FUTURE OF ENERGY: FUNDAMENTAL EDUCATIONAL PERSPECTIVES ON ENERGY CONVERSION, TRANSFER, STORAGE, AND CONSERVATION

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ABSTRACT

Multidisciplinary non-linear learning in higher education could be a foundation for creative and innovative ideas in science, engineering, and technology. This article presents fundamental perspectives on energy conversion, transfer, storage, and conservation. The overall educational perspectives help in understanding some basic principles, analyzing different factors/parameters, and making research decisions that contribute to the ever-growing sustainable global energy demand. The large-scale investment in green energy areas such as windmills, solar panels, batteries, and electric vehicles by multinational companies worldwide would improve global energy security. *[African Journal of Chemical Education—AJCE 16(1), January 2026]*

INTRODUCTORY PERSPECTIVES

The capacity to perform work or cause change is called energy. There are two forms of energy; potential energy and kinetic energy. Potential energy (PE) is the energy of an object caused by its position, composition, or condition. A duster held above the ground has a PE because of its position relative to the ground. The energy stored in the chemical bonds of a substance such as coal can be used to run a steam engine. When a coiled spring is compressed or stretched, its elastic PE increases. The energy of an object in motion is called kinetic energy (KE). A car traveling down the road has kinetic energy. The stored energy of water in a pond can become kinetic energy if the pond's edge breaks due to heavy rains, causing enormous destruction. The various types of energy include chemical, electrical, light/radiant, nuclear/atomic, magnetic, mechanical, sound, and thermal/heat energy. Chemical energy is stored in the bonds of molecules like biomass, coal, natural gas, and petroleum. Electrical energy is a form of kinetic energy resulting from the flow of electric charge and can be used to power electrical devices. The energy carried by visible light and infrared radiation is called radiant energy. The energy released during nuclear fission or fusion is known as nuclear energy. The energy created by the strength of a magnetic field is called magnetic energy. Mechanical energy is the sum of the kinetic energy and potential energy stored in a system by the position of its parts. Sound energy is a form of energy that can be heard by living things. The energy contained within a system that is responsible for its temperature is thermal energy. Green energy, such as biomass, geothermal, solar, and wind, is considered the cleanest form of energy. Energy can be broadly divided into renewable energy and non-renewable energy. The energy that comes from resources that are naturally replenished on a human timescale is known as renewable energy. Resources that exist in limited supply cannot be replaced in our lifetime and will eventually run out are called non-renewable resources. Solar, wind, hydro, tidal, biomass, and geothermal energy are renewable energy sources while nuclear energy, oil, natural gas, and coal are examples of non-renewable energy sources. A significant shortage of energy resources or an abrupt increase in prices can result in a global energy crisis with a negative impact on social, economic, and environmental sustainability. Common causes of energy shortage include overconsumption, overpopulation, poor energy infrastructure, lack of storage, wars and attacks, energy waste, poor power distribution, major natural calamities, and politics of border obstruction.

Global energy perspectives, energy reserves and resources, the energy transition, energy technology perspectives, sustainable energy resources, energy trends and challenges, and energy management systems provide insight into the evolving global energy market and world energy outlook for a better tomorrow [1-4]. Most of the global energy supply comes from fossil fuels such as coal, natural gas, oil, and petroleum. Rapid industrialization, rising living standards, and a growing world population are expected to increase global energy demand, and the international energy agency (IEA) predicts nearly double power demand by 2050 [5]. The transport sector is expected to grow faster over the next decade, driven by electric vehicles. Power demand in the industry and buildings is expected to double by 2050. Hydroelectric power is the largest renewable energy resource and with technological advancements and improved efficiency and environmental performance, global hydropower expansion is expected to slow growth. Similarly, tidal energy has the potential to contribute significantly to total power output. Global energy consumption will continue to grow in the future, and the ability to provide a reliable, eco-friendly, and affordable energy supply to consumers in the future is challenging, considering the interests of energy exporting and importing countries. Other factors that affect global energy security include conflicts and tensions, economic coercion, and cybersecurity.

