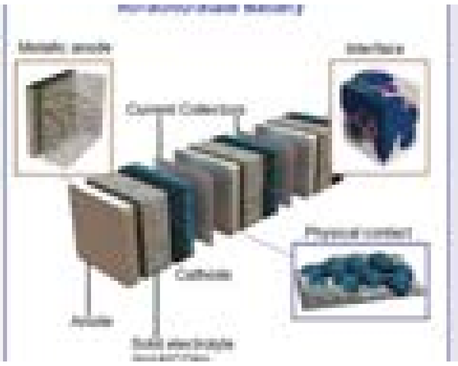


fig.3 Solid-state battery

Flow Batteries: Flow batteries are a type of rechargeable battery where energy is stored in two liquid electrolytes, which are pumped through a cell stack to generate electricity. Flow batteries, such as vanadium redox and zinc-bromine, offer advantages in terms of scalability, long-duration storage, and easy recycling.

One of the key strengths of flow batteries is their ability to scale up for grid storage applications. The energy capacity of a flow battery is independent of the size of the electrochemical cell, meaning that larger energy storage systems can be built by simply increasing the amount of electrolyte. However, flow batteries currently suffer from lower energy density and higher initial costs compared to lithium-ion batteries, making them less attractive for mobile applications like electric vehicles.

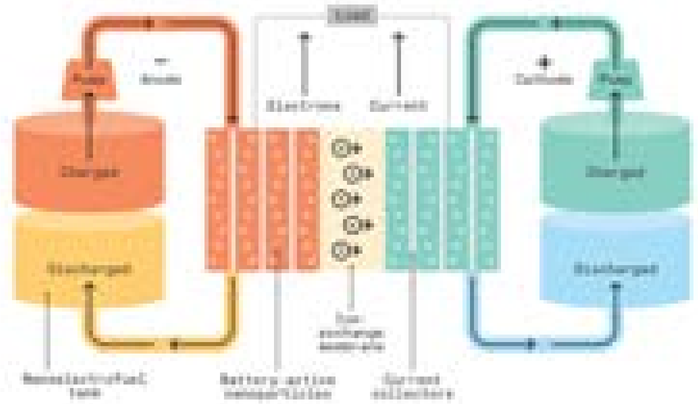


Fig.4 Flow Battery

Lead-Acid Batteries: Lead-acid batteries are one of the oldest and most well-known battery types. They are commonly used for backup power in uninterruptible power supply (UPS) systems and for starting engines in vehicles. While lead-acid batteries are inexpensive and widely available, they have a low energy density and a shorter lifespan compared to newer technologies like lithium-ion. Additionally, lead-acid batteries are less efficient in terms of charging and discharging rates.

Despite their limitations, lead-acid batteries continue to be used in specific applications where cost is a primary concern, such as in off-grid solar systems and small-scale backup storage.

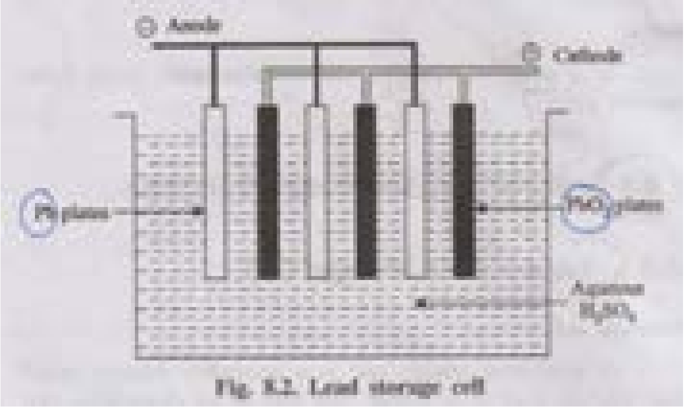


fig.5 Lead acid battery

Challenges in Battery Technology and Energy Storage

Despite significant advancements, several challenges remain in the development of battery technology and energy storage systems:

Cost and Affordability: While the cost of batteries has decreased over the past decade, high production costs are still a major barrier to widespread adoption, particularly for large-scale grid storage. The cost of raw materials, including lithium, cobalt, and nickel, significantly impacts the final price of batteries. Efforts to find cheaper, more abundant materials, such as sodium or solid-state electrolytes, are ongoing, but cost reduction remains a major focus.

Energy Density and Efficiency: Energy density (the amount of energy stored per unit weight or volume) is a critical parameter for applications like electric vehicles and portable electronics. Current battery technologies, especially lithium-ion, still face challenges in achieving the high energy densities required for long-range EVs or large-scale grid storage with minimal physical space requirements. Improving energy efficiency, both in terms of storage and charge/discharge cycles, remains a priority for researchers.

Safety and Durability: Battery safety is a key concern, particularly for lithium-ion batteries, which can catch fire or explode if damaged or overcharged. Innovations in battery management systems (BMS), better thermal regulation, and the development of safer electrolytes are helping to mitigate these risks. Durability, in terms of the number of charge/discharge cycles a battery can undergo before its capacity significantly degrades, is another area of focus for improving the lifespan of batteries.

Recycling and Sustainability: The environmental impact of battery production, use, and disposal is another significant concern. The mining of raw materials for batteries can have detrimental effects on ecosystems and local communities, while the disposal of batteries at the end of their life can lead to hazardous waste. Efficient recycling processes for lithium, cobalt, and other critical materials are crucial to minimizing the environmental footprint of batteries and ensuring the sustainability of the energy storage industry.

The Future of Battery Technology and Energy Storage

The future of battery technology holds immense promise, driven by the need for sustainable energy solutions and innovations across multiple sectors. Researchers are focusing on several key areas to push the boundaries of energy storage, including:
Improved Materials: Research into new materials, such as graphene, sulfur, and solid-state electrolytes, promises to significantly increase energy density and improve battery performance.

Integration with Renewable Energy: Energy storage systems will become increasingly integral to grid operations, helping to stabilize power supply and maximize the efficiency of renewable energy sources.
Smart Batteries and AI Integration: Advances in artificial intelligence and machine learning can optimize battery management systems, enabling more efficient energy storage, predictive maintenance, and real-time monitoring.
Sustainability and Recycling: Efforts to improve the recyclability of batteries and reduce reliance on scarce resources like cobalt will make energy storage systems more sustainable in the long term.

Global economics of Battery Technology and energy storage

The global economics of battery technology and energy storage is shaped by several key factors including the demand for electric vehicles (EVs), renewable energy integration, advancements in battery technology, and policy incentives. These factors interact to influence market trends, investment flows, and geopolitical dynamics. Here's an overview of the current landscape:

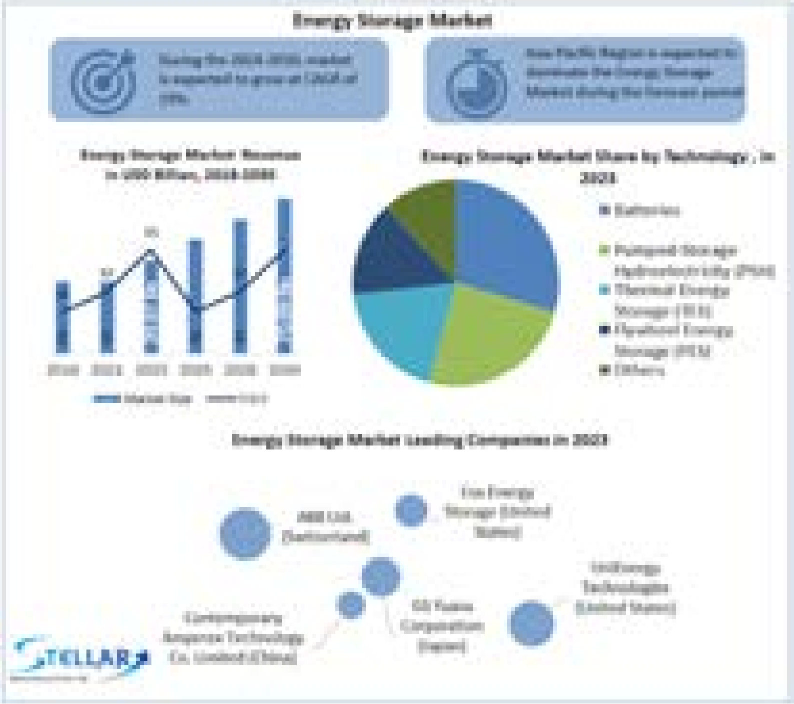


Fig.5 Battery Technology global Market report

1. Battery Market Growth

Electric Vehicles (EVs): The global shift toward electric mobility is a major driver of battery demand. Batteries are essential for EVs, and their adoption is expected to increase significantly. In 2023, EV sales grew to about 14 million, and this is projected to rise to 30 million by 2030. This growth is propelling the demand for lithium-ion (Li-ion) batteries, the dominant technology used in EVs.

Renewable Energy Storage: Batteries are also critical for storing energy from renewable sources like solar and wind, which are intermittent. This is increasingly important as countries strive for net-zero emissions goals and need to balance variable renewable generation with consumption. The need for large-scale storage systems for grid stability is growing, leading to significant investments in technologies like grid-scale batteries.

2. Cost Trends and Technological Advancements

Cost Reduction: Battery costs have fallen dramatically over the last decade. The price of lithium-ion batteries dropped by more than 80% from 2010 to 2020, mainly due to economies of scale, improved manufacturing techniques, and better chemistry. As of 2024, the average cost of lithium-ion batteries is expected to be under $100 per kWh, which is a key threshold for mass adoption of EVs and energy storage solutions.

Solid-State and Alternative Chemistries: There are ongoing efforts to develop more efficient and cheaper battery technologies. Solid-state batteries, for example, promise higher energy density and safety compared to traditional lithium-ion batteries, although they are not yet commercially viable at scale. Other chemistries, such as sodium-ion and zinc-based batteries, are also being explored as potential alternatives to lithium-ion, which could help reduce reliance on materials like lithium and cobalt.

3. Market and Investment Trends

Private Sector Investment: Major tech companies, automakers, and energy firms are investing heavily in battery technologies and energy storage projects. For example, Tesla, Panasonic, and CATL are investing billions in gigafactories. Additionally, the increased adoption of batteries for grid-scale storage is attracting investments from utility companies, particularly in countries with high renewable energy penetration.

Energy Storage Projects: Companies are increasingly focusing on the development of large-scale energy storage systems to stabilize grids and manage energy flow. Notable projects include Tesla’s Hornsdale Power Reserve in Australia and several battery storage initiatives in California, Texas, and the EU. These projects help mitigate the challenges posed by intermittent renewable energy sources like solar and wind.

4. Future Outlook

Battery Demand Surge: By 2030, global battery demand is expected to continue rising, with annual demand potentially reaching 3,000 GWh, driven by both electric vehicles and stationary energy storage systems.

Innovation in Battery Technologies: The next decade will likely see continued improvements in energy density, charging times, safety, and overall sustainability. Breakthroughs in solid-state batteries and alternative chemistries could lead to a more diverse market.

Environmental and Recycling Impact: As battery use becomes more widespread, recycling technologies will become increasingly important in ensuring that the growth of battery technology is sustainable both environmentally and economically

Conclusion

Battery technology and energy storage are critical to the successful integration of renewable energy, the growth of electric vehicles, and the optimization of global energy systems. While significant progress has been made in terms of energy density, cost reduction, and performance, challenges remain in terms of safety, sustainability, and scaling up to meet global demand. Continued research, innovation, and investment in energy storage technologies are essential to achieving a cleaner, more sustainable energy future. With ongoing advancements, the role of batteries in transforming how we generate, store, and consume energy is set to become even more important in the years to come.

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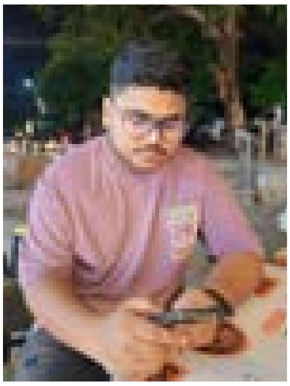

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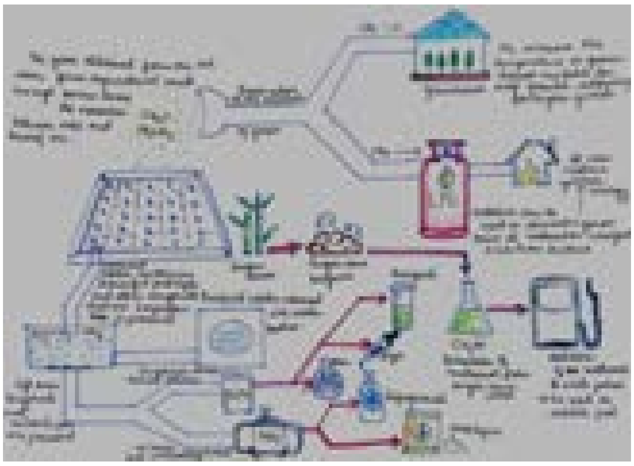
Agro Innovation

For a better India

Agriculture, with one of its allied sectors, is the largest source of livelihoods in India. 70 percent of its rural households still depend primarily on agriculture for their livelihood. India is the second largest producer of rice, wheat, sugarcane, cotton and groundnuts. India's climate varies from humid and dry tropical in the south to temperate alpine in the northern reaches and has a great diversity of ecosystems. Agriculture contributes a significant figure to the Gross Domestic Product (GDP). Sustainable agriculture in terms of food security, rural employment and environmentally sustainable technologies such as soil conservation, sustainable natural resource management and biodiversity

Natural Resorce Management

Now, sustainable natural resource management is one of the major concerns not only in India but across the world. It involves adopting practices that reduce negative impacts on the environment, promote social well being and maintain economic viability and prospeirity.



Schematic diagram of sustainable resource production from an agricultural field

In order to practice such resource management procedures we do not have to look in a broader prospective but just around us only. The things we come across daily for example a waste today can somehow become a sustainable resource tomorrow.

Agricultural lands are kept fallow to restore the soil's essential nutrients that got depleted also regain the soils fertility. The land is left uncultivated for one or more seasons during the transition from rabi to kharif season. This practice is known as field fallowing. Some stubbles i.e. crop remains after harvesting undergoes decomposition in order to release methane ,carbon dioxide and nitrogen in the air. Thus the air surrounding the agricultural fields becomes rich with the above mentioned gases. The carbon dioxide in the air mixture can be separated by direct air capture process i.e. scrubbing carbon dioxide from ambient air and then storing it either underground or in long lived products. It can also be separated by gas permeable membranes like silicone products. Now the methane in the mixture of gases can be separated by using metal-organic framework(MOF) which consists of nanoscale pores that function as molecular sieves. Methane and carbon dioxide can also be produced using hybrid electrochemical devices.

The carbon dioxide that is extracted can be directly used in greenhouses in order to grow plants in a regulated environment. Carbon dioxide increases photosynthesis, reduces transpiration hence increases crop yield. The methane gas captured can be used as domestic gases infused in LPGs at 120PSI. Methane has lower molecular weight than butane thus it reduces ignition energy so methane produces [illegible]

In case of sugarcane fields, after felling of the harvested sugarcanes some sugarcane bagasse as wastes remain in the fields. These wastes through pyrolysis conducted in a tube furnace at 450-500°C is converted into methanol. This methanol blended with gasoline in internal combustion engines can be used as automobile fuels. Methanol burns cleaner and cooler, is less inflammable and less expensive than gasoline.

Polluted water are released from agricultural fields that contains harmful constituents of fertilizers, pesticides and nutrients like nitrogen and phosphorus due to leaching. This polluted water is processed by activated carbon filtration ,reverse osmosis, as well as distillation and bioremediation in order to release purified water back to the water bodies. The sulphates and nitrates that are left behind after processing are then separated by ionic membrane separation technique using Ion exchange membranes(IEM).

Through contact process SO_2 is oxidized to sulfur trioxide (SO_3) at high temperature (about 450°C) in the presence of a vanadium catalyst. SO_3 then is dissolved in concentrated sulfuric acid forming fuming sulfuric acid (oleum). This can then be reacted safely with water to produce concentrated sulfuric acid. This oleum can be used in the production of dyes, manufacturing of nylon, used a sulfonating agent, dehydrating agent in laboratories

An eight-electron direct reduction of NO_3^- to NH_3, electrochemically catalyzed by a copper-incorporated 3,4,9,10−perylenetetracarboxylic dianhydride (Cu−PTCDA) or by the nitrate electroreduction to ammonia reaction (NO3RR). This ammonia can be converted in fertilizers like urea, ammonium nitrate etc. Ammonia can be converted into a refrigerant by vapor-compression refrigeration where heated ammonia is condensed into liquid.

India is a agriculture based country since time immemorial. India has made quite significant developments in agricultural areas and is still developing new measures. In this context if the above mentioned methods can be followed then resources can be conserved as well as many sustainable resource producing methods can be practiced which will further enhance India’s agriculture leading to its economy and biodiversity.

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Green energy

Green Energy: The Path Toward a Sustainable Future

Green energy, often referred to as renewable or clean energy, encompasses energy sources that are environmentally friendly, sustainable, and typically abundant. These energy sources include solar, wind, geothermal, hydroelectric, and biomass. Unlike fossil fuels such as coal, oil, and natural gas, green energy reduces carbon emissions, mitigates climate change, and ensures long-term energy security. The increasing shift toward green energy is driven by the urgent need to reduce greenhouse gas emissions, combat climate change, and transition away from finite fossil fuel reserves.

