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Evolution of Energy Conversion Technologies with a Focus on Emerging Fuel Cell Innovations

Mao Zedong
Department of Computing, University of Science and Technology of China, Hefei, Anhui Province, 230026, China.
maozedong12185@ustc.edu.cn

Correspondence should be addressed to Mao Zedong : maozedong12185@ustc.edu.cn

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Abstract – This paper presents a historical overview of energy-conversion technologies, tracing their evolution from early non-animal energy sources such as fire and wood to more advanced mechanical systems like waterwheels and windmills, which significantly improved efficiency and functionality in harnessing energy. It further examines the emergence of modern energy-conversion systems, with a particular focus on fuel cell technologies, including solid oxide fuel cells (SOFCs) and polymer electrolyte membrane fuel cells (PEMFCs), which offer promising solutions for efficient and sustainable power generation. The study discusses various types of fuel cells, highlighting their operational temperature ranges, efficiencies, and application domains. In addition, microbial fuel cells (MFCs) are explored for their ability to convert organic and inorganic matter into energy, although their relatively low power density remains a limitation. The paper also addresses challenges associated with portable fuel cells, particularly those related to fuel processing, purity requirements, and cost. Furthermore, it investigates the potential of advanced systems such as Alkali Metal Thermo-Electrochemical Energy Converters (AMTECs), which utilize beta alumina as an electrolyte and alkali metals like sodium or potassium as working fluids to efficiently convert heat into electricity, especially in space power applications. Overall, the study provides a comprehensive perspective on the evolution, classification, and future potential of energy-conversion technologies.

Keywords – Microbial Fuel Cells (MFCs), Alkali Metal Thermo-Electrochemical Energy Converters (AMTECs), Solid Oxide Fuel Cells (SOFCs).

I. INTRODUCTION

Energy is a fundamental principle that underlies all scientific and technical fields. An essential premise is that energy is a conserved quantity, meaning that the amount of energy in the universe remains immutable. The principle of energy conservation asserts that energy cannot be destroyed or generated, but can only be converted from one state to another. For example, chemical energy may be changed into heat, and electrical or wind energy could be transformed into electrical energy. The energy existence is crucial for the functioning of contemporary civilization. It plays a pivotal part in the development and prosperity of a country. Indeed, the measure of a nation's advancement may be determined by its per capita energy consumption. Energy has a profound impact on our lives and the means by which we make a living, even at the most basic and fundamental levels.

Energy may be most accurately defined in relation to its capacity for doing work. Energy is imperceptible to the human eye, since we can only see its consequences [1]. We lack the ability to create energy, but we may harness and use it. Similarly, we are unable to eliminate energy entirely, but we can squander it by wasteful practices. Energy innovations have recently regained substantial global attention. Essentially, they provide a diverse array of advantages, including as diminished greenhouse gas emissions, decreased reliance on fossil fuels, exceptionally effective energy conversion, and lowered air pollution. In order to be commercially viable, these energy devices must surpass current technologies in terms of efficiency, durability, and cost, while also exhibiting fewer emissions and better efficiency, comparable durability, and reduced cost.

Energy conversion or energy transformation refers to the process of converting one kind of energy into another [2]. In the field of physics, energy is the ability to do a task, such as lifting an object, or to generate heat. According the conservation of energy princile, energy may be transferred to a new place or object, but it cannot be generated or destroyed. Various manifestations of energy may be harnessed for natural processes or used to serve civilization, such as generating heat, refrigeration, illumination, or powering machinery via mechanical activity. To illustrate, the furnace utilizes combustion to transform the chemical potential fuel energy into thermal energy. This thermal energy is then transformed to the air within the house hence amounting to an upsurge in temperature.