Energy studies contribute significantly to the current body of literature by examining its vital role in economic development, environmental sustainability, social equity, energy technologies, and policies. Renewable energy adoption can act as a catalyst for sustainable economic growth [6,7]. It is essential to have reliable and affordable energy sources to have dynamic economic activities and ensure energy stability. The significance of the energy sector's role in achieving the sustainable development goals (SDGs) is clear when we consider clean energy and climate action connections. It is important to develop green energy technologies, policies, and practices for reducing global greenhouse gas (GHG) emissions and alleviating climate change [8,9]. The environmental benefits of renewable energy sources in conserving natural resources and reducing pollution are enormous. Enhancing energy conversion efficiency and sustainable energy practices will help decrease energy consumption and promote resource conservation. Equitable access to energy resources by marginalized communities, gender and energy access, and the social impacts of energy transitions, including community displacement and employment losses, need to be examined thoroughly [10,11]. Finally, energy policies and regulations, technological development, and modeling of energy systems' performance in sustainable energy transitions are crucial [12,13]. This brief article explores the perspectives on trending and evergreen topics of energy to rekindle the lamp of learning and raise general awareness. These multidisciplinary energy perspectives help the learners broaden their mental horizons on their learning journey. The authors emphasize the need for innovative teaching strategies to enhance learners' performance and interest in energy science and technology, as it is a crucial global topic. The manuscript aims to introduce informal and non-formal education techniques as a creative tool for building self-confidence and subject understanding among young learners.

ENERGY TRANSFORMATIONS (ET)

Energy transformation is the changing of energy from one form to another, while its transfer is the passing of energy from one object to another/one point to another. The changing of potential energy to kinetic energy or vice versa is one of the most common energy transformations. When objects fall to the ground, their height decreases, and hence their PE decreases. It is converted into KE as the velocity of the object increases. A falling asteroid to Earth at incredible velocity has a tremendous amount of kinetic energy. The chemical energy is converted into mechanical energy in the car/propulsion engine. The chemical energy of food is transformed into mechanical energy to move our muscles and thermal energy to maintain our body temperature. Electrical energy is converted into light/heat energy in the bulb and sound/light energy in televisions. A toaster changes electrical energy to thermal energy. Chemical energy is converted into electrical energy in a battery. The light energy is used in photosynthesis to generate the chemical energy of plants. Food and fuel are forms of stored chemical energy. Chemical bond-breaking results in energy release while bond-making requires energy. Nuclear energy is converted into electrical energy in power reactors. Photovoltaic devices convert radiant energy into electrical energy. Solar water heaters convert light energy into thermal energy. An alarm clock converts electrical energy into sound energy. The kitchen blender transforms electrical energy into mechanical and sound energy. The hair dryer converts EE into thermal/mechanical energy. A fan converts EE into mechanical energy, and a motor converts EE into mechanical energy, operating in a rotating mode. A microphone converts sound energy into electrical signals, while a loudspeaker transforms electrical energy into sound waves. A transducer device converts mechanical energy into electrical signals. Turbines generate electricity by transforming the kinetic energy of moving water into mechanical energy that is then converted into EE. Wind turbines convert the KE of the spinning rotor into EE. Mechanical energy from tides and waves in the ocean is a renewable energy resource to generate electricity. The above examples of energy transformations provide a comprehensive approach to understand/analyze/apply energy conversion outlook to develop an overall energy production perspective [14-16].