The Need for Green Energy

Fossil fuel consumption has long been the dominant source of energy worldwide, but this comes at a high environmental cost. The burning of fossil fuels releases harmful pollutants such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) into the atmosphere, contributing to global warming and severe climate change effects like rising sea levels, extreme weather patterns, and loss of biodiversity. The unsustainable extraction and use of these finite resources further exacerbates ecological degradation and geopolitical tensions, as nations vie for control over dwindling reserves.

In response to these challenges, green energy has emerged as a solution that not only addresses environmental concerns but also promotes energy independence, economic growth, and technological innovation.

Types of Green Energy Sources

Solar Energy: Solar power is one of the most abundant and widely accessible forms of green energy. It harnesses the power of the sun’s rays through photovoltaic (PV) cells, which convert sunlight directly into electricity. The solar industry has seen remarkable advances in efficiency and cost reduction, making solar panels increasingly affordable for both residential and commercial applications. Large-scale solar farms and solar rooftop installations are now integral to many countries' energy strategies.

Wind Energy: Wind energy is another critical renewable resource. Wind turbines capture the kinetic energy of wind and convert it into electrical power. Onshore and offshore wind farms are being developed at an unprecedented rate, with some of the largest projects located in regions with consistent wind patterns. Wind power has become one of the most competitive forms of energy generation, thanks to advances in turbine technology, which allow for larger, more efficient machines.

Hydroelectric Energy: Hydropower is the oldest and most widely used form of renewable energy. It involves the use of flowing water to generate electricity, typically through dams built on large rivers. The kinetic energy of moving water is used to turn turbines that produce electricity. While hydropower is highly efficient and capable of providing base-load power, concerns over environmental impact, such as ecosystem disruption and fish migration, have led to calls for more sustainable hydropower designs, including small-scale and run-of-the-river systems.

Geothermal Energy: Geothermal energy taps into the Earth's internal heat. By using steam or hot water from the Earth's crust, geothermal power plants can generate electricity or provide direct heating. Regions with significant tectonic activity, such as Iceland and parts of the United States, benefit from abundant geothermal resources. While the initial setup costs are high, geothermal energy offers long-term, reliable power with minimal environmental impact.

Biomass Energy: Biomass energy involves using organic materials, such as wood, agricultural waste, and even algae, to generate heat, electricity, or biofuels. It can serve as a renewable alternative to coal and natural gas. The main challenge with biomass is ensuring that it is sourced sustainably and does not lead to deforestation or food insecurity. However, when managed properly, biomass energy can be a key contributor to a circular economy.

fig.1 Types of Green Energy

The Advantages of Green Energy

Environmental Benefits: The most compelling reason to shift to green energy is its minimal environmental impact. Green energy technologies produce little to no greenhouse gases during operation, significantly reducing the carbon footprint associated with power generation. Furthermore, renewable energy sources typically require less water for cooling compared to conventional power plants, conserving valuable water resources.

Economic Growth and Job Creation: The green energy sector is rapidly becoming a major contributor to global economies. The renewable energy industry is a hub for innovation and has created millions of jobs in manufacturing, installation, and maintenance. In 2020, the renewable energy sector employed over 11 million people worldwide. Investments in green energy infrastructure can stimulate economic growth, especially in developing countries, by providing reliable and affordable energy access.
Energy Independence and Security: Renewable energy sources are often locally available, which allows nations to reduce their dependence on imported fossil fuels. By diversifying the energy mix with local renewable sources, countries can mitigate energy price volatility and improve energy security. This shift is particularly important for nations with limited fossil fuel reserves or those seeking to reduce the geopolitical risks associated with oil and gas imports.

Technological Innovation: The green energy transition has driven technological advancements in energy storage, grid management, and smart energy systems. Solar and wind energy have benefited from breakthroughs in materials science, such as more efficient photovoltaic cells and lightweight, durable wind turbine blades. Energy storage systems, including batteries and pumped hydro storage, are being improved to address the intermittent nature of renewable power and ensure a stable supply.

Challenges to Green Energy Adoption

Despite the benefits, there are several barriers to the widespread adoption of green energy.Intermittency and Storage: One of the primary challenges of solar and wind energy is their intermittent nature. The sun doesn’t shine all day, and the wind doesn’t blow constantly, which makes it difficult to rely solely on these sources for continuous power generation. To overcome this, significant advances are being made in energy storage technologies, such as lithium-ion batteries and next-generation solutions like solid-state batteries and pumped hydro storage.

Grid Integration: Integrating renewable energy into existing power grids poses technical challenges. The energy grid was originally designed to work with large, centralized power plants that provide steady, predictable energy. To accommodate decentralized renewable sources, grids must be modernized to handle variable energy inputs, incorporate energy storage, and ensure reliable delivery. This requires substantial investment in infrastructure, which is often a barrier for developing countries.

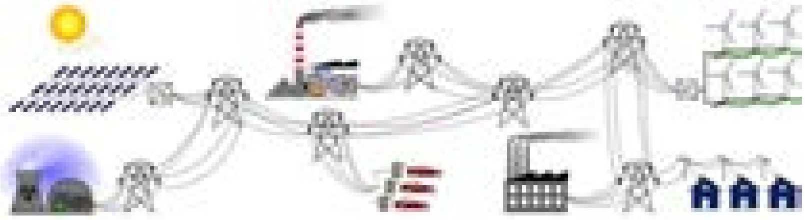

Fig.2 Grid Integration

High Initial Costs: While the long-term savings from green energy are substantial, the upfront costs for renewable energy infrastructure can be high. This includes the costs of manufacturing, installing, and maintaining renewable energy systems such as solar panels and wind turbines. In many cases, the financial incentives, such as tax breaks or government subsidies, are necessary to make green energy more affordable for individuals and businesses.

Political and Policy Barriers: The transition to green energy requires strong political will and supportive policies. In many countries, fossil fuel industries are heavily subsidized, and political resistance to change can slow the adoption of renewable energy technologies. Effective government policies, such as carbon pricing, renewable energy incentives, and grid modernization efforts, are essential to accelerate the green energy transition.

The Future of Green Energy

As technology advances, the future of green energy looks promising. Continued improvements in efficiency, storage solutions, and grid management systems will make renewable energy more reliable and cost-effective. Moreover, increased investment in research and development, along with policy support, can further reduce the costs of renewable technologies, making them more accessible to people and businesses worldwide.

International agreements such as the Paris Agreement have emphasized the importance of reducing global carbon emissions, and green energy will play a critical role in meeting these targets. Countries are setting ambitious renewable energy goals, and many have committed to achieving net-zero emissions by mid-century. This transition to green energy will require a global effort but offers a path toward a sustainable and prosperous future.

Conclusion

Green energy offers a solution to the pressing environmental, economic, and energy challenges faced by the world today. By embracing solar, wind, hydro, geothermal, and biomass energy, society can reduce its reliance on fossil fuels, mitigate climate change, and ensure a cleaner, more sustainable energy future. However, overcoming technical, economic, and political obstacles will be crucial for the widespread adoption of renewable energy. The path forward requires coordinated action, innovation, and strong policy frameworks, but the potential rewards of a green energy revolution are immense and necessary for the survival of future generations.

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Nanotechnology

Nanotechnology: Transforming Science and Industry at the Nanoscale

The Fundamentals of Nanotechnology

Nanotechnology is grounded in the understanding and control of materials at the molecular and atomic level. At the nanoscale, materials often exhibit different behaviors compared to their bulk counterparts due to quantum mechanical effects, increased surface area, and other phenomena that dominate at this scale. Nanotechnology is used to design, fabricate, and manipulate structures, devices, and systems that perform specific tasks with unprecedented efficiency.

The field of nanotechnology is inherently interdisciplinary, involving principles and techniques from physics, chemistry, biology, materials science, and engineering. It combines both theoretical and experimental approaches to explore and manipulate matter at the atomic and molecular level, allowing for the creation of nanostructures with highly specialized properties.

Unique Properties of Nanomaterials

At the nanoscale, materials exhibit distinct properties due to their size, surface area, and quantum effects. These properties are often in stark contrast to the behavior of bulk materials and make nanomaterials highly useful in a variety of applications:

Increased Surface Area: As materials are scaled down to the nanoscale, their surface area relative to volume increases significantly. This enhanced surface area makes nanoparticles highly reactive and efficient in catalysis, sensors, and energy storage.

Quantum Effects: At the nanoscale, quantum mechanics dictates the behavior of particles. This includes phenomena such as quantum confinement, where the electronic properties of materials depend on their size. For example, quantum dots—nanoscale semiconductor particles—can be engineered to exhibit size-dependent optical and electronic properties, such as fluorescence, that are not seen in bulk materials.

Mechanical Strength: Many nanomaterials, such as carbon nanotubes and graphene, exhibit exceptional strength-to-weight ratios and durability. Their unique structure allows them to be incredibly strong, yet lightweight, which is useful in aerospace, automotive, and construction applications.

Electrical and Thermal Conductivity: Some nanomaterials, particularly carbon-based materials like graphene and carbon nanotubes, exhibit superior electrical and thermal conductivity. These materials have the potential to replace conventional materials in electronics, energy storage, and thermal management systems.

Optical Properties: Nanomaterials can have novel optical characteristics, such as surface plasmon resonance, which enhances light absorption or scattering. These properties make nanomaterials suitable for use in applications like solar cells, sensors, and biomedical imaging.

Fig.1 Properties of Nano materials

Production Methods of Nanomaterials

Nanomaterials can be synthesized using a variety of techniques that are broadly categorized into two types: top-down and bottom-up approaches.

a. Top-Down Approaches:

Top-down methods involve breaking down bulk materials into smaller, nanoscale components. These processes often rely on physical or mechanical methods to shape the material, and they include:

Mechanical Milling: This process involves grinding larger particles into nanoscale materials using high-energy mills. It is often used for producing metal and ceramic nanoparticles.

Lithography: Commonly used in semiconductor manufacturing, lithography involves etching fine patterns onto a material’s surface. Nano-lithography, for instance, is used to fabricate nanoscale circuits in microelectronics.

Etching: In this process, material is selectively removed from a surface using lasers, plasma, or chemicals, creating nanostructures with specific features.

b. Bottom-Up Approaches:

Bottom-up techniques involve building nanomaterials from the atomic or molecular level. These methods allow for greater precision in structuring the material and include:

Chemical Vapor Deposition (CVD): In CVD, gaseous precursors react on a substrate to deposit thin films or nanostructures. This technique is commonly used to synthesize carbon nanotubes and graphene.

Sol-Gel Process: This involves creating nanoparticles through the chemical transformation of sol (a colloidal solution) into gel, which is then processed into the desired material.

Self-Assembly: This approach relies on the ability of molecules to spontaneously arrange themselves into organized structures. Self-assembly techniques are used to create complex nanostructures such as thin films, nanowires, and nanocapsules.

Chemical Reduction: In this method, metal salts are reduced chemically to form metal nanoparticles. It is widely used for producing noble metal nanoparticles, such as gold and silver, which are useful in catalytic and biomedical applications.

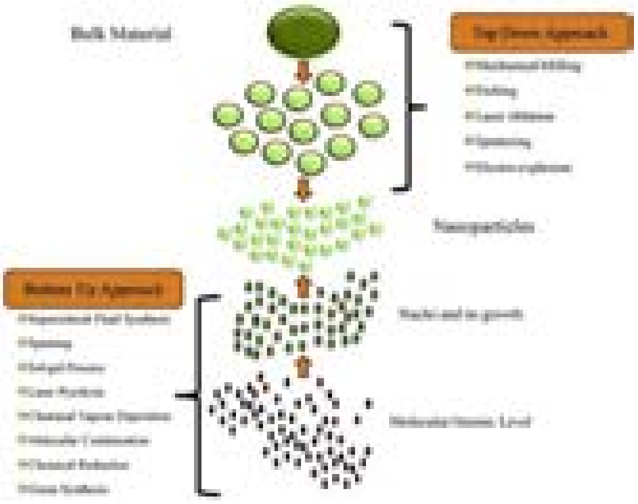

fig.2 Production methods of Nano materials

Applications of Nanotechnology

Nanotechnology has already found numerous applications across various industries, revolutionizing traditional practices and enabling innovations in science and technology.

a. Medicine and Healthcare: Nanotechnology has tremendous potential in the medical field, particularly in diagnostics, drug delivery, and tissue engineering. Nanoscale particles and devices can be engineered to deliver drugs directly to targeted cells, minimizing side effects and improving therapeutic efficacy. For example, nanoparticles can be designed to deliver chemotherapy drugs directly to cancer cells, improving the effectiveness of the treatment and reducing harm to healthy tissue. In addition, nanotechnology is being used in advanced imaging techniques, where nanoparticles can enhance the resolution and sensitivity of medical imaging devices like MRIs and CT scans.

b. Electronics: Nanotechnology has revolutionized the electronics industry by enabling the miniaturization of components. Nanomaterials like graphene, carbon nanotubes, and quantum dots are being explored for use in next-generation transistors, memory storage, and flexible electronics. These materials have the potential to make electronic devices faster, smaller, and more efficient, driving innovations in smartphones, wearable technologies, and flexible displays.

c. Energy: Nanotechnology is playing a pivotal role in enhancing the efficiency and performance of energy generation and storage devices. Nanomaterials are used in solar cells to increase light absorption and conversion efficiency. Nanostructured materials are also used in batteries and supercapacitors to enhance energy storage capacity and charge/discharge rates. For instance, lithium-ion batteries with nanoscale electrodes can hold more charge, leading to longer-lasting and faster-charging batteries for electric vehicles and portable electronics.

d. Environmental Protection: Nanotechnology has applications in environmental remediation, where nanomaterials are used to remove contaminants from air, water, and soil. Nanoparticles like titanium dioxide are effective in breaking down pollutants in wastewater and air filtration systems. In addition, nanomaterials can be used to develop more efficient and sustainable catalysts for industrial processes, reducing waste and energy consumption.

e. Materials Science: Nanotechnology has enabled the development of advanced materials with improved properties, such as enhanced strength, conductivity, and chemical resistance. Nanocomposites, for example, combine nanoparticles with polymers or metals to create materials that are lighter, stronger, and more durable. These materials are used in various industries, including aerospace, automotive, and construction.

fig.3 Application of Nanotechnology

Challenges and Risks of Nanotechnology

While nanotechnology holds enormous promise, several challenges and risks must be addressed to ensure its safe and ethical deployment.

a. Health and Environmental Concerns:

Nanomaterials, due to their small size, may pose risks to human health and the environment. Their high surface area and reactivity could lead to unintended interactions with biological systems, potentially causing toxicity. The long-term effects of exposure to nanomaterials are still not fully understood, and more research is needed to assess their safety in various applications.

b. Scalability and Cost:

While laboratory-scale synthesis of nanomaterials has been highly successful, scaling up production to meet industrial demand remains a challenge. Many of the techniques used to produce nanomaterials are expensive and energy-intensive, which could limit the widespread commercialization of nanotechnology.

c. Ethical and Regulatory Issues:

Nanotechnology raises several ethical and regulatory concerns, particularly with regard to privacy, security, and environmental impact. The use of nanotechnology in surveillance devices, for example, could lead to privacy violations, while the potential for creating new forms of warfare or surveillance presents significant security challenges. Governments and regulatory bodies are working to establish guidelines for the safe use of nanotechnology, but comprehensive regulations are still in their infancy.

Future Prospects of Nanotechnology

The future of nanotechnology is incredibly promising, with the potential to revolutionize numerous industries and improve the quality of life globally. Advancements in nanomaterial synthesis, better understanding of nanoscale interactions, and improved manufacturing techniques are expected to open up new possibilities in areas such as quantum computing, personalized medicine, and sustainable energy systems. Additionally, as nanotechnology continues to evolve, it will likely contribute to the development of more efficient and cost-effective solutions for global challenges, including climate change, resource scarcity, and public health.

Conclusion

Nanotechnology is a transformative field with the potential to impact virtually every aspect of modern life. From medical treatments and electronics to environmental sustainability and energy production, nanomaterials and nanoscale devices are already shaping the future of science and engineering. However, addressing the challenges associated with safety, scalability, and regulation will be crucial to realizing the full potential of nanotechnology. As research and development in this field continue to progress, the next decade will likely witness a wide range of groundbreaking innovations that will fundamentally alter industries and improve global quality of life.

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Bioplastic & Biodegradable polymers

Abstract

The increasing environmental concerns regarding plastic waste have necessitated the development of sustainable alternatives such as biodegradable plastics. The same durability properties which make plastics ideal for many applications such as in packaging, building materials and commodities, as well as in hygiene products, can lead to waste-disposal problems in the case of traditional petroleum-derived plastics, as these materials are not readily biodegradable and because of their resistance to microbial degradation, they accumulate in the environment. In addition, in recent times oil prices have increased markedly. These facts have helped to stimulate interest in biodegradable polymers and in particular biodegradable biopolymers. Biodegradable plastics and polymers were first introduced in 1980s. Derived from renewable biomass like starch, cellulose, and lignin, these materials degrade naturally, minimizing environmental harm. There are many sources of biodegradable plastics, from synthetic to natural polymers. Natural polymers are available in large quantities from renewable sources, while synthetic polymers are produced from non-renewable petroleum resources. This review explores the potential of bioplastics, including biodegradable, bio-based, and compostable polymers, as eco-friendly solutions.