Energy conversion is a continuous and ubiquitous process, which happens constantly throughout the day. There are different types of energy, such as thermal, mechanical, sound, electrical, chemical, energy, electromagnetic energy etc. [3]. The term "energy transformation" is utilized when defining the process of converting energy from one condition to another. The laws of energy conservation states that the general quantity of energy remains immutable, irrespective of the fact of whether it is converted or transported. **Fig 1** defines the process of converting different sources of energy into another. Thermodynamics refers to a scientific field that describes energy transformation from a single state to another. A detailed review of thermodynamics applications and related laws of energy transformation is provided in the schematic diagram. The first principle of thermodynamics asserts that energy is conserved implying that it cannot be destroyed or generated, but can only be transformed from a single state to another. The principle is sometimes known as the law of energy conservation and the law of energy conversion.

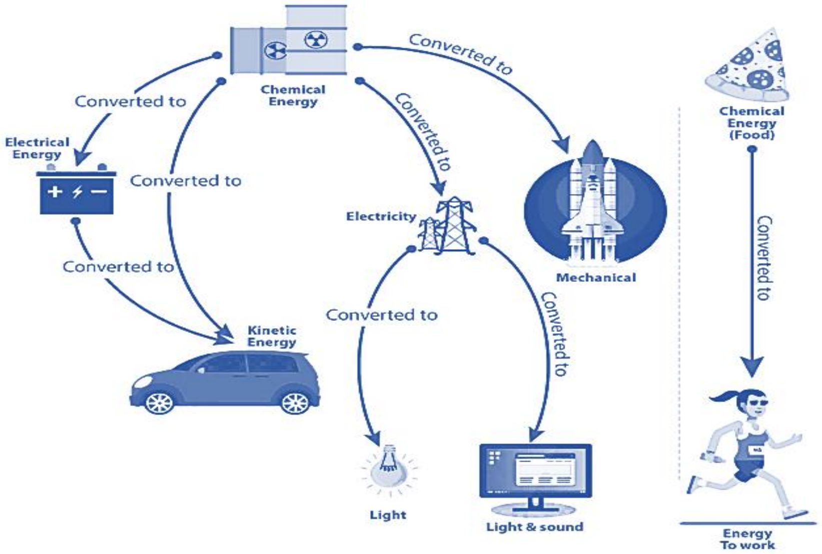

Fig 1. The law of Energy Conversion.

This research provides a detailed and ordered description of the development of energy-conversion technology, focusing particularly on the advancement of waterwheels and windmills as early devices for harnessing mechanical energy. Furthermore, it analyzes several classifications of fuel cells, including their working temperatures and efficiency. The research highlights the potential of new fuel cell advancements, such as direct carbon and microbial fuel cells, to fundamentally revolutionize power production and use. Additionally, it examines the challenges and advancements in portable fuel cell devices and introduces the concept of Alkali Metal Thermo-Electrochemical Energy Converters (AMTEC) as a method of converting heat into electricity. The remainder of the paper has been organized as follows: the second section presents the history of energy-conversion technology. The third section reviews different technologies related to energy conversion. These technologies include (a) next-generation fuel cells, (b) energy fuel cell, and (c) the alkali metal thermos-electrochemical energy converters. Lastly, a conclusion and a recommendation of future scope is provided in the fourth section.

II. HISTORY OF ENERGY-CONVERSION TECHNOLOGY

The use of fire marked the first instance in which early humans harnessed an external, nonanimal energy source. By combusting desiccated botanical material (mostly wood) and refuse of animal, they harnessed the electricity derived from these organic materials to provide warmth and facilitate culinary activities. The advent of mechanical energy as a replacement for human or animal power occurred around 2,000 years ago, when basic mechanisms were devised to tackle the force of wind and water.

Waterwheels

Initially, waterwheels were used for the purpose of grinding grain. They were later used to power pumps and sawmills, to facilitate the bellows operation in forges and furnaces, to operate trip or tilt hammers for forging of iron, and to provide direct mechanical energy to fabric mills. Prior to the Industrial Revolution in the late 18th century, flash wheels were the predominant method of generating mechanical energy, sometimes competing with windmills [4]. Consequently, several industrial cities, particularly in early America, emerged in places where a consistent water supply could be guaranteed throughout the year. The first mention of a water mill may be traced back to around 85 BCE.