ENERGY TRANSFER PROCESS (ETP)

Thermal energy transfer from warmer points to cooler ones/a system and its surroundings occur in three modes. i) 'conduction' is the energy transfer by the collision of particles (mostly in solids), i.e., energy flow from direct contact. It requires physical contact between the bodies or portions of bodies exchanging heat, ii) 'convection' happens with currents moving through liquids/gases. It occurs when a liquid/gas is in contact with a solid body at a different temperature and is always accompanied by the motion of the liquid/gas, and iii) 'radiation' energy transfer takes place through space, i.e. energy radiating from an object into surroundings (e.g., energy from the Sun). It does not require contact or the presence of any matter between the bodies. Thus, the three energy transfer mechanisms involve surface-to-surface, surface-to-air, and direct exchange across space. Normally, heat transfer occurs by a combination of these three types randomly. In an electrochemical cell, the reactant species is transported to the electrode surface by processes like diffusion, migration, and convection from the bulk of the solution. Diffusion current arises because of a concentration gradient, migration current occurs due to the movement of charged particles along an electric field, and convection current involves physical movement (stirring). In another energy transfer process, a fan uses electrical energy to move its blades, creating movement in the air that produces a cooling effect. In resonance energy transfer (RET), energy is transferred from one molecule to another through dipole-dipole interaction. For instance, a light photon can excite a fluorescent molecule (donor), which then transfers its excess energy (excited molecule) to another molecule (acceptor) [17-19]. This optical process is widely used in studies of biomolecular structure and dynamics and is also known as fluorescence resonance energy transfer (FRET). Processes involving energy transfer occur widely in science, ranging from simple redox reactions in chemistry to processes that drive energy storage and respiration in complex biological systems.

ENERGY STORAGE SYSTEMS (ESS)

An energy storage system captures and stores energy from various sources for later use [20-22]. It can store energy in different forms such as chemical, electrical, mechanical, thermal, and electromagnetic. In small-scale systems such as computers/watches/uninterruptible power supplies (UPS), batteries store energy as a chemical reaction that is released as electricity. In large-scale systems, solar panels/heat pumps store thermal energy for later use. Mechanical energy storage systems use kinetic or gravitational forces to store energy. Flywheel energy storage systems and compressed air energy storage are typical examples. Superconducting magnetic storage systems store magnetic energy. These ESS can help make better use of renewable energy sources and can be clubbed with other resources to improve their economic efficiency. They can make the electric grid more stable and reliable to balance energy supply and demand. A power conversion system converts alternating current to direct current (AC/DC), and inverters convert DC to AC, used to power electronic devices and household appliances when the main power is not available. A rectifier is used to supply DC power to recharge the batteries when the main power is restored. Long-duration energy storage council (LDESC) in its annual report emphasizes that energy systems must have the capacity to store excess energy during peak production times and release it during peak demand [5]. There is an immediate requirement to scale up of long-duration energy storage solutions to meet global climate goals and to achieve a dedicated energy storage target of 1.5 terawatts by 2030.

ENERGY CONSERVATION PRACTICE (ECP)

The global transmission and distribution (T & D) losses (technical and commercial) are about 8 % of electric power output. ECP involves energy consumption analysis and benchmarking, energy management systems, electric company bill management, and energy conservation projects to reduce end-use energy consumption [23-25]. For instance, turning lights off when not required, either manually/with timers/motion sensor switches, is an energy conservation measure, it is the decision and practice of using less energy. Other practices that reduce the amount of energy used include using LED bulbs, unplugging appliances when not in use, skipping the dryer on a breezy day, and setting the refrigerator/freezer to a slightly higher temperature. ECP can help reduce energy bills, greenhouse gas emissions, and demand on the electric system. Using lightweight cookware/dishes, cleaning light bulbs, using task lighting, walking instead of driving, and using energy-efficient bulbs/appliances/vehicles are other examples of changing behaviors or using technology to reduce energy consumption. Renewable energy replaces traditional fuels in electricity generation, air/water heating/cooling, motor fuels, and rural energy services. Less use of non-renewable sources of energy causes less pollution of the atmosphere. Renewable energy usage is essential because of the unreliability of non-renewable resources (depletion of oil wells) and increasing oil prices. The development of renewable energy technologies is essential, considering the environmental aspects of energy utilization. Regular maintenance and upgrades, energy management systems, waste heat recovery, supply chain optimization, process redesign, employee engagement, system optimization, and the use of renewable energy in industrial settings enhance energy efficiency and save a lot of energy. Investment in technology, visionary planning, education and training, industry-institute collaboration, policy advocacy, employee engagement, and performance tracking play a pivotal role in energy efficiency management.