Keywords: Biodegradable Plastics, Sustainability, Renewable Biomass

Introduction

Human responsibility for environmental protection has increased alongside economic development, particularly in developing countries. Global challenges such as climate change and biodiversity loss are at the forefront of environmental concerns today. Among these, plastic waste has become a significant global issue. Plastics are valued for their versatility, durability, and low cost, playing an essential role in various industries. However, their widespread use has led to an alarming rise in plastic production, with over 3.59 million tonnes produced annually as of 2018, a figure projected to continue growing (Zhu and Wang, 2020). By 2050, an estimated 26 billion tonnes of post-consumer plastic waste will be generated, half of which will end up in the environment, exacerbating waste management problems.

Fig.1 plastic waste

Plastic pollution (Fig. 1) has led to severe environmental degradation, particularly in marine ecosystems, with plastic particles found in the Arctic ice and seabirds ingesting them. To combat this, nations are exploring alternative materials, with biodegradable plastics emerging as a potential solution. These plastics, made from renewable biomass like starch, cellulose, and lignin, offer a more sustainable option. However, the adoption of biodegradable plastics faces significant challenges, primarily related to their higher cost and limited public awareness. Additionally, the question remains whether biodegradable plastics can fully replace traditional plastics and contribute to long-term environmental sustainability. This review explores the potential of biodegradable plastics, addressing their benefits, limitations, and the standards necessary to make them a viable solution to global plastic pollution.

Types of Bioplastics

A) Biodegradable plastic

Biodegradable plastics are plastics that break down through the action of natural microorganisms like bacteria, fungi, and algae. These plastics can be derived from petroleum sources and include materials such as poly (butylene succinate) (PBS), poly(ε-caprolactone) (PCL), polyester amides (PEA), and polyvinyl alcohol (PVA). PBS is widely used in applications like packaging films, bags, and cutlery due to its chemical and thermal resistance, biodegradability, and melt processability. PCL, known for its low melting point and viscosity, is used in products such as biodegradable films, orthopedic casts, and controlled release fertilizers. PEA is a thermoplastic with enhanced biodegradability, often used in agricultural products like plant pots and bio-waste bags. PVA, a water-soluble polymer, has a range of applications, including adhesives, coatings, and films, and is also utilized in textiles and paper production. These biodegradable plastics can replace a significant portion of conventional polymers, with studies showing that bio-based and biodegradable plastics could substitute up to 94% of conventional plastics used today (Shen et al., 2009).

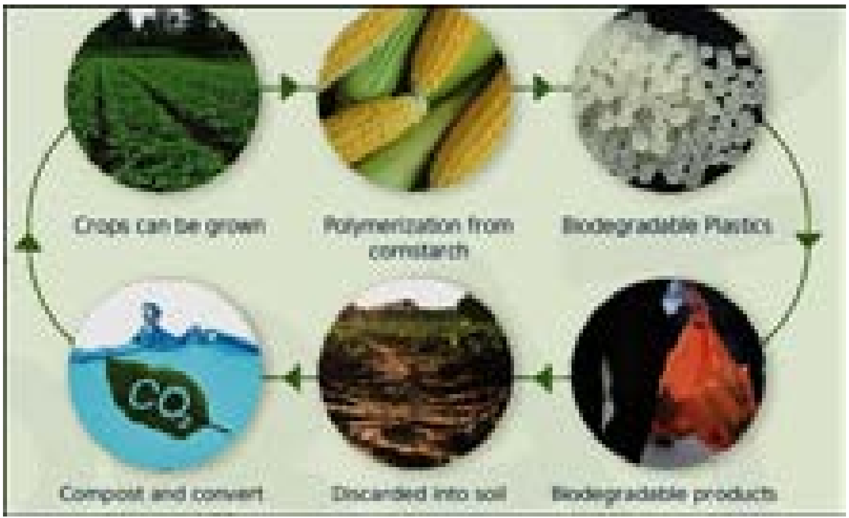
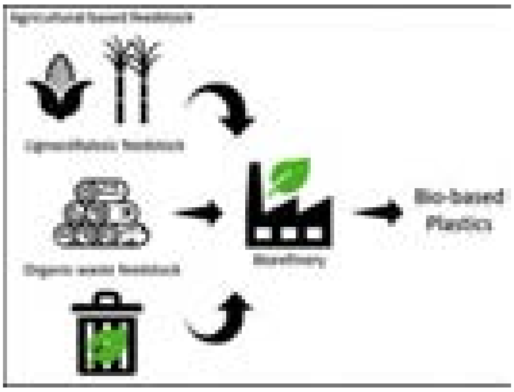


Fig.2 life cycle of Biodegradable polymers

B) Bio-based plastic

Bio-based plastics are derived from renewable biomass sources such as plants, algae, and microorganisms (Fig. 3), offering an eco-friendly alternative to traditional petroleum-based plastics. These plastics can be classified into three categories: bio-based bioplastics, biodegradable bioplastics, and bio-based and biodegradable bioplastics. Key examples of bio-based plastics include polylactic acid (PLA), polyhydroxyalkanoates (PHA), and thermoplastic starch (TPS). PLA, produced from renewable resources like corn and sugar beets, is widely used for packaging, biodegradable films, and medical applications due to its biodegradability and biocompatibility. PHA, synthesized by bacteria from renewable resources such as starch and oils, offers versatile mechanical properties, suitable for packaging, agricultural films, and medical devices.

TPS, derived from natural starches like corn and potatoes, is used in products like packaging materials and disposable cutlery. Other bio-based plastics, such as bio-based polyethylene (Bio-PE) and bio-based polyethylene terephthalate (Bio-PET), are produced from biomass-derived ethanol and ethylene glycol, respectively, offering similar properties to conventional plastics. Bio-based plastics reduce reliance on fossil fuels, lower carbon emissions, and mitigate environmental pollution. While challenges remain in cost and scalability, ongoing research is improving their performance and making them a promising sustainable alternative for various applications.



c) compostable Plastics

Compostable Plastics are materials that degrade through biological processes during composting, resulting in water, CO2, inorganic substances, and biomass, without leaving toxic residues. Composting is a natural decay process involving organic materials like grass, food waste, and manure, which are transformed into stable humic substances known as compost. This process is especially useful for plastics that cannot be recycled due to contamination. The ASTM D6400 standard defines compostable plastics as materials that degrade in compost and do not leave distinguishable or harmful residues. Composting methods include drum reactors, row composting, and tunnel composting, all of which aim to break down organic waste into compost for agricultural and horticultural use.

Compostable plastics can be derived from both petrochemical and renewable sources. Petrochemical-based compostable plastics include PBS (Polybutylene Succinate), PCL (Polycaprolactone), PEA (Polyester amides), and PVA (Polyvinyl Alcohol). Renewable-based compostable plastics include PLA (Polylactic Acid), PHA (Polyhydroxyalkanoates), TPS (Thermoplastic Starch), cellulose, chitin, and proteins. Blending biodegradable polymers, such as starch with high-cost plastics, helps improve physical properties and reduce costs. One example is Mater-Bi, a starch-based compostable plastic used in various applications. Compostable plastics are widely used in packaging (e.g., films, bags, and tableware), agriculture (e.g., mulch films, plant pots), and transportation (e.g., tire fillers). They also have applications in the production of disposable items like cutlery, cups, and cotton swabs. The main goal of compostable plastics is to offer an environmentally friendly alternative to traditional plastics, supporting waste reduction and circular economy practices.

Biodegradation of bioplastics and its mechanism

Biodegradability of bioplastics is a complex process that involves a range of biochemical and microbiological factors, yet many studies tend to overlook or fail to adequately address the key aspects of polymer chemistry, microbial enrichment methods, and the biochemical processes involved in degradation. Biodegradability depends largely on the polymer's basic chemical structure, molecular weight, molecular weight distribution, and purity. These factors, which influence the material's degradation rate, are often neglected in biodegradability evaluations, leading to incomplete or inaccurate conclusions. Moreover, the microorganisms involved in the degradation process—primarily fungi and bacteria—play a critical role in breaking down bioplastics by modifying their chemical composition, including altering the degree of polymerization. For a bioplastic to be considered biodegradable, it is essential that the process is supported by microorganisms capable of metabolizing the material, and these microorganisms' metabolic capabilities should be well understood. One of the first steps in studying biodegradability is to isolate and enrich the right microorganisms. This is typically achieved by incubating bioplastics in environments where the plastic is the sole carbon and energy source, thus selecting for microorganisms capable of biodegrading the polymer (Fig. 4). Once the appropriate microbial population has been enriched, their metabolic processes can be further examined. Importantly, biodegradation claims must be substantiated with evidence of microbial activity, as well as detailed biochemical pathways that explain how polymers are broken down.

Fig.4 Machanism of biodegradation of bioplastic

To assess through various methods, including measuring the evolution of CO_2 (aerobic) and CH_4 (anaerobic), which serve as key biodegradability indicators. Other methods include tracking reductions in total carbon, visual changes in surface morphology (e.g., erosion or discoloration), and weight loss, although the latter may also result from abiotic factors. Biodegradation typically occurs in three stages: biofilm formation (biodeterioration), depolymerization, and mineralization (bio-assimilation). During biofilm formation, microorganisms attach to the plastic, secrete enzymes, and initiate polymer breakdown. In depolymerization, enzymes catalyze the cleavage of polymer chains into smaller molecules. Finally, in mineralization, the broken-down molecules are absorbed by microbes for growth and converted into water, CO_2, or CH_4. The biodegradation rate is influenced by factors like surface morphology, crystallinity, temperature, pH, oxygen, and microbial activity. Degradation in natural environments such as soil, compost, or landfills can be more complex due to variable moisture, temperature, and microbial diversity. Controlled laboratory tests provide more predictable results, but real-world conditions introduce additional variability. Effective biodegradability testing requires understanding the polymer’s properties, microbial involvement, and environmental factors to ensure environmentally sustainable degradation.

Agricultural applications of biodegradable and compostable plastics

Agricultural applications of biodegradable and compostable plastics, particularly bioplastics, are gaining traction as sustainable alternatives to traditional plastics. Plasticulture, which involves using plastics in agriculture, accounts for around 6.7 million tons of global plastic consumption annually, or approximately 2% of total plastics production. Plastics are used in a variety of agricultural applications, such as greenhouse covers, irrigation systems, packaging, soil mulching, and silage storage. However, many of these plastics are difficult to recycle and, when discarded, are often buried in soil, leading to significant environmental harm. These practices can degrade soil quality, reduce water retention, disrupt gas exchange, and contribute to groundwater contamination and microplastic pollution. To address these environmental concerns, biodegradable and compostable bioplastics are emerging as promising solutions. These bioplastics can break down naturally through microbial action, reducing waste and contributing organic matter that enhances soil fertility. Materials like starch, cellulose, polyhydroxyalkanoates (PHA), and polylactic acid (PLA) are being explored for agricultural applications, offering functional benefits without long-term environmental persistence.

1. Mulching and Mulch Films

Plastic mulching (Fig.5) is widely practiced, covering over 128,500 km² globally, primarily for crop protection, water conservation, weed suppression, and yield enhancement. Traditional plastic mulches, made from non-biodegradable materials, create significant waste. To address this, biodegradable mulch films are being developed from bioplastics like starch-based polymers, PLA, PHA, and poly-β-hydroxybutyrate (PHB).

These materials meet the mechanical and durability requirements for effective mulching while degrading naturally in the soil, reducing waste and improving soil quality. The European Standard EN 17033 provides guidelines for biodegradable mulch films, ensuring they are both functional and environmentally friendly.


Fig.5 plant mulching

2. Grow Bags

Grow bags, commonly used for holding plants and soil, are typically made from low-density polyethylene (LDPE). However, LDPE can leach toxic substances into the soil and water upon degradation. Bioplastics like PHA are emerging as a safer alternative. PHA is biodegradable, non-toxic, and compatible with plant growth, making it ideal for grow bags. Unlike LDPE, PHA does not leach harmful chemicals and is more favorable for plant root systems. After use, PHA grow bags break down naturally, eliminating the need for recycling or disposal in landfills, contributing to a more sustainable agricultural practice.

3. Agricultural Nets

High-density polyethylene (HDPE) is commonly used for agricultural nets, which protect crops from pests, support plant growth, and provide shade. However, HDPE nets are non-biodegradable, contributing to plastic waste. Biodegradable alternatives like PHA and PLA blends are now being explored. These materials offer similar tensile strength and elongation properties to HDPE, making them suitable for agricultural netting. Additionally, PHA-based nets are compostable, breaking down in the soil without leaving harmful residues, thus reducing environmental impact and promoting sustainability in agriculture.

Sustainability of biodegradable plastics

Sustainable growth is a critical goal in global policy, aiming to meet present needs without compromising future generations. This concept is central to balancing economic growth, environmental preservation, and social well-being. Achieving sustainability in biodegradable plastics is key to minimizing plastic waste while addressing environmental and social challenges. Biodegradable plastics, particularly bioplastics, align with the principles of sustainability by focusing on resource management, environmental protection, and societal fairness.

The Triple Bottom Line (TBL) (Fig. 6), introduced in 1994, emphasizes the integration of environmental, economic, and social sustainability in project execution. For biodegradable plastics, this includes ensuring environmental protection, enhancing economic performance, and fostering social fairness without sacrificing financial gains. The sustainable development of biodegradable plastics involves managing human and environmental needs while minimizing reliance on non-renewable resources. It also aims to avoid ecological and societal failures to secure the well-being of both current and future generations. Key elements of sustainable biodegradable plastics include social, economic, biophysical, and technical considerations.

fig.6 Triple bottom line (TBL)

Social sustainability focuses on improving quality of life and providing equitable costs in bioplastic production. Economically, bioplastics should be affordable, generate employment, and boost competitiveness. Biophysically, the extraction of renewable resources and reduced environmental pollution are essential. From a technical perspective, bioplastics must be durable, reliable, and functional. Biodegradable plastics are increasingly used in food packaging, shopping bags, and agricultural applications.

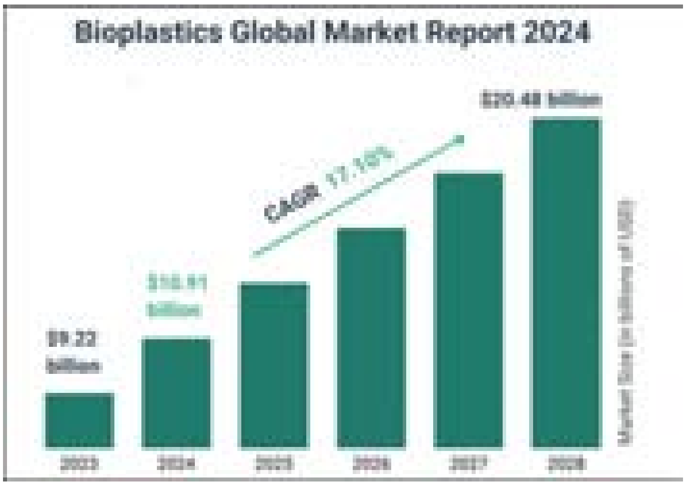


fig.7 Bioplastic global Market report

Their market share is growing, with expectations for bio-based plastics to rise from 1% to 2.5% of global plastic production by 2020 (Fig. 7). Despite higher production costs, biodegradable plastics are becoming more cost-competitive due to advances in manufacturing and scale. Proper disposal methods depend on the plastic’s use and available infrastructure for recycling or composting. Ultimately, sustainable management of biodegradable plastics is essential for reducing environmental impact and fostering a circular economy.

Conclusion and future outlook

Biodegradable polymers have received much more attention in the last decades due their potential applications in the fields related to environmental protection and the maintenance of physical health. The findings suggest that the biodegradable plastics industry can help address environmental challenges by adopting sustainable practices. At present only few groups of the mentioned biopolymers are of market importance. The main reason is their price level, which is not yet competitive. The future of each biopolymer is dependent not only on its competitiveness but also on the society ability to pay for it. The future outlook for development in the field of biopolymers materials is promising.

Although bio-based biodegradable plastics currently represent a small fraction of global plastic production, their demand is rising, especially in niche applications like agriculture. The focus should be on evaluating which applications benefit most from biodegradability, particularly those that cannot be addressed by conventional plastics. Moreover, global guidelines for bioplastic production, usage, and degradation should be developed. Educating communities about bioplastics' benefits and proper waste sorting is essential for achieving long-term sustainability.

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Production of Hydrogen from renewable & non-renewable resources

Abstract

Hydrogen is currently used mainly in the chemical industry for ammonia and methanol production, but it is expected to play a larger role as a fuel to improve air quality. It can be sourced from both renewable (biomass, solar, wind, algae) and non-renewable (natural gas, coal) sources through various processes. Currently, most hydrogen is produced from fossil fuels via techniques like hydrocarbon reforming, pyrolysis, and co-pyrolysis. However, future developments may focus on biological methods for hydrogen production. As urbanization and population growth increase global energy demands, hydrogen offers a promising alternative to fossil fuels, addressing issues like air pollution, CO2 emissions, and climate change. This review explores the potential of renewable hydrogen production and compares it to conventional methods, examining energy sources, costs, and environmental impacts. It highlights the need for sustainable hydrogen production methods to mitigate environmental degradation and meet future energy needs.

Keywords: pyrolysis, co-pyrolysis, biological methods, conventional methods.