In the early 19th century, curved paddles for undershot were devised by engineers such as the French Jean-Victor Poncelet, in order to facilitate the smooth entry of water [5]. The design was predicated on the notion that water would ascend the curved vanes, accumulate at the inner diameter, and then drop with little speed. The use of this design resulted in a 65% improvement in the efficiency of undershot wheels [6]. The breast wheels, which allow water to enter at the 2- or -10 o'clock position, are superior in efficiency compared to overshot wheels and less susceptible to vandalization caused by floods. He used concave containers and implemented a tightly-fitted stone structure to prevent lateral water leakage. In 1828, Fairbairn created aerated buckets that included openings at each bucket`s bottom, enabling the release of trapped air. Additional enhancements included the implementation of a governor to regulate the operation of the sluice gates, as well as the integration of spur gearing for the power takeoff.

Windmills

Windmills, similar to waterwheels, were one of the first mechanisms that substituted animal strength as a power source. For millennia, windmills have been used in many regions around the globe to tackle the power of wind and transform it into mechanical energy. This energy is then employed for tasks like as grinding grain, pumping water, and emptying low-lying areas.

Hero of Alexandria (in the 1st century CE) provided the first documented description of a wind device. The device was designed based on a water-powered propeller and its purpose was to operate a plunger pump that generated airflow via a wind organ, resulting in music production [7]. The first documented mentions of wind-powered flour mills, discovered in Arabic texts from the ninth century, known as the 644 CE Persian Millwright. However, it is possible that windmills were used far earlier. The mills, constructed in close proximity to the current border of Afghanistan and Iran, had a perpendicular shaft equipped with paddle-like sails extending outward. These mills were situated inside a structure that had opposing entrances for the wind to enter and exit. Each mill operated a solitary pair of millstones without the use of gears. The first mill were constructed with millstones positioned over the sails, imitating the design of the early watermills from which they originated. China had already developed similar mills by the thirteenth century.

Europe acquired windmills with perpendicular sails mounted on plane pikes via cultural exchange with the Arabs. Builders started incorporating concepts from modern waterwheels by replacing the traditional waterwheel with fabric-covered, wood-framed sails positioned above the albatross. These sails were used to power the millstone via a gears system. The entire mill, together with its equipment, was mounted on an immovable pillar, allowing it to spin and align with the direction of the wind. Millworks were first enclosed by a rectangular ligneous frame construction and subsequently often by a “round-house,” which also worked as storage. The mill could be stopped using a rim brake, which was operated by a brake disk attached to the axis. For the brake to be released, a fail-safe system early example, a substantial lever needed to be lifted. These mills first appeared in France in 1180, then in crusader-controlled Syria in 1190, and finally in Britain in 1191 [8]. The Windmill Psalter, made in Canterbury, England, in the late thirteenth century, is the earliest known representation.

III. ENERGY CONVERSION TECHNOLOGIES

Fuel Cells—The Next Generation

There is already a diverse range of commercially available structures of fuel cell, varying in size from a few watts to megawatts. The literature has extensively explored their working conditions and the significant differences in their performance characteristics. Historically, these devices have been classified primarily based on the electrolyte type and subsequently reliant on the type of fuel used. Fuel cells may be categorized based on their working temperature. Polymer Electrolyte Membrane Fuel Cells (PEMFC) [9] often operate at temperatures around 100°C, which is the lowest range. On the other hand, Solid Oxide Fuel Cells (SOFCs) [10] work at the greatest temperatures, usually about 800°C or more (see **Fig 2**).