CURRENT GLOBAL ENERGY SCENARIO

At present, the global electricity generation mix includes renewables (hydro, solar, wind, geothermal, 12.6 %), natural gas (24.7 %), coal (27.2 %), oil (31.2 %), and nuclear (4.3 %) of the global energy supply. Global electricity demand in 2024 is 4.3 % of the global energy supply [3, 26]. Global energy consumption is primarily divided into fossil fuels (oil, coal, and natural gas), nuclear, and renewable energy (hydropower, solar, wind, hydrogen, geothermal, and bioenergy). Currently, fossil fuels dominate the energy mix, with oil being the largest single source, followed by coal and natural gas, and there is a continued challenge of transitioning away from these polluting energy sources. Nuclear energy contributes a smaller but still significant portion, while renewables are a growing but still relatively smaller part of the global energy supply. Global electricity demand is growing rapidly, driven primarily by wind and solar energy. It is important to note that the share of different energy sources varies by region and country, with some relying more heavily on certain sources than others, and the global energy mix is constantly evolving, with renewables experiencing significant growth in recent years. Renewables (wind and solar) are expected to continue growing, with some projections showing renewables-based electricity generation overtaking coal-based thermal power generation by 2030. Electrification of sectors like transport, heating, and industry is a major driver for decarbonization, leading to increased global electricity demand. Asia has experienced significant growth in energy demand and remains heavily reliant on fossil fuels, especially coal. Conversely, advanced economies are seeing declines in fossil fuel consumption and faster adoption of green and clean energy. Meeting climate goals will require significant acceleration in renewable energy deployment, green grid infrastructure development, and energy efficiency improvements. Current geopolitical events and energy crises have brought energy security to the forefront, influencing national energy strategies and sometimes slowing the pace of the energy transition [27-29].

The global energy landscape is undergoing a significant transformation. This scenario is driven by population growth, increasing demand in emerging economies, and the urgent need for energy security and cleaner energy sources. Key trends include a projected increase in total energy demand, a shift towards renewable energy, especially solar and wind, and a focus on transitioning to net-zero emissions. Geopolitical factors, such as conflicts and realignments, are increasingly impacting the energy sector, affecting both energy supply chains and investment decisions. The need to reduce greenhouse gas emissions and mitigate climate change is a major driving force behind the shift towards cleaner energy sources and the pursuit of net-zero emissions trajectories. Ensuring a stable and reliable energy supply is crucial, particularly in the face of increasing demand and potential disruptions. Energy consumption patterns vary significantly across regions, with developed countries typically having higher per capita consumption than developing countries. Energy scenarios are used to explore potential future pathways for the energy system, considering various factors like technological advancements, policy changes, and economic growth. The green energy transition requires balancing the need for affordable and secure energy with the imperative to reduce emissions and protect the environment. Continued research and innovation in renewable energy technologies, energy storage mechanisms, and energy conversion efficiency are crucial for enabling a successful green transition [30-32]. Governments play a pivotal role in setting policies that incentivize renewable energy development, promote energy conversion efficiency, and phase out all fossil fuels. Addressing the global energy challenge requires international cooperation and collaboration to share knowledge, technologies, and resources. In essence, the global energy scenario is characterized by a complex interplay of factors, including growing demand, the rise of renewables, the continued reliance on fossil fuels, and the urgent need to address climate change. Navigating this complex landscape requires a multifaceted approach involving technological innovation, progressive policy changes, and multilateral global cooperation.