Introduction

Hydrogen is primarily used in the chemical industry for ammonia, methanol production, and refining, but its role as an alternative fuel is gaining attention due to ecological concerns and increasing global energy demands. Currently, around 55 million tons of hydrogen are produced annually, with about 96% derived from fossil fuels, particularly through steam reforming of natural gas. The remaining 4% comes from water electrolysis, a highly energy-intensive process. As global energy demand rises by approximately 1.3% annually, there is growing interest in alternative hydrogen production methods, including biomass gasification, enzymatic processes, and photolytic cracking using solar energy and microorganisms.

Fig.1 Hydrogen production

Biomass is seen as a promising renewable source for hydrogen production, offering low sulfur emissions and potential for sustainable energy use, though its hydrogen yield remains relatively low (16-18% of dry biomass weight). Pyrolysis and co-pyrolysis of biomass, especially when combined with waste polymers, show promise due to low costs and valuable by-products. However, efficiency and economic viability remain key challenges. Biological methods, such as dark fermentation and enzymatic processes, are also under development but need further optimization.

Hydrogen production from renewable sources (Fig. 1) is critical to achieving net-zero emissions by 2050, reducing reliance on fossil fuels, and mitigating climate change. While current hydrogen production methods largely rely on fossil fuels, there is significant research into biofuels and other renewable sources to make hydrogen production more sustainable. Technologies like water electrolysis combined with renewable energy, as well as advanced thermochemical processes like pyrolysis, are expected to play an important role in the future hydrogen economy. This paper reviews and compares hydrogen production methods, evaluating their costs, environmental impacts, and commercial viability, while highlighting the growing potential of sustainable hydrogen technologies.

A. Conventional Methods for Hydrogen Production

The treatment of fuels involves converting raw materials like gasoline, hydrocarbons, ammonia, methanol, or ethanol into hydrogen-rich gases. Many hydrocarbon fuels contain sulfur, which must be removed for a successful hydrogen economy.

Thermochemical processes, which occur at temperatures between 200°C and 3000°C, are key to this transformation. These processes are classified into oxidation and reduction reactions. In oxidation, the oxidizer is present in a stoichiometric or higher amount, while reduction processes (like gasification or pyrolysis) use sub-stoichiometric or zero oxidizer, which is essential for hydrogen production.

Hydrogen can be generated from hydrocarbon fuels through three primary techniques: steam reforming (SR), partial oxidation (POX), and autothermal reforming (ATR). These methods typically produce significant amounts of carbon monoxide. To address this, a subsequent water-gas shift (WGS) reaction is used to convert carbon monoxide into carbon dioxide and additional hydrogen.
While these conventional processes are already used at a commercial scale, there is growing interest in biomass as a future hydrogen source. However, to make biomass gasification more cost-effective, advancements in processing routes and catalytic systems are needed to reduce costs and improve efficiency.

1. Steam Reforming (SR)

Steam reforming is a widely used and cost-effective method for hydrogen production, accounting for over 90% of global hydrogen supply. The process operates with high efficiency and low production costs, primarily using natural gas, lighter hydrocarbons, or coke oven gas. It involves two stages. In the first stage, hydrocarbons react with steam at 500-900°C and 0.3-2.5 MPa in a nickel-based catalyst reactor, producing syngas (H_2 + CO) and small amounts of CO_2. Oxygen or air is added to generate heat through partial combustion of the raw material. In the second stage, carbon monoxide undergoes a water-gas shift reaction to form carbon dioxide and additional hydrogen. The CO_2 is then removed using ethanolamine-based absorbers. The efficiency of SR is about 70-85%, but it produces significant CO_2 emissions (7.05 kg CO_2 per kg of hydrogen). Alternative feedstocks, such as solid waste or biomass, are being explored.

2. Partial Oxidation (POX)

Partial oxidation is another method for hydrogen and syngas production. It is a non-catalytic process where raw materials like methane or heavy oil fractions react with oxygen at 1300-1500°C and 3-8 MPa to produce CO, H_2, CO_2, and H_2O. The resulting syngas typically has a lower H_2:CO ratio (1:1 to 2:1) compared to steam reforming. POX is complemented by a water-gas shift reaction to adjust the CO content. While POX is cheaper to operate, the conversion process is more expensive, and it also generates sulfur compounds like hydrogen sulfide. However, it does not require sulfur removal from raw materials, making it more cost-effective for certain applications, including small-scale systems like fuel cells.

3. Water gas Shift

Syngas can be modified to meet specific requirements, such as converting CO and H_2O to CO_2 and H_2, adding gases to adjust component ratios, or completely removing carbon monoxide. The water-gas shift (WGS) reaction ($CO + H_2O \rightarrow CO_2 + H_2$) is commonly used to reduce CO concentrations to 0.5-1 mol% at temperatures of 400-500°C in the presence of catalysts like Cr_2O_3 or Fe_2O_3. This exothermic reaction favors hydrogen and CO_2 formation at lower temperatures, so the process typically involves two steps: high-temperature conversion (350-370°C) and low-temperature conversion (200-220°C) for further CO reduction. In some cases, methanation ($CO + 3H_2 \rightarrow CH_4 + H_2O$) is used to lower CO concentration to 10 ppm, though this increases hydrogen demand. The WGS reaction is central to hydrogen production via steam reforming, with various catalysts used depending on the temperature and reactor conditions. Technologies for CO and sulfur removal are widely employed in industry.

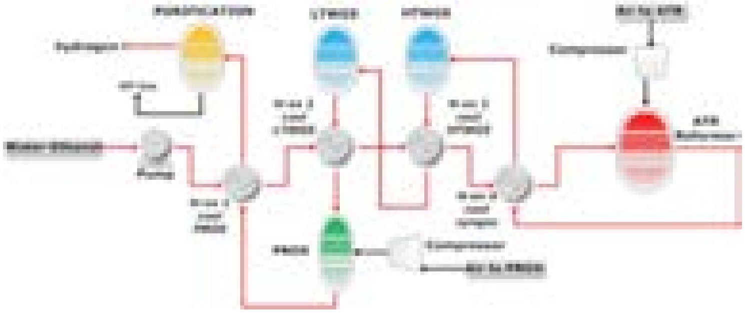

Figure 2: Steam Reforming, Partial Oxidation and Water Gas Shift Methods for Hydrogen Production

B Biological Methods for Hydrogen Production

Interest in biohydrogen research has grown due to the increasing availability of waste materials and the need for their reduction. Biological processes, unlike electrolysis and thermochemical methods, use microorganisms in an aqueous environment at ambient temperature and atmospheric pressure. These processes are cost-effective and suitable for locations with accessible biomass or waste, reducing transport and energy costs. Key criteria for raw material selection include cost, carbohydrate content, biodegradability, and availability. Biological hydrogen production involves microorganisms like anaerobic bacteria and algae, utilizing enzymes such as nitrogenase and hydrogenase. These enzymes enable hydrogen production, with nitrogenase producing hydrogen from ATP and hydrogenase managing hydrogen creation and consumption. The processes for biohydrogen production are categorized into five types: direct and indirect biophotolysis, biological water-gas conversion, photofermentation, and dark fermentation. While these processes show potential, they are not yet fully developed and require further research for commercial viability.

1. Direct Biophotolysis

Direct biophotolysis (Fig. 3) involves the use of photosynthetic microorganisms, such as green algae and cyanobacteria, to split water molecules into hydrogen and oxygen under solar radiation. The process is described by the reaction:

$$2H2O \rightarrow 2H2 + O2$$

This reaction occurs within the photosynthetic systems of microorganisms, specifically Photosystem I (PSI) and Photosystem II (PSII), which are responsible for oxygen and hydrogen ion generation. Microalgae like Chlamydomonas reinhardtii and Anabaena sp. utilize these systems, aided by molecules like ferredoxin and reverse hydrogenase, to produce hydrogen. However, the presence of oxygen inhibits the hydrogenase enzyme, requiring oxygen levels to be kept below 0.1%. While the process is simple and uses easily availablstrains, such as Scenedesmus obliquus and Chlorella species, have been explored for their hydrogen production capabilities, with genetically modified strains showing improved tolerance to oxygen and enhanced hydrogen yield.

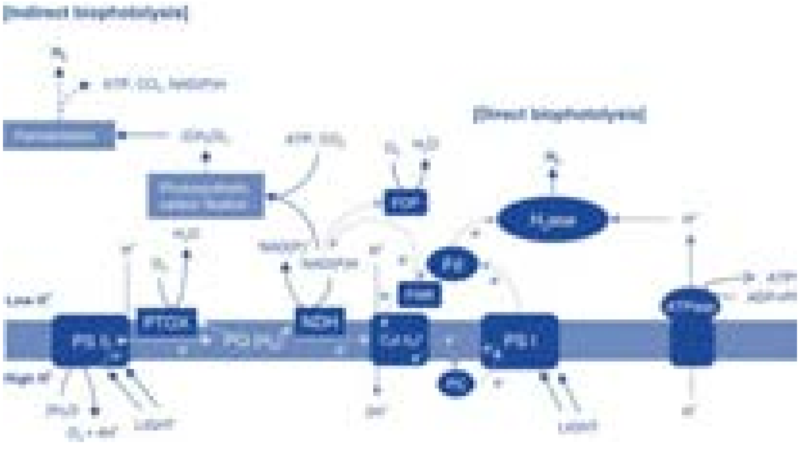

Fig.3 Direct and indirect biophotolysis

2. Indirect Biophotolysis

Indirect biophotolysis (Fig. 3) is a multi-step process that combines photosynthesis with fermentation. The process includes four main stages: (1) biomass production via photosynthesis, (2) biomass concentration, (3) aerobic dark fermentation, and (4) conversion of fermentation products into hydrogen. The process is summarized by the following reactions:

$$6CO_2 + H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$
$$C_6H_{12}O_6 + 6H_2O \rightarrow 12H_2 + 6CO_2$$

In this system, cyanobacteria such as Anabaena and Synechococcus sp. are used, and hydrogen is produced by the enzyme nitrogenase. The process can occur with or without nitrogen fixation. Under anaerobic conditions, hydrogen production occurs as nitrogenase catalyzes the conversion of protons to hydrogen. Studies with Anabaena cylindrica and other strains have shown varying hydrogen production rates, with Anabaena variabilis producing hydrogen at a rate of 0.355 mmol/h per liter. While indirect biophotolysis produces hydrogen at a higher efficiency than direct biophotolysis, its production rate still lags behind other methods, such as dark fermentation or photo fermentation.

3. Water-Gas Conversion

The water-gas conversion process is still in the early stages of development but shows promise due to its ability to produce hydrogen directly from carbon monoxide (CO) and hydrogen gas. This process uses specialized microorganisms such as Rhodospirillum rubrum, Rhodobacter gelatinosus, and Carboxydothermus hydrogenoformans, which are capable of converting CO and H_2 into hydrogen and CO_2 under anaerobic conditions. The reaction typically follows this scheme:

$$CO + H_2 \rightarrow CO_2 + H_2$$

This process is thermodynamically favorable under low temperatures and pressures. The presence of proteins like carbon monoxide dehydrogenase and hydrogenase facilitates this conversion, allowing the oxidation of CO and reduction of protons to produce hydrogen. However, the presence of CO at high concentrations (above 0.02 MPa) inhibits hydrogen production. Rhodospirillum rubrum is an important photoheterotrophic bacterium used for this process, operating in dark fermentation conditions and requiring light for growth. Other bacteria, such as Citrobacter sp. Y19, have shown higher hydrogen production rates, with up to 27 mmol/g cells per hour, three times higher than R. rubrum. The advantage of this process is its potential to work in conventional, closed reactors similar to those used in wastewater treatment, offering a cost-effective method for biohydrogen production.

C Pyrolysis and Co-Pyrolysis for Hydrogen Production

Pyrolysis and co-pyrolysis are promising methods for hydrogen production, where raw organic materials are heated in the absence of oxygen (500-900°C) to produce hydrogen, methane, carbon monoxide, and other by-products. The reaction can be summarized as:

$$\text{Organic material} + \text{heat} \rightarrow H_2 + CO + CH_4 + \text{other products}$$

Pyrolysis is divided into low (up to 500°C), medium (500-800°C), and high-temperature (>800°C) processes. The emerging method of fast pyrolysis converts organic materials into products with higher energy content, producing solid, liquid, and gaseous phases.

Co-pyrolysis involves combining coal with organic waste (plastics, rubber, textiles, etc.), which helps reduce waste disposal burdens. This process, often studied using thermogravimetric analysis (TGA), has been explored with materials like acrylonitrile butadiene styrene (ABS) and lignite, showing promising results for hydrogen production. High-temperature co-pyrolysis (e.g., 900°C) generates pyrolysis gas and a solid carbon residue, with methane enhancing the heating value of the gas (around 17 MJ/m³).

Further research into two-stage co-pyrolysis (at temperatures up to 1200°C) has shown that it can produce hydrogen-rich gas (up to 81% H_2 by volume) when organic materials like rubber and plastics are used. Factors like high heating rates, longer dwell times, and catalyst use (e.g., Na_2CO_3, Ni-based catalysts, and rare metals like ruthenium and rhodium) enhance hydrogen yields.Pyrolysis and co-pyrolysis are well-developed technologies with commercial potential, offering a sustainable method for hydrogen production and waste management.

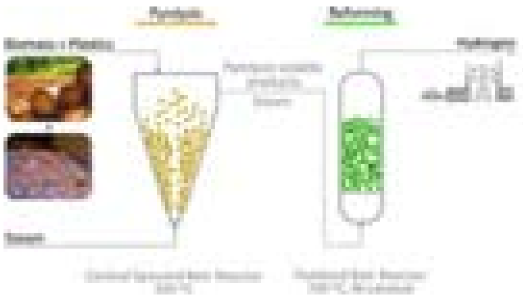

Fig.4 pyrolysis

D. Economic Aspects of Hydrogen Production

Currently, the most widely used and cheapest method of hydrogen production is steam methane reforming (SMR) of natural gas, which accounts for about half of global hydrogen production. The cost of hydrogen via SMR is approximately $7/GJ. Other thermochemical processes, like partial oxidation and gasification, produce hydrogen at similar costs but require greenhouse gas capture, increasing hydrogen prices by 25-30%. Hydrogen from biomass gasification and pyrolysis is more expensive, with costs ranging from $8.9 to $15.5/GJ, depending on feedstock and equipment. These methods are not competitive with SMR due to their higher costs, which are about three times more expensive.

Electrolysis of water is another option, producing hydrogen without by-products, but its high electricity costs make it less competitive. Biological processes, such as those catalyzed by microorganisms at room temperature and pressure, are less energy-intensive, making them suitable for small-scale, decentralized production, especially in regions with easy access to biomass. Hydrogen from biological processes like biophotolysis is estimated to cost $10-$20/GJ. Looking forward, by 2030, steam reforming and biomass gasification are expected to dominate hydrogen production, with electrolysis and coal gasification used on a smaller scale. Solar energy's role in hydrogen production is uncertain but could increase by 2050. Among biological methods, dark fermentation combined with photofermentation shows promise for higher efficiency and technological feasibility.

Conclusion

Hydrogen is emerging as a key fuel of the future, with the potential to address local air quality issues, especially in transport. Since hydrogen combustion produces only water and no carbon oxides, it is seen as a clean alternative to fossil fuels. Hydrogen can be sourced from various renewable and non-renewable resources, and many hydrogen production methods have minimal environmental impact, which could reduce reliance on fossil fuels. Currently, steam reforming of natural gas dominates global hydrogen production due to its low costs. Pyrolysis and co-pyrolysis of biomass are also viable methods but are more expensive than steam reforming, with costs depending on feedstock and equipment. While electrolysis powered by renewable energy offers a low-emission approach, it is still costly due to high energy consumption. Recent developments in thermochemical cracking and photoelectrolysis show promise, with photoelectrolysis being one of the most cost-effective and efficient methods, though still less common. Biological methods, such as dark fermentation, photofermentation, and microbial electrolysis cells, offer energy-efficient alternatives, especially at small scales. Dark fermentation is particularly promising with an efficiency of 60-80%, comparable to conventional methods, and does not require large land areas or sunlight. The BEAMR (Biological Electrochemical and Anaerobic Method) process stands out, with efficiencies up to 92%, making it a leading contender for future hydrogen production. Ultimately, hydrogen production is evolving with various technologies offering distinct advantages, and while thermochemical processes currently dominate, biological methods, especially dark fermentation and BEAMR, hold significant potential for the future. By 2030, hydrogen production methods will likely include a mix of steam reforming, biomass gasification, and advanced biological techniques.

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Hydrogen Economy & Fuel Cells

Hydrogen Economy and Fuel Cells: A Research Perspective

The hydrogen economy, which focuses on producing and using hydrogen as a sustainable energy source, has become a key area of global study. Hydrogen presents a viable solution to the challenges of energy supply and environmental degradation by acting as a clean substitute for fossil fuels. Its main use is in fuel cells, which transform hydrogen into electricity, with water as the sole emission. Yet, despite years of research, issues such as efficient production, affordable storage, and infrastructure challenges impede its widespread use.

The Promise of the Hydrogen Economy: -
Hydrogen is attractive due to its abundance and adaptability. It can be generated through several methods:
Electrolysis of water: This technique divides water into hydrogen and oxygen using electricity from renewable sources, resulting in green hydrogen.

Steam methane reforming (SMR): A prevalent but carbon-heavy process for extracting hydrogen from natural gas.

Biomass gasification: Creating hydrogen from organic resources like agricultural byproducts.