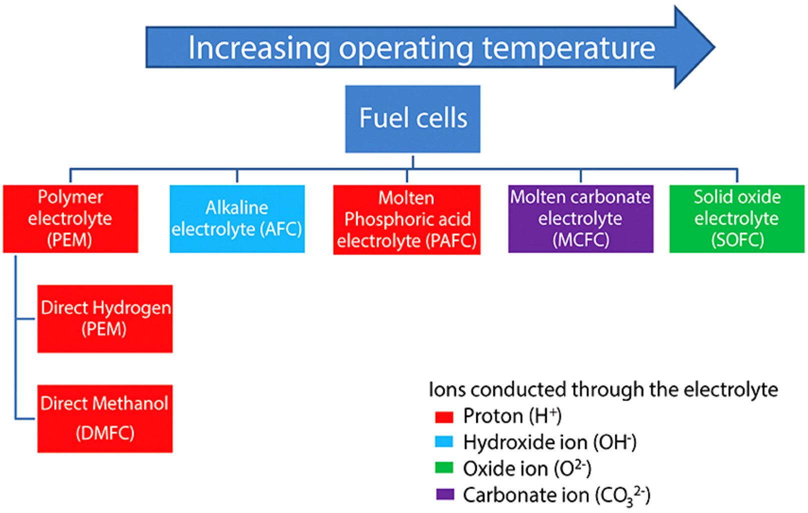

Fig 2. The Categorization of Almost or Existing Commercial Systems of Fuel Cell.

Conventional Fuel Cells

In traditional fuel cells, operating temperatures is an important metric to consider since it dictates the fuel type, material selection, electrical effectiveness, and end-user application. Extreme temperature systems, like SOFCs and molten carbonate, function at temperatures that are sufficiently elevated to facilitate the internal conversion of hydrocarbon fuels. These systems achieve electrical efficiencies ranging from 45% to 60%. Unlike the low-temperature fuel cell systems, which rely on hydrocarbon fuels, the process of externally reforming and cleaning the hydrocarbon fuel utilized inside the system is necessary to remove carbon monoxide. The low working atmospheres of this category of fuel cells make them unsuitable for reforming hydrocarbon fuels, resulting in lower electrical efficiencies for such systems (about 35-40% overall system electrical competence when run on fuels of hydrocarbon) contrasted to high-temperature systems.

Additionally, the PEMFC has a notably limited tolerance towards carbon monoxide (CO). Fuel cells working at intermediate temperatures, usually ranging from 150 °C to 350 °C, often exhibit greater resistance to contaminants in the fuel and need lower amounts of catalyst. As a result, these fuel cells have extended operational lifespans, yet the efficiency of electricity is comparable to that of low-temperature fuel cells.

By operating intermediate or low temperature FC systems directly on hydrogen, it is possible to attain electric efficiencies above 50%, with a system competence of over 80% when recovery of heat is used. This is due to the avoidance of fuel processing losses. **Table 1** presents a differentiation of the system and several systems electrical efficiencies of fuel cells that are powered by reformed hydrocarbon fuels. These results are compared to fuel cells that directly electrochemically oxidize a fuel, as reported by Krewer, Vidaković-Koch, and Rihko-Struckmann [11]. All energy that is not turned into electrical energy from the fuel is dissipated as waste heat. The process for determining the overall fuel cells systems efficiency is well explained in the reference provided by Gao et al. [12]. In systems with potential efficiencies over 100%, the fuel cell requires a continual supply of heat input to function.

Table 1. Fuel Cells Theoretical Electrical Efficiency When Operated on Different Fuels

Fuel cell type	**Operating temperature (*C)**	**Fuel**	**Actual system efficiency (%)**		**Theoretical efficiency (%)**	**Overall reaction**
			CHP	Electric	Electric	
DCFC	500-1000	Carbon	90	70-80	100	$C(s) + O_{2(g)} = CO_{2(g)}$
PEMFC	60-80	H_2	80-90	45-50	83	$H2(g) + 1/2O_{2(g)} = H_2O_{(l)}$
MCFC	650	NG	90	45-55	92	$2O_{2(g)} + CH_{4(g)} = 2H_2O_{(g)} + CO_{2(g)}$
PEMFC	60-80	NG	80-90	35-40	-	$2O_{2(g)} + CH_{4(g)} = 2H_2O_{(l)} + CO_{2(g)}$
SOFC	600-1000	NG	90	45-60	92	$2O_{2(g)} + CH_{4(g)} = 2H_2O_{(g)} + CO_{2(g)}$
DMFC	20-60	CH_3OH	n/a	20-25	97	$CH_3OH_{(g)} + 1{}^1/_2O_{2(g)} = CO_{2(g)} + 2H_2O_{(l)}$
PAFC	200	NG	90	40	-	$CH_{4(g)} + 2O_{2(g)} = CO_{2(g)} + 2H_2O_{(g)}$
AFC	70	H_2	n/a	45-60	83	$H_{2(g)} + {}^1/_2O_{2(g)} = H_2O_{(l)}$
AFC - Alkaline Fuel Cell; PEMFC - Polymer Electrolyte Membrane Fuel Cell; PAFC - Phosphoric Acid Fuel Cell; DCFC - Direct Carbon Fuel Cell; DMFC - Direct Methanol Fuel Cell; MCFC - Molten Carbonate Fuel Cell; SOFC - Solid Oxide Fuel Cell						