ENERGY PROSPECTS AND OUTLINE

As the impacts of climate change are more visible now than before, the unwavering commitment of all nations worldwide to build a cleaner and greener planet has never been more critical. Green hydrogen mission, production-linked incentives (PLI) schemes for solar photovoltaic modules, and a focus on renewable energy to enhance energy generation capacity can drive meaningful change. A journey toward clean, sustainable energy solutions involves embracing new and innovative approaches to clean energy transition to reduce reliance on fossil fuels and enhance social well-being. There is an urgency for nations to accelerate their shift toward green energy to achieve long-term climate objectives. This will reduce carbon footprints (net-zero emissions target), create huge economic opportunities, and provide energy access in remote locations. Investing in clean energy sources like battery storage, green hydrogen, solar, and wind power in the commercial and industrial segments could create a mega-market opportunity. Technological advances coupled with bold policy actions can help address the challenges of eco-degradation and energy security, leading to a green transition. It is essential to enhance environmental awareness, improved accessibility, and implement energy-saving initiatives where consumers are ready for efficient options to benefit from long-term cost savings and satisfaction of contributing to sustainability efforts.

As the oceans cover 75 % of Earth's surface, thermal energy conversion from the Sun's heat and mechanical energy from tides and waves is the largest renewable energy source that should be exploited to contribute to energy security and reduce greenhouse gas emissions. Biomass renewable energy resources, such as trees, branches, paper, and microorganisms, must be used to generate biofuel on a mass scale to contribute to future energy needs. Governments worldwide provide incentives to promote renewables that encourage entrepreneurs to make heavy capital investments in the renewable energy sector [2, 33, 34]. Renewable solar energy can be considered an alternative to non-renewable resources like coal/oil (fossil energy). The windows/walls/floors in solar building design can be made to collect, store, and distribute heat energy in the winter and reflect solar heat in the summer. Sustainable energy meets the demands of the present generation without compromising the ability of future generations to meet their needs. Developing the most abundant solar energy resource on Earth is an important part of our clean energy future that can be used in several ways. Developing fusion reactor technology at a power plant scale to produce potentially limitless electricity is much closer than ever before to meet the globe's electricity needs, and giant companies have already invested millions of dollars to make fusion machines for generating power for factories in the next decade in a commercially relevant way [35, 36]. Energy conversion efficiencies of converted energy from chemical/electrical/radiant/thermal must be significantly enhanced to have improved energy technologies. It is essential to develop state-of-the-art technologies capable of efficient energy conversion, avoiding transmission and distribution losses, tracking individual energy usage, better implementation of energy policy framework, urgent energy transition, and delivery of concrete action with exponential speed and scale. It would have a profound impact, and sending a strong signal is critical for the future global energy security, fostering a culture of sustainability.

FUTURE OF ENERGY

Aggressive action on energy efficiency is critical to address the rising energy demands from domestic, commercial, and industrial sectors. Capacity-building efforts and powerful responses to the dual challenge of development and decarbonization are essential in the clean energy transition. Green energy gigafactories and renewable energy conversion hubs must be established across the nation to contribute to the global energy market. Raw material sourcing, skill development, increased investment in R & D, critical technological infrastructure, collaboration between government and private sector, electricity transportation issues, and cost competitiveness are other challenges to be addressed for achieving sustainable energy solutions and energy independence. Modernization across various domains, collaboration and co-development efforts, initiatives igniting a technological revolution, game-changing reforms, and the need for continuous technological upgrades are multifaceted challenges in the innovation journey, driven by dynamic, evolving policies and changing societal attitudes towards higher education. Strong energy investments in diversified energy sources, energy supply chain management, energy conservation, and setting new industry standards provide a model worth replicating. Energy development and acceleration cells can coordinate and collaborate with start-ups to translate promising ideas into practical applications, develop cutting-edge technologies, technology transfer, digital management systems, industrial automation, quality control, create new opportunities across sectors, promote responsible business practices, and supportive policies to boost efficiency and productivity.

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