Fuel cells that utilize hydrogen can serve various purposes, from powering vehicles to supplying backup energy in isolated locations. Unlike batteries, fuel cells continuously generate electricity while hydrogen is available, making them highly effective for prolonged use.

Nonetheless, several factors limit the large-scale implementation of hydrogen:
Production Expenses: The cost of green hydrogen from renewable energy is higher than that of hydrogen obtained from fossil fuels.

Storage and Transport: Hydrogen's high flammability necessitates advanced storage solutions, such as high-pressure tanks or cryogenic systems.

Infrastructure Deficiencies: The absence of a comprehensive hydrogen refueling network hampers its application, particularly in the transportation sector.

Recent Advances in Hydrogen Research: -

Research is concentrated on addressing these challenges, particularly in the following domains:

Hydrogen Production: Researchers are investigating affordable electrolysis methods that employ advanced catalysts. For instance, the use of nanostructured materials, including alternatives to platinum like cobalt and nickel-based catalysts, aims to lower production costs.

Storage Innovations: The development of metal hydrides and chemical carriers is underway to enable safe and compact hydrogen storage. Solid-state storage options, which combine hydrogen with solid substances, show promise for enhancing safety and efficiency.

Fuel Cell Innovations: Improvements in proton exchange membrane (PEM) fuel cells and solid oxide fuel cells (SOFCs) are enhancing performance, longevity, and scalability.

Role of Research in Driving Policy and Industry:-

Research is essential not only for advancing technology but also for influencing policies and industry standards. Life cycle assessments (LCAs) of hydrogen production techniques assist policymakers in establishing low-emission strategies. Furthermore, collaborations between academia and industry are encouraging pilot initiatives to evaluate the practical application of hydrogen.

Countries like Japan, Germany, and South Korea have heavily invested in hydrogen research, creating hydrogen hubs and promoting green hydrogen production. Such initiatives aim to achieve economies of scale that lower costs and accelerate the shift toward hydrogen.

Challenges and Future Outlook

Despite advancements, hydrogen research faces ongoing challenges:

Scaling Production of Green Hydrogen: Expanding renewable energy capacity is crucial for producing green hydrogen in larger quantities.

Economic Feasibility: Research must prioritize reducing the cost of hydrogen per kilogram to compete effectively with fossil fuels.

International Collaboration: The hydrogen economy relies on global cooperation to standardize technologies and build infrastructure.

In the coming years, breakthroughs in materials science, process engineering, and renewable energy integration could establish hydrogen as a central element in the global energy landscape. Researchers play a critical role in guiding this evolution, ensuring that hydrogen fulfills its promise as the clean energy source of the future. With a solid foundation in research, the hydrogen economy has the capability to transform energy systems, combat climate change, and promote sustainable development globally.

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CO2-H2O-Air Equilibria and Its Effects on Environment

Brief overview

Due to the ever increasing population in this world and hence the increase in global warming, the content of carbon dioxide has increased in the atmosphere. One of the most concerned reasons for the rise in content of carbon dioxide is the burning of fossil fuels. This has therefore, caused disturbance in the CO2-H2O-Air equilibria.

Significance of the study

The following findings will allow us to understand how the ever increasing global warming due to the dis-balanced equilibria of CO2-H2O-Air is leading to massive impact on our planet earth.

Aims and objectives

To understand the meaning of CO2-H2O-Air equilibria in the atmosphere and its eff on the environment.

To understand the steps of the carbon cycle including the inflow and outflow of carbon dioxide to and from the atmosphere

To understand the historical maximum and minimum carbon dioxide concentration in air and water

Statement of Problem

The dis-balance in the CO2-H2O-Air equilibria in the atmosphere affects the environment.

Findings

Carbon is incorporated in the various life forms through the basic process of photosynthesis. It is the process by which atmospheric carbon dioxide or carbon dioxide dissolved in water is converted into glucose molecules.

Another process by which carbon dioxide adds up to the atmosphere is by the process of combustion or by the burning of fossil fuels.

Both the release of glucose molecules and the burning of fossil fuels generates energy required for various other biological, physical and industrial processes.

The percentage of carbon dioxide has doubled since the industrial revolution.

(i) The carbon cycle

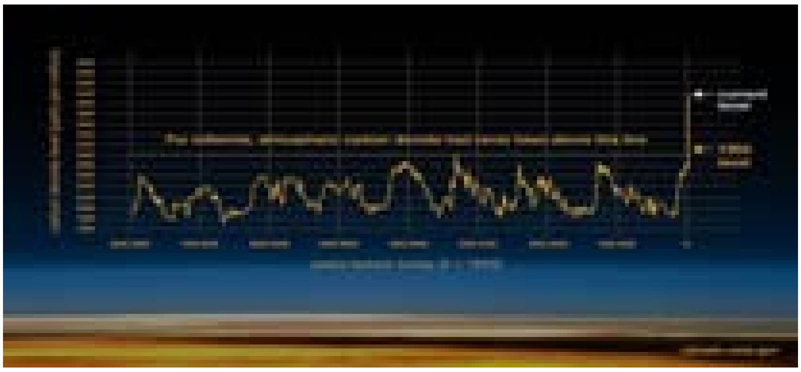
The carbon cycle involves a cyclical process. The carbon dioxide in the atmosphere is absorbed by plants which follows different pathways in order to return the carbon dioxide back to the atmosphere.

- The first pathway: the animals and other living beings take up the carbon dioxide from the plants and return it back to the atmosphere via the processes of respiration and decomposition.

- The second pathway: the carbon which is not returned back to the atmosphere turns into fossil fuels (petroleum, coal etc.). This is used in various man-made activities which led to the regeneration of carbon in the atmosphere.

(ii) Total quantity of carbon in atmosphere

During the time of earth’s formation, the atmosphere was comprised of helium and hydrogen. Then came volcanic eruptions leading to emissions of gases which led to the formation of ammonia, carbon dioxide and other gases. There was a time around almost 500 million years ago, when the concentration of carbon dioxide in the atmosphere was around 5000 ppm. Before the onset of industrial revolution, the carbon dioxide content was around 280 ppm. After the increase in burning of fossil fuels to fulfil the various needs of human beings, the carbon dioxide content has risen up to almost 421 ppm. Not only has the industrial revolution brought up the rise in the content of carbon dioxide but also other greenhouse gases leading to global warming in high levels. Due to this uneven rise in the content of greenhouse gases in the atmosphere, there has been a huge impact on the environment.



In correspondence with the facts discussed above this provided figure, we can infer from the graph:

- During the ice ages, the content of carbon dioxide was around 200 ppm.
- During the warmer, interglacial periods, it was fluctuating between 280 ppm to 300 ppm, as seen in the graph.
- The current level of carbon dioxide has reached around 400 ppm as recorded in 2022.

Due to this uneven rise in the content of greenhouse gases in the atmosphere, there has been a huge impact on the environment.

(iii) Total quantity of carbon in lithosphere

The hard and solid outer part of the Earth is the lithosphere. It is bounded by the atmosphere above it and the asthenosphere below it. Almost 99% of the total carbon content of the Earth is found in the lithosphere. Most of the carbon is contained in sedimentary rocks within the planet's crust. Around 4100 GtC is stored in the earth's crust as hydrocarbons which has been formed over million years. These hydrocarbons are what we know as fossil fuels. In the form of carbonate, carbon is stored in the lithosphere.

We can infer from this diagram that carbon moves through the lithosphere in both organic and inorganic forms.

- Living organisms constitute the organic carbon content.
- Rocks, sediments and other solid forms found on the crust of the earth constitutes the inorganic carbon content.

(iv) Total quantity of carbon in hydrosphere

The hydrosphere consists of the water bodies of the Earth. The oceans are a huge carbon source. There have been many exchanges of carbon between the water bodies and the atmosphere.Carbon dioxide is soluble in water. It can exist in all the states of matter, solid, liquid and gas. The content of carbon dioxide in the waters differs with depth. The surface waters have around 10 ppm of dissolved carbon dioxide while the deeper waters have several hundred ppm of carbon dioxide. The rate of carbon dioxide is the major cause of acidity in unpolluted waters. It has been through a varied range over time.

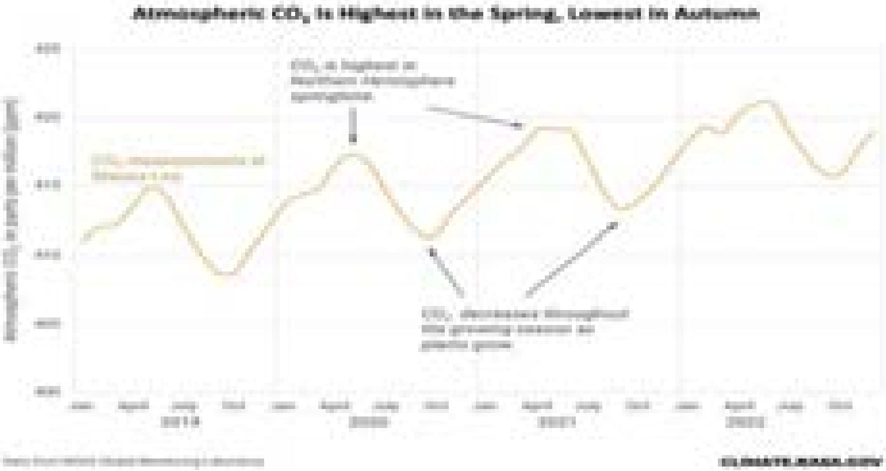
We can infer from this diagram that:

- Carbon content in the oceans and other water bodies is stored either within the carbonate sediments or in the form of dissolved gases.
- We can also infer that more than around 70 percent of carbon dioxide emissions will eventually end up in the oceans in the coming future.

(v) Effect of CO2-H2O-Air Equilibria on the Environment

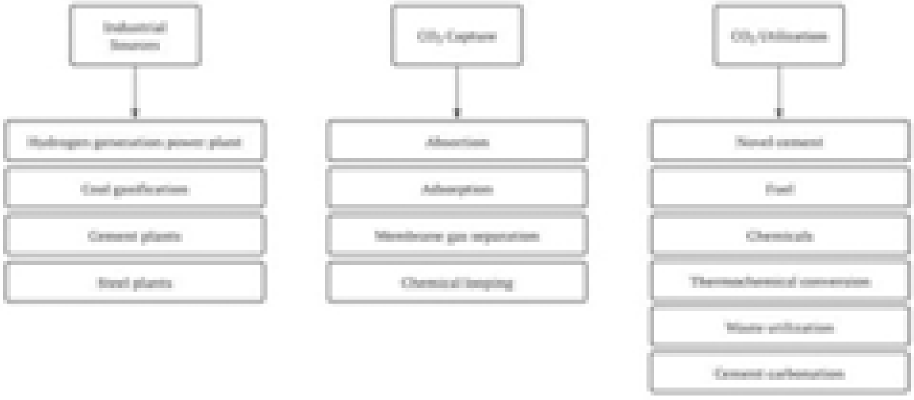
The average temperature on earth is decided by the presence of gases in the atmosphere. H2O and CO2 are considered to be two of the most important greenhouse gases that provides the maintains the equilibrium in the atmosphere. At equilibrium, the energy received by earth's atmosphere becomes equal to the energy radiated from the earth. But, due to the increase in carbon dioxide in the atmosphere, as discussed earlier, there has been a shift in the CO2-H2O air equilibria which has led to a destructive impact on the environment. Some of the effects include:

- Increase in the temperature of our planet Earth leading to a multitude of climate changes.
- Increased exposure to CO2 leads to various health problems ranging from rapid breathing, elevated blood pressure and even fatal ones like death by suffocation due to increased levels of CO2 in the blood stream.



As depicted in the above graph, we can see that the levels of carbon dioxide vary with the rate of photosynthesis during every other seasons.
As we had discussed earlier, via the carbon cycle, the carbon dioxide is given back to the atmosphere by the process of decomposition of the plant matter.

Is Chemical engineering solving the problem of the misbalanced equilibria?
While answering this question one thing that comes across our minds is the CCU technology. It is of immense usage in the very field of chemical engineering. It is the process by which carbon dioxide is captured from industrial processes and other combustions, and then stored for later usage.



In this field of engineering and several other fields of engineering, CCU technologies have crucial aspects to fulfil.

- Helps in reducing various kinds of emissions which might have negative impacts on the lives of human beings.
- Help reduce climatic changes
- Substitution of fossil fuels for playing the important role of providing energy for our daily activities.

Hence its safe for us to conclude that the misbalanced equilibria can be improved with the technologies this field of engineering has to offer.

Recommendation and Suggestions

- A lot of research has been undertaken on renewable energy sources and fossil fuel energy to reduce the carbon dioxide emissions with technologies of its correct utilization and storage.
- We must encourage reducing the global temperatures by reducing the emission of the greenhouse gases.
- We must encourage afforestation to ensure the carbon cycle continues with replenishment and regeneration.
- To maintain the equilibria of CO2-H2O-Air, there must be equivalent usage and release of the said gases in the atmosphere.

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FUEL CELL AND IT'S APPLICATIONS

Abstract

Energy plays a crucial role in almost every aspect of our daily lives, from powering our homes and transportation to supporting industrial processes. However, with the rising costs and environmental concerns associated with traditional energy sources, there is an increasing need for alternative, more sustainable solutions. This is where fuel cells come in as a promising technology. Fuel cells offer a cost-effective, renewable, and environmentally friendly way to generate energy. They work by directly converting the chemical energy from fuels such as hydrogen or methane into electricity, with water and heat as the primary byproducts, making them much cleaner than conventional combustion-based power generation methods.

Fuel cells are electrochemical devices, similar to batteries, that consist of three key components: an anode, a cathode, and an electrolyte. The fuel (e.g., hydrogen) is supplied to the anode, where it undergoes an electrochemical reaction with oxygen from the air, releasing electrons that generate an electric current. The electrolyte serves to separate the anode and cathode, allowing for the controlled flow of ions. This simple yet highly efficient design allows fuel cells to be used in a wide range of applications, from stationary power generation to portable devices and even transportation. This paper explores the working principles, advantages, and potential of hydrogen fuel cells as a sustainable energy source.

Introduction

Fuel cell is an electrochemical device that generate electricity through a chemical reaction between a fuel (primarily hydrogen) and an oxidant (usually oxygen). Unlike traditional combustion engines, which convert chemical energy into thermal energy, then mechanical energy, and finally electrical energy, fuel cells perform the conversion in a single step.This direct process offers several benefits. For example, traditional combustion-based energy systems contribute to major environmental issues like climate change, ozone depletion, acid rain, and the loss of vegetation. Additionally, these systems rely on finite fossil fuels. Fuel cells, in contrast, are more efficient and environmentally friendly, producing less pollution. They can also work with renewable energy sources, like hydrogen, which makes them a promising option for sustainable energy solutions.

Moreover, fuel cells are quiet, have no moving parts, and are modular, meaning they can be easily scaled and used in various applications, from portable devices to stationary power plants to vehicles. Overall, fuel cells offer a cleaner, more efficient, and flexible way to convert chemical energy into electricity. A major difference between a battery and a fuel cell is that it requires continuous supply of fuel and is not as portable as a battery. Some of the types of fuels include metal hydrides, methanol, Formic acid, ethanol and hydrogen. Depending on the type of cell, the oxygen atoms, together with the negatively charged electrons, would combine with the positively charged ions of the fuel. A fuel cell which consists of a cathode, an anode, and an electrolyte, is similar to electrochemical cells.

Working of a fuel cell

The working principle of a fuel cell is based on an electrochemical Reaction that directly converts the chemical energy of a fuel, such as Hydrogen, into electrical energy, heat, and water. Unlike traditional Combustion engines, which rely on burning fuel to produce heat that is Then converted into mechanical or electrical energy, fuel cells operate Through a clean and efficient electrochemical process. This method does Not involve combustion, making fuel cells much more efficient and Environmentally friendly, producing minimal emissions. This process is Particularly advantageous because it reduces harmful pollutants like CO_2, Making it an important technology for sustainable energy solutions. Below is a detailed explanation of how a fuel cell functions

1. Fuel Supply and Anode Reaction

In a typical hydrogen fuel cell, the fuel supplied to the anode (the Negative electrode) is hydrogen (H_2), which is a clean, abundant, and Efficient fuel. The hydrogen molecules enter the anode and undergo a Process called oxidation. At the anode, a catalyst, usually made of Platinum, facilitates the splitting of the hydrogen molecules (H_2) into Protons (H^+) and electrons (e^-). The reaction that takes place at the Anode is as follows:

This reaction effectively separates the hydrogen into two charged Particles: positively charged protons (H^+), which move toward the Cathode, and negatively charged electrons (e^-), which travel through an External circuit to generate electricity. The protons, however, cannot Pass directly through the anode and must instead move through the electrolyte.

Electron Flow and External Circuit

Electric current, which can be used to power external devices, machinery, Or even vehicles. This flow of electrons is what provides the electrical Energy that the fuel cell generates. The electrons do not travel directly Through the electrolyte because the electrolyte is specifically designed to Allow only the protons to pass through, while blocking the electrons.
The movement of electrons through the external circuit is critical, as it Creates the electrical power that can be harnessed for practical use. This Current is what makes fuel cells a versatile and efficient source of energy For various applications, such as portable electronics, stationary power Generation, and even in the transportation sector for hydrogen-powered Vehicles.