Fuel cell systems that use reformatted fuel typically have a much lower maximum electric efficiency than those that use directly oxidized fuel in their electrochemical reactions. The reason for this is because all existing fuel cells function using either pure hydrogen or, at high temperatures, a combination of carbon monoxide and hydrogen. Typically, these fuels are generated by the process of gasification or reforming of a hydrocarbon fuel. A substantial energy input is required for the process of reforming any easily accessible hydrocarbon fuel. This is especially harmful when exterior reformers and fuel processes are employed, which are typically the case for systems of intermediate low temperature fuel cells, since none of the waste energy (majorly poor quality) produced from reactions of fuel cells can be employed for reforming. Fuel processing and exterior reforming are necessary for all systems of low-temperature, since these structures run much below the atmosphere threshold for exterior reforming, which is around 500°C. Waste heat generated by the processes occurring inside in the fuel cell may be used by systems operating at elevated temperatures to reform the incoming cell. Consequently, commercial systems operating in this way have much greater electrical efficiency, often ranging from 45% to 60% [13].

Technologies for Emerging Fuel Cell

Technologies for emerging fuel cell are not easily classified under existing fuel cell categories, mostly because of the diverse systems of fuel management and the departure from standard electrolytes. Consequently, the condition and type of the fuel play a more significant role in defining them, rather than the electrolyte chemistry. This distinction is particularly essential in design of the system`s terms and the ultimate purpose of the system. Instances of this include carbon fuel cells, ethanol, or direct methanol. The current categorization method is flawed due to substantial uncertainty about the appropriate classification of fuel cells. Specifically, the fuel may exist as either a liquid or a gas, depending upon the operating temperature or pressure. **Fig 3** displays a comprehensive categorization of various fuel cells under investigation, depending on the kind of fuel used. The color coding of the figure provides insight into the possible uses of each fuel cell type for end users.

Systems using solid fuels has the advantage of these fuels being often inexpensive and more plentiful compared to gaseous or liquid fuels. Gaseous fuels have the benefit of being sufficiently plentiful and can be conveniently delivered over extensive intervals using traditional pipe networks. Liquid fuels have the lowest abundance among all viable sources of fuel, but their ease of transportation and high-power densities make them particularly suitable for applications of transport or mobility. Microbial Fuel Cells (MFC) and Direct Carbon Fuel Cells (DCFC), are two kinds of fuel cells under the solid fuel category, that have the potential to bring about a significant change in power production and application possibilities.

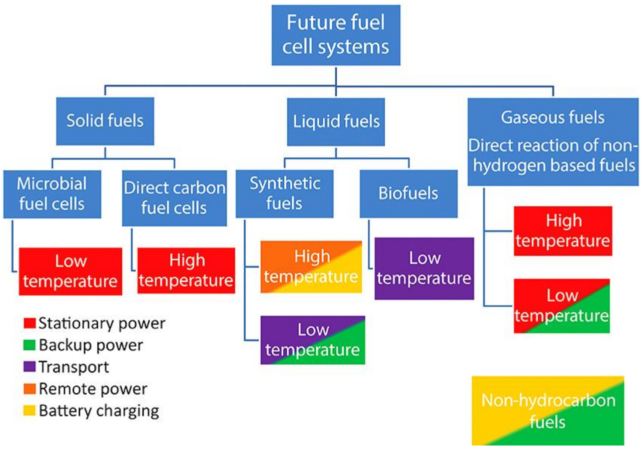

Fig 3. Categorization of Upcoming Systems of FC.