Electrolyte and Proton Movement

The electrolyte is a key component of the fuel cell, as it serves to allow the protons (H^+) to pass through from the anode to the cathode. The type of electrolyte varies depending on the kind of fuel cell being used. In a Proton Exchange Membrane Fuel Cell (PEMFC), for example, a solid polymer membrane serves as the electrolyte. In other types of fuel cells, such as Solid Oxide Fuel Cells (SOFC), a ceramic material is used instead. The electrolyte's role is to conduct protons while keeping the electrons in the external circuit, thus ensuring that the electrochemical reaction proceeds in a controlled manner.
By allowing the protons to move from the anode to the cathode, the electrolyte facilitates the continuation of the electrochemical reaction. Without this step, the overall energy conversion process would be incomplete..

Cathode Reaction

Once the protons (H^+) reach the cathode, they react with oxygen (O_2) From the air. The oxygen molecules combine with the protons that have Traveled through the electrolyte, as well as the electrons that have Traveled through the external circuit, to form water.
At this stage, the hydrogen fuel has been converted into water, and the Electrochemical reaction is complete. The production of water at the Cathode is a significant feature of fuel cells, as it is a clean byproduct, Unlike the carbon dioxide and other pollutants produced by conventional Combustion processes.

Byproducts and Heat Generation

The primary byproduct of this electrochemical process is water (H_2O). This water is typically expelled from the fuel cell as vapor, although it can Also be condensed into liquid form depending on the temperature and Humidity levels inside the cell. The production of water is one of the Main advantages of fuel cells from an environmental standpoint, as it Contributes to the technology's reputation as a clean energy source.

In addition to water, fuel cells also generate heat as a byproduct of the Reaction. The heat can be utilized for various purposes, such as heating Systems in residential or commercial buildings, or it can be used to Increase the efficiency of the fuel cell itself, especially in combined heat And power (CHP) systems. However, managing this heat is important for Ensuring the fuel cell operates efficiently and safel

Cathode Reaction: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

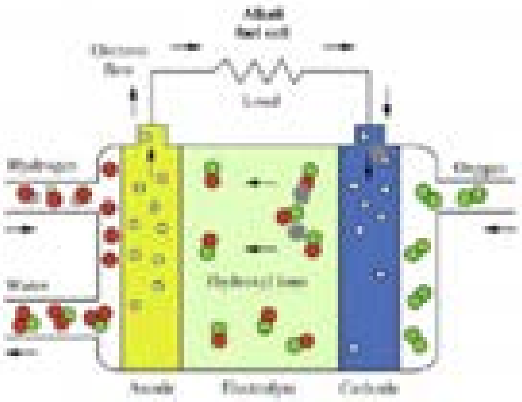
Anode Reaction: $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$

Net Cell Reaction: $2H_2 + O_2 \rightarrow 2H_2O$

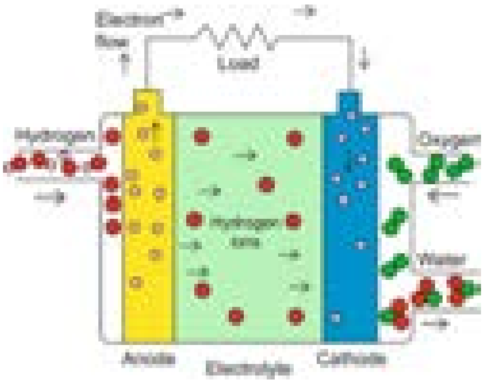
Types of Fuel Cells

Fuel cells can be categorized into various types based on factors like operating temperature, efficiency, applications, and costs. They are primarily distinguished by the type of fuel they use and the nature of the electrolyte involved in the electrochemical process. The six main types of fuel cells are:

Alkaline Fuel Cell (AFC): AFCs utilize an alkaline electrolyte, typically potassium hydroxide, which offers high efficiency. These fuel cells are widely used in specialized applications, such as space missions, where their reliability and performance are critical.



Phosphoric Acid Fuel Cell (PAFC): These fuel cells use phosphoric acid as the electrolyte and operate at moderate temperatures, typically around 150-200°C. PAFCs are commonly employed for stationary power generation, providing electricity for commercial buildings, industrial facilities, and large-scale power plants.



Solid Fuel Cell (SOFC): SOFCs operate at high temperatures (600-1,000° C) and use a solid ceramic material as the electrolyte. They offer high efficiency and are suited for large-scale power generation, both for stationary power plants and industrial uses where heat integration is beneficial.

Molten Carbonate Fuel Cell (MCFC): MCFCs use a molten carbonate salt mixture as the electrolyte, and they also operate at high temperatures (around 600°C). These fuel cells are primarily used in large industrial applications, where they can produce significant amounts of power while efficiently utilizing heat.

Proton Exchange Membrane Fuel Cell (PEMFC): PEMFCs are known for their low operating temperatures (around 80°C) and use a solid polymer membrane as the electrolyte. Due to their quick start-up times, high power density, and suitability for integration with hydrogen, PEMFCs are widely used in transportation applications, especially in hydrogen-powered vehicles.

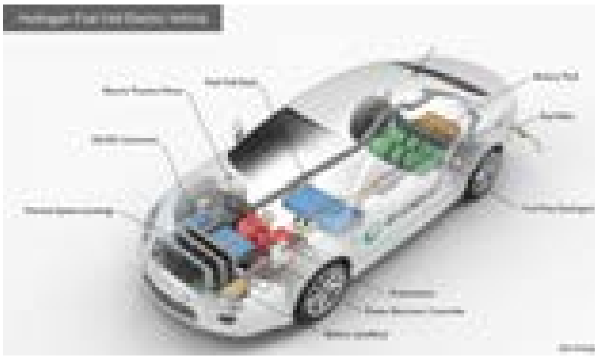
Direct Methanol Fuel Cell (DMFC): DMFCs operate by directly using methanol as the fuel, which reacts with a proton exchange membrane to produce electricity. These fuel cells are ideal for portable applications, such as laptops, mobile phones, and other small electronic devices, due to their compact size and ability to work with liquid fuel.
Each type of fuel cell offers distinct advantages and is suited for different applications based on its operating conditions, fuel requirements, and efficiency.

APPLICATIONS OF THE FUEL CELL

Fuel cells are increasingly recognized for their efficiency, environmental benefits, and versatility in providing electrical power. These advantages make them suitable for a wide range of applications across various sectors. Here are some of the key uses of fuel cells:

1. Transportation

Hydrogen-Powered Vehicles: Fuel cells are most notably used in hydrogen-powered vehicles, including cars, buses, trucks, and trains. These vehicles typically use Proton Exchange Membrane Fuel Cells (PEMFCs), which offer high efficiency and zero emissions, producing only water vapor. Hydrogen-powered vehicles have the advantage of longer driving ranges compared to battery electric vehicles and can be refueled in just a few minutes



Aerospace: In space missions, fuel cells have been a crucial source of power for decades. NASA, for example, has used fuel cells to power spacecraft and rovers, where solar power may not be reliable. These fuel cells also provide water as a byproduct, which can be used by astronauts.
Trains and Ships: Hydrogen fuel cells are also being explored for use in trains and ships. These applications aim to replace diesel engines and reduce emissions.

2. Stationary Power Generation

Backup Power: Fuel cells are used in backup power systems for critical facilities such as hospitals, data centers, and communication towers. They provide reliable power during grid outages and are valued for their quiet operation and lack of emissions.

Combined Heat and Power (CHP) Systems: In residential and commercial buildings, fuel cells can provide both electricity and heat through CHP systems. The waste heat generated can be used for hot water or space heating, increasing the system's overall efficiency.

Distributed Energy: Fuel cells are ideal for decentralized power generation, particularly in remote or off-grid areas where connecting to the main grid is not feasible. They can offer reliable, on-site energy solutions.

3. Portable Power

Consumer Electronics: Fuel cells are being considered for powering portable devices like laptops, smartphones, and tablets. Direct Methanol Fuel Cells (DMFCs), which use methanol as a fuel, are particularly attractive for these applications due to their compact size and ability to provide continuous power without frequent recharging.

Military Equipment: The military uses fuel cells to power equipment such as radios, GPS devices, and portable generators in field operations. Fuel cells offer a higher energy density than batteries, allowing soldiers to carry lighter equipment and extend mission durations.

4. Industrial Applications

Material Handling Equipment: In warehouses and distribution centers, fuel cells are used to power forklifts and other material handling equipment. These fuel cell-powered vehicles can be quickly refueled, unlike battery-powered ones that require long charging times, improving efficiency in high-demand environments.

Data Centers: Fuel cells also provide backup power to data centers, ensuring that critical systems and servers remain operational during power outages. They are preferred over traditional diesel generators for their quiet operation and lower maintenance requirements.

5. Renewable Energy Integration

Energy Storage: Fuel cells play a key role in storing energy from renewable sources like solar and wind. When there is excess energy, it can be used to produce hydrogen via electrolysis, which can then be stored and used in fuel cells for later power generation. This helps address the intermittent nature of renewable energy sources and supports grid stability.

Microgrids: Fuel cells are used in microgrids, which are small, self-contained energy networks that can function independently or alongside the main grid. They offer reliable and clean energy solutions for remote communities or areas with unreliable grid connections.

6. Power for Remote Locations

Off-Grid Power: Fuel cells are an ideal solution for providing power in remote locations where conventional infrastructure is lacking. These can include isolated communities, remote telecommunications towers, and field operations that require reliable energy sources.

Disaster Relief: In areas affected by natural disasters, fuel cells provide temporary power for emergency response teams, medical facilities, and shelters. Their ability to operate without emissions or noise makes them highly suitable for post-disaster recovery.

7. Environmental Applications

Wastewater Treatment: Fuel cells, particularly microbial fuel cells (MFCs), are being explored for wastewater treatment. They generate electricity from organic waste, offering a sustainable method of waste processing while producing power.

Air Purification: Fuel cells are also used in air purification systems, particularly in enclosed spaces like submarines, spacecraft, and underground facilities. These systems help maintain safe air quality by remoaving contaminants through the electrochemical process

8. Portable Military Power

Field Power for Soldiers: Fuel cells are used by the military to power portable field equipment, such as radios and GPS units. Their higher energy density compared to traditional batteries allows soldiers to carry lighter equipment while ensuring extended operational capability without the need for frequent recharging.

CONCLUSION

In conclusion, fuel cells offer a clean, efficient, and versatile alternative to traditional energy sources. By directly converting chemical energy into electricity with minimal emissions, they hold significant potential across various sectors, including transportation, stationary power, and portable applications. Although challenges like cost and infrastructure remain, ongoing advancements in technology make fuel cells an increasingly viable solution for sustainable energy. As a result, fuel cells could play a crucial role in reducing carbon emissions, enhancing energy security, and contributing to a more sustainable, low-carbon future. Their widespread adoption promises a cleaner and more efficient energy landscape

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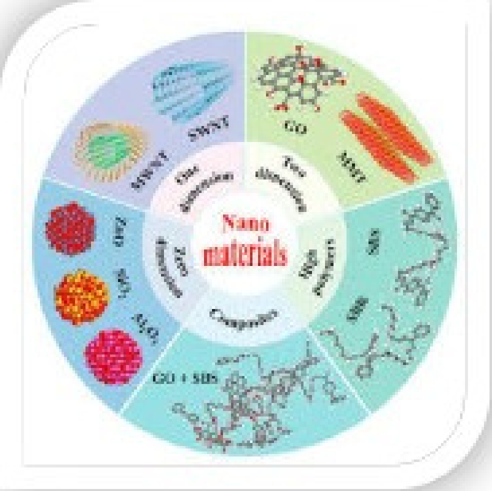
DEPT: Chemical Engineering
YEAR: 1st

NANOMATERIALS AND ITS APPLICATIONS

Introduction

In recent years, the field of nanotechnology has emerged as one of the most transformative and promising areas of scientific research. At the heart of this revolution lies nanomaterials—materials that are engineered at the nanoscale (typically between 1 and 100 nanometers). These materials possess unique physical, chemical, and mechanical properties that differ significantly from those of their bulk counterparts, opening up a wealth of opportunities across various industries. From medicine to electronics, energy to environmental sustainability, nanomaterials are shaping the future of technology in profound ways.This magazine explores the various types of nanomaterials, their properties, and a broad spectrum of applications, demonstrating how they are poised to revolutionize industries and improve the quality of human life.

What Are NANOMATERIALS?



Nanomaterials are materials with structures, properties, or compositions that are tailored at the nanoscale. This small scale often results in remarkable properties that emerge from quantum effects, increased surface area, and other phenomena that do not occur at larger scales. These materials can be naturally occurring or engineered and include a wide range of forms such as nanoparticles, nanowires, nanorods, nanotubes, and nanocomposites.

There are two primary categories of nanomaterials:

Zero-Dimensional Nanomaterials (0D): These materials are confined in all three spatial dimensions. The most common example is nanoparticles, where the size of the particle is typically below 100 nm.

One-Dimensional Nanomaterials (1D): These are materials that have one dimension significantly larger than the others, such as nanowires and nanotubes, which can extend in one direction while being nanoscale in the other two.

Two-Dimensional Nanomaterials (2D): These materials are confined in two dimensions. Graphene and other forms of layered materials like molybdenum disulfide (MoS2) are prime examples.

Three-Dimensional Nanomaterials (3D): These materials have nanoscale features in all three spatial dimensions but maintain their bulk properties. These materials include nanocomposites and nanoporous structures.

Properties of Nanomaterials

- High Surface Area: As particles become smaller, their surface area-to-volume ratio increases dramatically. This property makes nanomaterials highly reactive and useful in applications like catalysis, drug delivery, and energy storage.

- Quantum Effects: At the nanoscale, materials begin to exhibit quantum mechanical properties, such as quantum tunneling and superposition, that are not present at the macroscopic scale. This can result in enhanced electrical, optical, and magnetic properties.

- Increased Strength and Durability: Many nanomaterials, such as carbon nanotubes and graphene, possess remarkable mechanical strength, often much greater than that of steel. This makes them useful for creating lightweight yet strong materials for aerospace, automotive, and construction industries.

- Optical Properties: Nanomaterials can exhibit unique optical properties, including changes in color, transparency, and fluorescence. Gold nanoparticles, for example, appear red or purple depending on their size, and quantum dots can be tuned to emit specific wavelengths of light.

- Electrical Conductivity: The electrical properties of nanomaterials can be finely tuned for use in electronic devices, sensors, and even batteries. Conductivity may vary based on the material, structure, and external factors such as temperature or magnetic fields.

Applications of Nanomaterials

Nanomaterials have found applications across a wide variety of fields. The following sections explore how they are being utilized in key industries.

1. Medicine and Healthcare

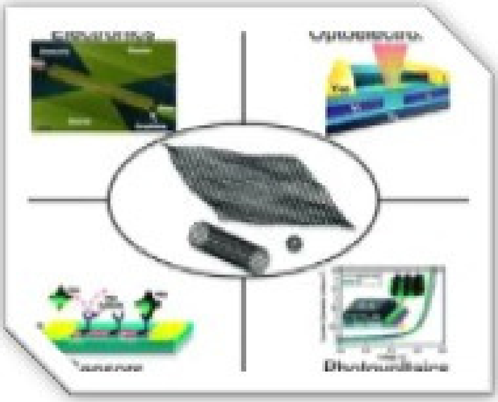
Nanomaterials are making a significant impact in the medical field, offering new ways to diagnose, treat, and prevent diseases. Some of the key applications include:

Drug Delivery: Nanoparticles, such as liposomes or polymeric nanoparticles, can be engineered to deliver drugs directly to specific cells or tissues. This targeted delivery improves the efficacy of drugs while reducing side effects, particularly in chemotherapy and gene therapy.

Medical Imaging: Nanomaterials, particularly gold and iron oxide nanoparticles, are used in medical imaging to improve the resolution and accuracy of diagnostic techniques like MRI, CT scans, and ultrasound.

Biosensors: Nanomaterials are used in biosensors to detect biomarkers of diseases at very low concentrations. The high surface area and reactivity of nanomaterials allow for highly sensitive and specific detection, making them valuable in disease diagnostics.

Regenerative Medicine: Nanomaterials are also being explored for their role in tissue engineering and regenerative medicine. Nanostructured scaffolds can be used to promote the growth and regeneration of tissues, such as bone, cartilage, and skin.

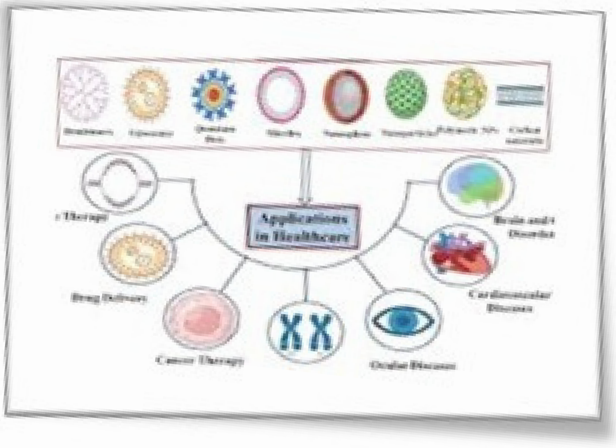


2. Electronics and Computing

Nanomaterials are poised to revolutionize the electronics industry. The miniaturization of devices and improvements in performance rely heavily on the integration of nanomaterials:

Semiconductors: Nanomaterials such as carbon nanotubes and graphene are being investigated as alternatives to traditional silicon-based semiconductors. These materials offer superior electrical conductivity and can potentially lead to faster, more efficient transistors for next-generation computing.