Microbial Fuel Cells (MFC)

Previously, it was believed that only a limited number of microbes had the ability to generate energy. In recent times, the majority of microorganisms have the ability to serve as a biocatalyst in MFC. Potter showed the original idea of microbial fuel cells (MFC) in 1910 by employing live cultures of Saccharomyces and Escherichia coli to produce electricity using electrodes of platinum [14]. Nevertheless, it did not get more attention until the early 1980s, when the notion was further advanced by the employment of electron mediators to significantly increase power output.

Microbial fuel cells (MFC) are systems, which employ microbes as stimulus to produce electrical current directly from biodegradable organic and inorganic substances. Bacteria are often used in MFCs to produce power while simultaneously breaking down organic substances or waste materials. MFCs have effectively treated various types of wastewaters, such as domestic, animal, brewery, and food processing wastewaters. These MFCs remove organic contaminants from the wastewaters and generate valuable energy as electrical power or hydrogen gas.

The fundamental design of a microbial fuel cell comprises an electrical circuit, an anode, a proton exchange membrane, and a cathode. The cathodic and anodic chambers are divided by a proton exchange membrane. The anode compartment is usually kept in an anaerobic environment, whereas the cathode might be exposed to air or immersed in aerobic solutions. Through external electrical connection electrons go to cathode from anode, which usually involves a battery, a resistor, or another device of electricity. The microorganisms present in the MFC anodic chamber metabolize the introduced substrates, amounting to the generation of electrons and protons. Carbon dioxide is generated via the process of oxidation. Nevertheless, there is a lack of carbon emissions overall due to the fact that the carbon dioxide included in the sustainable biomass originates from the aerosphere during the photosynthesis process.

In contrast to a direct burning procedure, the currents are taken in by the anode and conveyed to the cathode through an exterior circuit. Upon traversing a salt bridge or a Proton Exchange Membrane (PEM) [15], the protons go into the chamber of cathode, where a reaction with O2 happens to generate H2O. The microorganisms in the chamber of anode absorb protons and electrons via the process of dissimilative of oxidizing organic substrates. The following reactions of electrode are often seen, using acetate as an illustrative substrate.

- Cathodic reaction: $O_2 + 4e^- + 4H + 2H_2O$.
- Anodic reaction: $CH_3COO^- + 2H_2O\ 2CO_2 + 7H^+ + 8e^-$

The overall process involves the decomposition of the substrate into water and carbon dioxide, resulting in the electricity generation as a secondary outcome. The efficacy of the method is contingent upon several elements. Efficiently optimizing these parameters may effectively address the energy issue by using industrial and home trash to generate power. The usage of anaerobic microorganisms in MFCs for power generation represents a pioneering technology that has significant promise for alternative energy production and environmental restoration (see **Fig 4**)

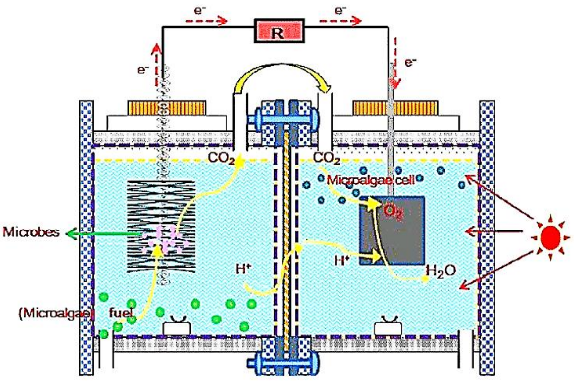

Fig 4. Microbial Fuel Cell Basic Configuration.

Microbial fuel cells (MFCs) use the metabolic activities of microorganisms to convert organic matter into electric power, The use of microorganisms for the generation of electric energy has been investigated since the 1970s, but it has lately been reexamined as a potential origin of power for applications in small-scales due to the demonstration of increased power densities [16]. MFCs typically exist in two configurations: single chamber fuel cells and membrane reactors . In a membrane reactor, the cathode and anode are segregated by an electrolyte membrane into two chambers. In contrast, single chamber gadgets have both the cathode and anode in the same chamber, but they are parted by organic matter. The second kind is often known as sediment cells. Microorganisms in both kinds of MFCs adhere to the anode surface and engage in the process of oxidizing organic matter, resulting in the formation of a biofilm. Subsequently, these microorganisms convey electrons to the fuel cell anode, either via direct means using indirectly or micro-pili with the assistance of a mediator.

Microbial fuel cells (MFCs) show great potential due to their ability to function at or close to ambient temperature and their capacity to use low-quality waste materials like agricultural waste streams, soils, waste water, and sediments that are not suited for any other energy production technology. The primary concern is in the very low density of power shown by this particular kind of fuel cells, often ranging in the order of μWcm−2. This value is many magnitude orders lower compared to other fuel cells types. While these fuel cells show potential in certain low energy need scenarios, their widespread implementation in such applications necessitates a significant improvement in power densities, reaching at least the mWcm−2 region.

Small and Portable Fuel Cells

Moreover, there is a significant drive to advance portable or tiny sources of power, in summation to sophisticated systems of fuel cell that operate with solid and gaseous fuels at very high efficiency. The key determinants in these systems are the dimensions and mass of the apparatus, the energy concentration of the fuel, and the ease of fuel conveyance. Although the overall efficiency of the system is noteworthy, it is somewhat less crucial in comparison to stationary generation of power. Portable systems of fuel cells often use low-temperature PEM fuel cells stacks, which work near or at ambient temperature and are powered by pure hydrogen.

Nevertheless, there are a limited system`s number now under development that either use solid oxide fuel cell (SOFC) technology or function by directly using methanol/water mixtures inside proton exchange membrane (PEM) systems. When using pure hydrogen, the fuel cell is often stored in either a metal hydride or a lightweight compressed cylinder of hydrogen. Other potential fuel alternatives being evaluated include of biofuels like synthetic hydrocarbon like non-hydrocarbon fuels, and methanol like ammonia, ethanol. To use fuels other than hydrogen for fuel cells, with the straight methanol fuel cells exception, a fuel processor is needed to transform the fuel to pure hydrogen or a combination of hydrogen and carbon monoxide. However, the latter is only good for usage in fuel cells with high temperatures.

Using a fuel processor often increases the device`s complexity, but also simplifies the fuel`s storage, particularly for liquid fuels that usually have very high-power densities and are more cost-effective than gaseous or batteries option of hydrogen storage. Nevertheless, the stringent purity requirements for hydrogen need expensive fuel processors, which may importantly hyper the overall price of the gadget. Indeed, the cost of the fuel processor may exceed that of the fuel cell stack itself. Generally, this limitation confines the use of fuel processor/fuel cell combinations to scenarios where the price per kilowatt-hour (kWh) outweighs the cost per kilowatt (kW). This is because it allows for the costly processor of fuel to be offset by the far more affordable fuel storage alternative. Similarly, the additional mass resulting from the CPU may be counterbalanced by the much higher density of energy of the system of fuel storage.

Alkali Metal Thermo-Electrochemical Energy Converters

A thermally regenerative electrochemical device that enables the heat to electricity direct conversion is known as the Alkali-Metal Thermo-electrochemical Converter (AMTEC). The device in question demonstrates a spectrum of anticipated efficiency, ranging from 15% to 40% [17]. It can produce direct electrical current from heat sources between 900 and 1300 K in temperature. The device has an encrypted thermodynamic cycle, which makes use of reservoir of heat with various temperatures to establish sodium propulsion. AMTEC utilizes a novel process where sodium atoms are disintegrated into sodium electrons and ions. This is attained by sodium vapor isothermal expansion over solid electrolytes. AMTEC effectively transform the vapor into electric power. The results and concepts of AMTEC have been unified in literature works. This work provides a critical analysis of the concept, such as a snippet of prior experimentations, description of setting up AMTEC experiments, and the findings in [18]. In addition, it presents the results derived from inquiries into potential AMTEC applications in space exploration.