Quantum Computing: Quantum dots, a type of nanomaterial, are critical components in the development of quantum computers. Their ability to exist in multiple states simultaneously could enable vastly superior computational power for complex tasks.



Flexible Electronics: Nanomaterials such as graphene and conductive polymers are used in the development of flexible and wearable electronic devices. These materials enable the creation of lightweight, flexible screens, sensors, and other electronics.

Energy-Efficient Displays: Nanomaterials are used in the production of more energy-efficient displays, such as OLEDs (Organic Light Emitting Diodes) and quantum dot displays. These displays offer superior brightness, color accuracy, and energy consumption compared to traditional technologies.

3. Energy and Environmental Applications

Nanomaterials are increasingly being employed to address the world’s energy and environmental challenges. Their applications range from enhancing renewable energy sources to environmental cleanup:

Solar Cells: Nanomaterials, particularly perovskite solar cells, are being developed as low-cost alternatives to traditional silicon-based solar panels. Their high efficiency and ease of fabrication have made them a promising option for large-scale solar power generation.

Energy Storage: Nanomaterials are improving the performance of batteries and supercapacitors. For example, lithium-ion batteries are being enhanced by the incorporation of nanostructured anodes and cathodes, resulting in batteries with higher capacity, faster charge times, and longer lifespans.

Hydrogen Storage: Nanomaterials such as carbon nanotubes and metal-organic frameworks (MOFs) are being researched for their potential in efficient hydrogen storage, which is a critical component of the hydrogen economy and clean energy systems.

Water Purification: Nanomaterials are being used in water filtration and purification systems. Nanomaterial-based filters can remove contaminants at the molecular level, providing clean and safe drinking water.

Environmental Cleanup: Nanomaterials are employed in the remediation of pollutants, particularly in soil and water. Nanoparticles can adsorb toxic metals, break down organic pollutants, and even detect the presence of hazardous materials in the environment.

4. Manufacturing and Materials Science

Nanomaterials are transforming manufacturing processes by enabling the creation of materials with superior properties:

Nanocomposites: By incorporating nanomaterials such as nanoparticles or nanofibers into traditional materials, manufacturers can produce stronger, lighter, and more durable composites. These are used in industries ranging from aerospace and automotive to construction and packaging.

Coatings and Surface Treatments: Nanomaterials are used to create protective coatings that are highly resistant to wear, corrosion, and scratches. For instance, nanocoatings are used in electronics to enhance the durability and lifespan of devices.

Sensors: Nanomaterials are employed in a wide range of sensors, from gas and chemical sensors to strain gauges and biosensors. The high surface area and reactivity of nanomaterials enhance the sensitivity and specificity of these devices.

Challenges and Future Directions

While the potential of nanomaterials is immense, there are several challenges that must be addressed for their widespread commercialization:

Toxicity and Safety: The small size and large surface area of nanomaterials can make them more reactive, which raises concerns about their toxicity, especially when they enter biological systems. More research is needed to understand the potential health and environmental risks associated with nanomaterials.

Scalability: Producing nanomaterials on a large scale while maintaining their unique properties is a significant challenge. Advances in manufacturing techniques, such as bottom-up and top-down methods, are required to meet the demand for nanomaterials in industry.

Regulation and Standards: As the use of nanomaterials expands, regulatory frameworks and standards need to be established to ensure their safe use in consumer products, medical devices, and industrial applications.

Conclusion

Nanomaterials are at the forefront of technological innovation, enabling breakthroughs across industries and offering solutions to some of the world's most pressing challenges. From medicine to energy, electronics to environmental sustainability, the applications of nanomaterials are vast and diverse. As research continues to evolve, it is likely that nanomaterials will play an even more central role in shaping the future of science and technology.

The journey of unlocking the full potential of nanomaterials is just beginning. As we move forward, it is crucial to balance innovation with caution, ensuring that the benefits of nanomaterials are realized while minimizing any potential risks. With continued investment in research.

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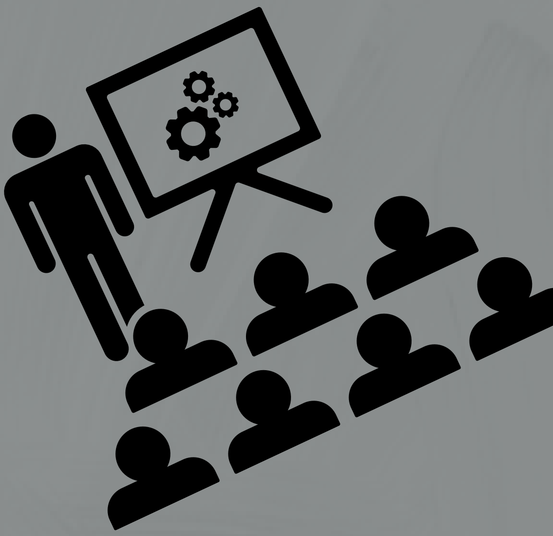

DEPARTMENTAL EVENTS

CHEMCON 2023

CHEMCON 2023

INTRODUCTION: CHEMCON conference was initiated in 1996 to serve the chemical sector as a regular event dealing with issues of regulatory affairs.CHEMCON 2023 was the 76th annual session of the Indian Institute of Chemical Engineers,organised by Indian Institute of Chemical Engineers Headquarters,Kolkata from December 27 to december 30,2023 in association with Heritage Institute of Technology,Jais,Jadavpur University and Rajiv Gandhi Institute of Technology.Our college Heritage Institute of Technology felt honoured to get the opportunity to organise this mega event after 16 years.The theme of CHEMCON-2023 is "Energy Transition: Challenges and Opportunities"Calcutta University.

EVENTS:

Memorial Lectures: Three memorial lectures ,namely Dr. H.L.Roy Memorial Lecture(the Founder President),Prof.N.R.Kamath Memorial Lecture(a distinguished professor associated with the University Institute of Chemical Technology,Mumbai,and IIT,Mumbai.

Shri Dhirubhai Ambani Commemoration Day: Every year,the day of 28 December is observed as Dhirubhai Ambani Commemoration Day on the occasion of his Birth Anniversary of the late Shri Dhirubhai Ambani and the Dhirubhai Ambani Oration on varied topics is delivered by eminent personalities of the country to celebrate the occasion.

Technical & Parallel Sessions: During CHEMCON,several technical and parallel sessions are held.Lecture sessions comprises of CHEMCON Distinguished Lectures,invited lectures,and paper/poster presentations.

Joint Symposiums: The aim of the symposiums is to exchange knowledge,insights,sharing views amongst each other to discuss and explore future challenges in delivering research results to society and to strenghten research networks.

Industrial Exhibitions: Industrial Exhibitions are usually organized so that organizations in a specific interests or industry can showcase and demonstrate their latest products,service,study activities of competitors and examine recent trends and opportunitues.

TECHNICAL SESSION:

1.Energy and Environment (EE): Energy Transition & Decarbonisation; Sustainable Energy Generation & Environment; Hydrogen Energy and Fuel Cells (Solid oxidized fuel cells); Solar Photovoltaic Cell and Solar Thermal Energy; Biomass Energy, Innovations in Energy-Measurement; Policy Analysis & Interventions; Technological Advancements & Alternatives Energy; Waste to energy; CO_2 reduction & sequestration; Electrochemical reduction of CO_2.

Transformation for Energy Transition (TET): Hydrogen Production from various routes, Storage, Transportation and its Application; Catalysts for energy conversion, Li-ion Battery; Redox Flow Battery; Electric Vehicle and its advancement; Grid Scale Energy Storage; Solar PV and Solar Thermal Energy; Wind Energy; Tidal energy; Geo-Thermal Energy; Battery Management System; Bio fuels.

2.**Advanced Nano-Materials & Nanotechnology (ANN):** Synthesis of nanomaterials; Nanophotonics and Nanoelectronics; Nanobiotechnology; Nanomagnetism; Self assembly of nanomaterials; Nanoparticles for Biomedical Applications; Nanofibers and Nanotubes; Gold Nanoparticles and Carbon Nanotubes; Application of Functional Nanomaterials and 2D Materials; Synthesis, Characterization and Applications of Sustainable Advanced Nanomaterials; Novel Green Nanotechnologies Applied in Environmental Protection and Health; Quantum Dots.

3.Water and Wastewater Treatment (WWT): Wastewater treatment technologies: Zero Discharge Liquid (ZLD), Ultrafiltration, Nanofiltration, UV; Arsenic removal; Reverse Osmosis; Ceramic & Polymeric Membranes; Solar powered micro filters; Safety and Quality of Underground Water; Industrial & agricultural Wastewater Treatment; Sedimentation, filtration and oxidation; Water reclamation; Water cycle.

4.**Advanced Chemical Engineering (ACE):** Carbon Capture and Sequestration; Computational Fluid Dynamics Polymer Engineering and Technologies; Catalysis and Reaction Engineering; Chemicals and Fertilizers; Novel Separation Processes; Crystallization, Filtration & Drying; Novel Drugs; Instrumentation and Process Control; Upstream and Downstream Petroleum Processes; Membrane

5.**Separations; Membrane Technology**; Process Modeling Simulation and Optimizations; Wastewater Treatment; Industry 4.0; 3D-Printing; Applications of Machine Learning & IoT in Chemical Engineering.
Advanced Polymer and Composite (APC): Polymer composites in electronic mobility; Polymer composites in aviation and aerospace applications; Multifunctional polymer composites in artificial intelligence; Sustainable green composites; Fire-retardant lightweight composites for battery applications; Biomimicked polymers and their applications; Processing, Modeling, and Properties of advanced polymer and composites.

6.**Biochemical and Bioscience Engineering (BBE)**: Biomass, Biofuel, and Bioenergy; Bioresource Technology for Bioenergy; Environmental Biology; Sustainability and Biodiversity; Brewing and food technology; Fermentation; Food safety and its analysis; Food production and engineering; environmental biotechnology; biochemical engineering; cell and tissue engineering; protein engineering; biomedical engineering; and bioinformatics; Biosensors; Biosynthesis and production.
Our college organised this mega event after 16 years and proudly said that our college became successful to make this event resplendent.Our beloved faculty members,students did a great job otherwise this event couldn’t be triumphant.

ICRESS 2024

ICRESS 2024

The “International Conference on Renewable Energy with Sustainable Solutions (ICRESS24)” a two day international conference that took place on 24th & 25th of July 2024 at Heritage Institute Of Technology, Kolkata. This is basically a platform for researchers, practitioners, and industry experts to come together and exchange ideas on the most pressing issues in renewable energy and sustainability. This conference served as a dynamic forum to discuss the latest innovations, challenges, and opportunities in the field of renewable energy, with a focus on achieving a sustainable future.

The conference had mainly related to design, analysis and optimization of energy harvesting processes from renewable resources and their applications in energy production, distribution with a focus on environmental impact, sustainability and other critical issues encountered in engineering applications in renewable engineering around the world. Along with this main theme, the conference will also cover important but nascent areas in Renewable energy Research such Advanced Energy Storage Technologies, Hydrogen as an Energy Carrier, Next-Generation Solar Technologies, Offshore Wind Energy, Energy-Positive Buildings and Communities, Smart Grid 2.0, Green Hydrogen production, Circular Economy for Renewable Technologies etc.

There were paper presentations, poster presentation based on a wide range of topics related to renewable energy and sustainability like energy storage and grid integration, global transition to clean energy ,solar ,wind ,hydro and bio energy technologies etc.

ICRESS 2024 hosted under - **IICHE**
prof. Dr. Diptendu Datta (convener ICRESS)
prof. Dr. Sangita Bhattacharjee (convener ICRESS)

The invited guests on 25th July were:-

1. Prof.(Dr.) S.V.A.R. Sastry
(HBTU, Kanpur)
Topic: Promoting Environmental Sustainability Through Green Chemistry
2. Prof.(Dr.) Rituparna Samanta
(University of South Florida, USA)
Topic: An implicit model-based integrated framework to advance membrane protein structure prediction and design.
3. Prof. (Dr.) Hiralal Pramanik
(Dean (Resource & Alumni) & Associate Dean (Faculty Affairs) IIT-BHU)
Topic: Recent Advances in Materials Development for Sustainable Power Generation from Low Temperature Fuel Cells.

4. Dr. Ishita Sarkar
(Scientist, CSIR-CMERI, Durgapur)

Topic: Enhancement of syngas production and hydrogen
content in syngas from catalytic slow pyrolysis of
biomass in a pilot scale fxed bed reactor
5. Prof. Nandor Nemestothy
(University of Pannonia, Hungary) (online)
Topic: The Role of Membranes in Renewable Energy Production.

CHEMSPARK'24

CHEMSPARK2024

Chemspark 2024 was a one-day programme that aims to provide a platform for students and professionals in the field of chemical engineering to come together and share ideas and knowledge.
Chemspark was hosted under- **Prof. (Dr) Sulagna Chatterjee (Chairperson Chemspark).**

Prof. (Dr) Abhyuday Mallick (convener chemspark)

Prof. (Dr) Aparna Ray Sarkar (convener chemspark)

This years chemspark consisted of the following events-

- Inaugural programme.

- Workshop On "Introduction to molecular simulation" by **Dr. Monojit Chakraborty (**AssistantProff. Department of chemical engineering, IIT Kharagpur).

- Technical Quiz Competition.

The inauguration commenced with a welcome address by **Prof (Dr) Sulagna Chatterjee,** HOD of Chemical Engineering Department, HITK, where she talked about the department of Chemical engineering, HITK, its achievements and importance of chemspark 2024. This was followed by Lighting of the lamp ceremony.

The distinguished dignitaries who participated in the lighting of the lamp ceremony were**- Prof. (Dr) Basab chowdhury,** Principal of HITK, Mr. Sisir Chakraborty, Honorary Secretary of IICHE, Calcutta Regional Centre, Our esteemed Chief Guest **Mr. Deepak Sen Chowdhury** President R&D Exide Industry Limited., our guest of honour,

Prof. (Dr) Monojit Chakraborty, Assistant Prof, Department of CHE, IIT Kharagpur.
The session was further addressed by Prof(Dr) Basab Chowdhury followed by the esteemed dignitaries.

The distinguished Guests were then felicitated for their various contributions in the field of engineering and education.

Prof (Dr) Basab chowdhury, Principal, HITK felicitated our Chief Guest, Dr. Deepak sen chowdhury, President R&D Exide Industry Limited .

Prof. (Dr) Sulagna Chatterjee, HOD of Chemical Engineering Department, HITK, felicitated, our guest of honour, Prof. (Dr) Monojit Chakraborty, Assistant Prof, Department of CHE, IIT Kharagpur.

Prof(Dr) Pinaki Bhattacharya felicitated Mr. Sisir Chakraborty, Honorary Secretary of IICHE, Calcutta Regional Centre.

The Inaugural session was concluded with a vote of thanks by Prof(Dr). Abhyuday Mallick, Department Coordinator, ChE, HITK., dedicated to our principal and HOD, and all the esteemed dignitaries who graced the session.

Events-

- The days events commenced with a workshop on "Molecular Simulation" conducted by Dr Monojit Chakraborty, Asst prof ChE department, JIT Kharagpur, inviting all the second and third year students of our department.

- A Technical Quiz Event was conducted by Prof(Dr) Abhyuday Mallick, as the Quizmaster. The teams battled with their knowledge.

Workshop Topic : Molecular Simulation

Molecular simulation is a computational technique used to model and study the behavior of molecules at the atomic and molecular levels. By employing methods like molecular dynamics (MD) and Monte Carlo (MC) simulations, it helps researchers understand complex phenomena such as protein folding, chemical reactions, and material properties. These simulations rely on physical principles, such as quantum mechanics and classical mechanics, to predict molecular interactions and dynamics under various conditions. Molecular simulation plays a vital role in fields like drug discovery, materials science, and biophysics, providing insights that are often difficult or impossible to achieve experimentally.

INDUSTRIAL VISIT 2024

DEPARTMENT OF CHEMICAL ENGINEERING
(2ND YEAR)

The students of department of chemical engineering of HERITAGE INSTITUTE OF TECHNOLOGY went on a one day industrial visit to **IVL DHUNSERI PETROCHEM LIMITED, sitd in Haldia, on 6th November 2024.**

IVL Dhunseri Petrochem Industries Pvt. Ltd. manufactures the finest bottle grade PET resin, for packaging of drinking water, carbonated soft drinks, edible oil, pharmaceuticals and many more. The Company has two PET resin plants in Haldia (port town in West Bengal) with an effective capacity of 4,80,000 TPA and one PET resin plant in District Karnal in the State of Haryana with an effective capacity of 2,16,000 TPA. So that total capacity of both the units is around 7,00,000 TPA. The product of the Company are being marketed and sold with trademarks owned by Indorama Ventures Public Company Limited (“IVL”), holding company of IVGS “RAMAPET” and by DPL “ASPET” in around 55 countries across the Indian sub continents, North America, South America, the European Union, the Middle East, Eastern Europe and North Africa.

The senior executives of the company welcomed us wholeheartedly and spent their valuable time on making us understand the production system. They also told us the use of technology in the field of PET production and the use of lab operations .Our teachers Sir AVIJIT GHOSH and Sir ABHYUDAY MALLICK helped us understand the concepts more clearly. All the students not only enjoyed the industrial visit but also learned a lot about the working principle of IVL DHUNSERI PETROVHEM LIMITED.

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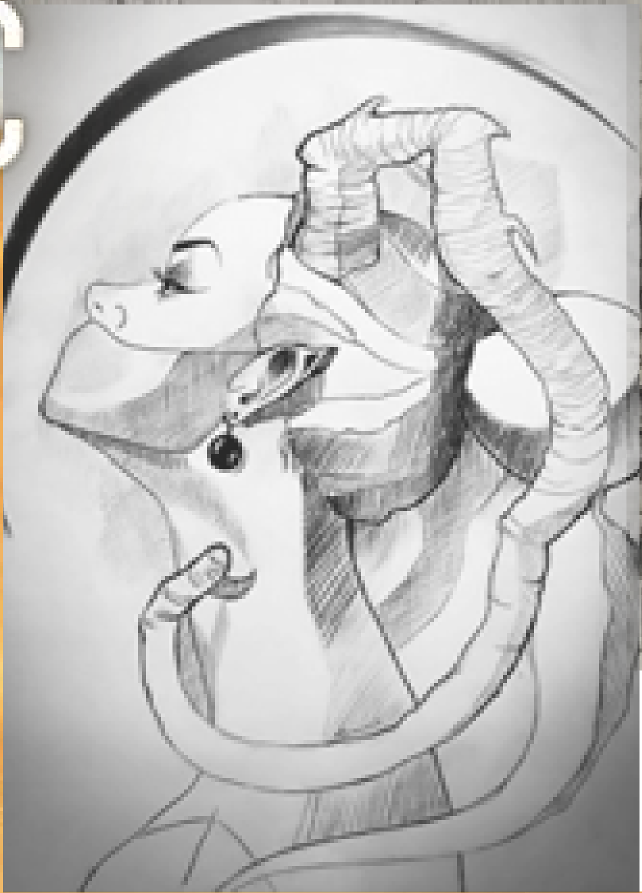


Debojit Seal
2nd year

Tirthotoya Haldar
2nd year

Sriza Ghosh
2nd year

AMRITA BOSE
2nd year

Shaptarshi Das
2nd year

Koduru Siddhant
2nd year

Soumili Basak
2nd year

Sachin Yadav
2nd year

Piyush Ranjan
2nd year

Abhishek Kumar Singh
2nd year

SHUTTER STOCK

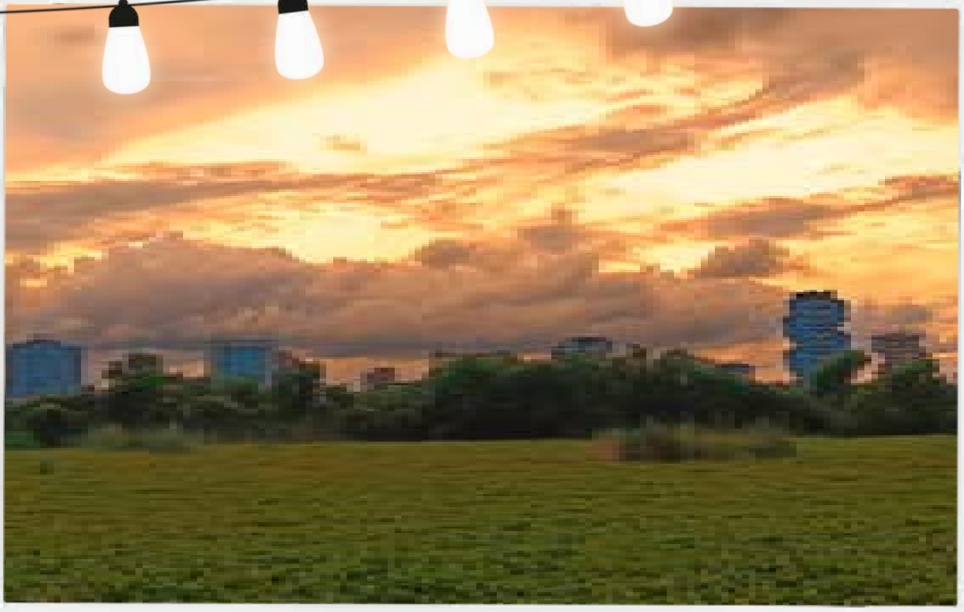
Soloni Mukkharjee
2nd year

Agnir Ghose
3nd year

Anuska Saha
1st year

Barsha Deb
2nd year

koduru Siddhant
2nd year



Pritam Dhara
2nd year

Aditya Chatterjee
1st year

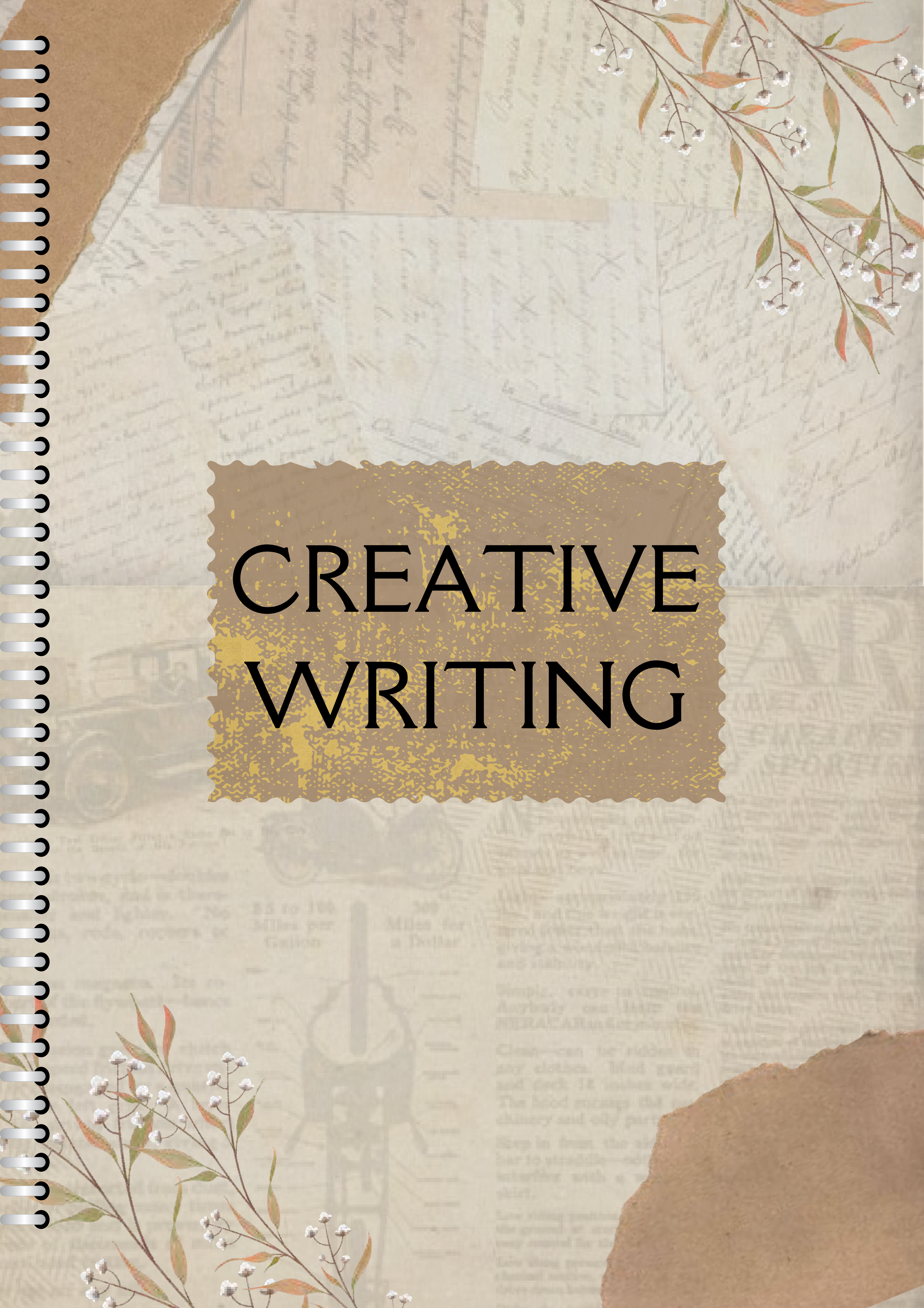
Sriza Ghosh
2nd year

Amrita Bose
2nd year

Shaptarshi Das
2nd year

Souvik Roy
2nd year

Devaditya Goswami
2nd year



CREATIVE WRITING

THE WEIGHT OF SILENCE

The library was always quieter in the morning, before the world crowded in. He sat in the same place, notebook open but empty. He wasn't writing; he was just waiting, his pen lingering in his fingers, as though he expected something to happen. The air smelled faintly of old paper and dust, a perfume that seemed to settle into the silence itself.

She noticed him, of course, though she didn't want to. The chair was hers, but it felt like he had been sitting there for longer than she had been coming. Still, she didn't leave. There was something about the stillness he carried, like an invisible wall between him and the rest of the world.

"You're in my spot," she said, more to fill the silence than anything else.

He looked up, his face too calm, like it had forgotten how to express anything. "I didn't think it was yours."

She didn't argue, just sat down.

They didn't speak at first, as if their presence was enough to fill the space. Her eyes would wander over the books, his hand would hover over the paper. Sometimes, they would glance at each other, but neither acknowledged it. It wasn't awkward, though. The silence between them had its own texture—unspoken yet alive.

"What are you writing?" she asked, breaking the quiet one day. Her voice felt almost too loud for the space.

"Nothing worth mentioning," he answered, his voice steady but faint.

"Why write it, then?"

He didn't look up, but his hand froze. "To remember. Or maybe to forget. I'm not sure which yet."

She could feel the weight of his words, even though they didn't say anything. It was the kind of answer that left more questions than it resolved, yet she didn't press. There was something in his tone that suggested the conversation couldn't go further, even if she wanted it to.

The mornings passed like that, filled with the kind of stillness that made her feel both present and distant. She found herself lingering longer, even when she had nothing to do, as though her presence might coax something more out of him. One day, she noticed his hand trembling, his pen slipping in his fingers, like the paper couldn't hold the weight of what he was trying to write. "Are you okay?" she asked, but the question felt too simple, too obvious.

He didn't answer right away. His gaze remained fixed on the page, the ink smudged where his hand had faltered. "Some things break so easily," he said slowly. "Others... they just bend until they don't anymore."

The answer wasn't what she expected, but it felt like the right one. She wanted to say something, to ask what he meant, but the silence returned, heavier now. The moment passed, and they didn't speak again that day.

And then, one day, he wasn't there.

At first, she thought he was just late. But the next day passed, and then the next. The chair remained empty. She told herself it didn't matter, that she barely knew him. Yet she found herself waiting, her eyes drifting to the door every time it opened.

It was on the third day that she found a piece of paper tucked under the edge of the table. Her heart caught in her throat as she unfolded it.

I thought silence would be easier than noise, but it's not. It just sits there, like something you can't see, but it presses against you until you can't tell where you end and it begins.

I've been writing, I guess. Writing things that don't make sense, but they're mine.

I'm sorry if I've taken up too much of the space you wanted.

The note didn't explain anything, but it was enough. She read it several times, as though the weight of it might shift, might make sense. But it didn't. There was something in the note, some finality, that couldn't be fixed.

She didn't leave. Instead, she waited, as though waiting could make the silence easier, or maybe less obvious. The chair across from her stayed empty, but somehow, that was the only thing that felt like it could stay.

Weeks passed, and she continued coming to the library each morning. The emptiness across from her grew familiar, though not comfortable. She started bringing her own notebook, filling the silence with words she wasn't sure anyone would ever read. At first, they were just fragments—thoughts, questions, echoes of the conversations they'd had. But slowly, they became something more.

One morning, she noticed a new book on the table. It hadn't been there the day before. Her name wasn't on it, but somehow she knew it was for her. The cover was plain, unmarked, but when she opened it, she found page after page of handwriting she recognized.

He had been writing all along. Stories, observations, puzzles without solutions. Some pages were smudged, the ink blurred where his hand had trembled. Others were pristine, the words so carefully written they almost seemed like they belonged to someone else. She read until the library closed, losing herself in his labyrinth of thoughts.

The words didn't always make sense, but they hinted at something larger, something she couldn't quite grasp. A recurring phrase caught her eye: "There is no edge to the mirror." It appeared in different contexts, scattered through the pages, each time feeling like a clue to something unseen.

The next day, she brought the book back, but this time she added her own pages. She slipped them inside, tucking them between his words. It felt strange, like a conversation they were having across time and space. She didn't know if he would ever see them, but it didn't matter. For the first time, the silence felt shared, not empty.

Months turned into seasons, and the library became their unspoken meeting place, even though he never returned. She continued writing, filling the notebook with pieces of herself. Each page felt like a step closer to understanding something she couldn't quite name. The weight of his absence remained, but it no longer felt so heavy.

One evening, as the sun dipped below the horizon, she found another note. It was tucked inside her notebook this time, the handwriting unmistakable.

The mirror bends but doesn't break. You're part of the reflection now.

She stared at the note, her breath catching. It wasn't an answer, but a question folded into a statement, as if daring her to look deeper. For the first time, she felt the vastness of what she didn't know, the edges of an understanding that would always remain just out of reach.

She left the library that night, the notebook clutched tightly in her hands. The silence in the air felt different now, like a pause instead of an end. The questions lingered, unanswered but alive, stretching out into the infinite.

The story was complete. And yet, it wasn't.

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পুরনো দিন

-দেবজিৎ শীল~

হয়তো আর ফিরে আসবেনা সেই দিন,

সকাল ছটায় মা বাবার বকায় ঘুম থেকে ওঠা..
বাবার হাত ধোরে পিঠে ব্যাগ নিয়ে স্কুল যাওয়া..
কাঁদতে কাঁদতে স্কুলের গেটে ঢোকা..
কড়া রোদ্দুরে অ্যাসেম্বলি লাইনে দাঁড়িয়ে জন-গণ-মন গাওয়া..
টিফিন ব্রেকে বন্ধুদের সাথে গল্প
শেষ পিরিয়ডে ক্লাসের পিছনে বসে হ্যান্ড ক্রিকেট..
ছুটি হলেই দৌড় স্কুলের সেই ফেমাস ক্যান্টিন,

হয়তো আর ফিরে আসবে না সেই দিন।।

ভেজা গায়ে মাঠে ফুটবল খেলা..
বাড়ি ফিরে মায়ের জুতোর মার খাওয়া !
স্কুলের সেই রেগুলার হোমওয়ার্ক আর হতো না শেষ,
মায়ের ঝাটার বাড়ি খেতে খেতে অভ্যাস হয়ে গেছিল বেশ!
আটটা থেকে কার্টুন নেটওয়ার্ক, দশটা হলে মিস্টার বিন..

হয়তো আর ফিরে আসবেনা ছোটবেলার সেই দিন।।

মাধ্যমিকের পর যেন আবার নতুন জীবন..
সাইন্স নেব না কমার্স ?
এই চিন্তায় থাকতাম সারাক্ষন।
আস্তে আস্তে বাবা-মায়ের থেকে দূরে চলে যেতে হল,
আনন্দ মজা গুলো যেন সব হারিয়ে গেল।
উচ্চমাধ্যমিক শেষ
ছেলেমেয়েরা এবার যাবে অন্য দেশ..
স্কুল থেকে বেরোনোর পর যেন জীবনটা হলো আরও কঠিন..

হয়তো আর কখনোই ফিরে পাবোনা সেই পুরনো দিন।

শুরু হলো কলেজ লাইফ,
এই ভিড় শহরে ব্যস্ততার মাঝে নিজেকে গড়ে উঠতে হবে,
মা-বাবার বুকটা গর্বে ভরিয়ে দিতে হবে,
বাবার সাথে এবার সংসারের বোঝ তুলতে হবে,
নির্ভরতার জীবন কাটিয়ে এবার দায়িত্বশীল হতে হবে,
সামনে নতুন পথ নতুন রাস্তা
নতুন যুদ্ধের হতে হবে সম্মুখীন..

স্মৃতি হয়েই রয়ে গেল আমাদের ছোটবেলার পুরনো সেই দিন।।

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CLASS PHOTOGRAPHS

1st year

2nd year

3rd year

4th year

TEAM
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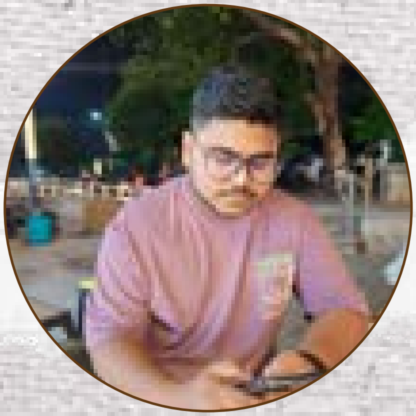

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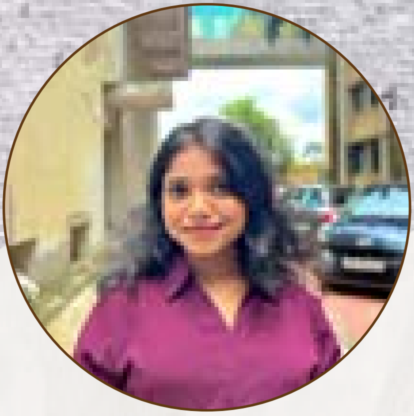

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