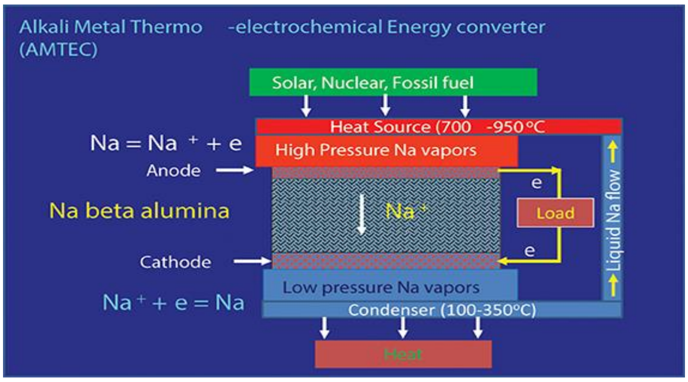

Fig 5. Principle of Operation of the AMTEC.

AMTEC electrolyte for Na+ or K+ ions conveyance is typically beta alumina, which is a material integrated with potassium or sodium. Currently, the fluid employed for propulsion is either sodium or potassium metal. The ionic propulsion figures for potassium and sodium in the materials are approximately the same as one, recommending a vital ionic conductivity degree. The device consists of two distinct sections: a high-pressure component, operating at pressures above 20 kPa and temperatures ranging from 700 to 950°C, and a low-pressure component, operating at pressures about 100 Pa and temperatures ranging from 100 to 350°C. These two sections are separated by the electrolyte. **Fig 5** illustrates a diagram of the AMTEC system using sodium as the operational fluid. A solid electrolyte is infused with liquid metal from one side. Upon external heating, the metal undergoes evaporation, transitioning from its liquid form to a gaseous state. This process results in the formation of a high-pressure environment (>20 kPa) consisting of sodium vapors at the interface between the thick electrolyte and the porous anode. The sodium vapor pressure is quite low, around 100 Pa, at proximity to the cathode.

The Na+ partial pressure of differential conducting membrane of electrolyte causes a potential difference, typically in the V range. The production of sodium electrons and ions at the electrolyte/anode interface occurs when sodium vapor is ionized due to the potential gradient, which occurs when the connection of a cell is done through a load externally. The process of producing electricity involves transferring sodium ions across the membrane of electrolyte and recombining with electrons at the cathode, which is the side with lower pressure. The process is then repeated by cycling the sodium vapors back to the side of anode for pulverization after condensation. By connecting many cells in a series/parallel arrangement, a module may be constructed to meet the application`s requirements of power. The device needs little upkeep since there are no locomotion parts inside the cell. With its modular construction, AMTECs are similar to batteries and fuel cells in many ways.

IV. CONCLUSION AND FUTURE SCOPE

In summary, the advancement of energy-conversion technology has evolved over thousands of years, beginning with the use of non-animal energy sources such as fire and wood. Later, mechanical energy was used by using waterwheels and windmills. These first technologies established the groundwork for the development of more intricate energy conversion systems. Fuel cells are a rapidly growing field of energy storage and transportation technologies that have the potential to fundamentally revolutionize power production and use. Classification of fuel cells is according to their operating temperature, with several types of fuel cells operating within certain temperature ranges. Conventional fuel cells operate at high temperatures and need external reforming and cleaning. However, intermediate-temperature fuel cells offer extended operational lifetimes and comparable electrical efficiency.

Emerging fuel cell technologies, such as ethanol, carbon fuel cells, or direct methanol, have the capacity to bring about major changes in energy production and application possibilities. Solid fuels, gaseous fuels, and liquid fuels have unique advantages and may be used in different fuel cell setups. MFCs are auspicious kind of renewable energy technology that use microbes as catalysts to generate electric current from inorganic and organic molecules. Microbial fuel cells (MFCs) may use low-grade waste materials; nevertheless, their current power density is inadequate and requires improvement to promote widespread usage. A significant trend in the field is the development of tiny and portable fuel cells, which seek to produce highly efficient fuel cell devices that can operate using both gaseous and solid fuels. Portable fuel cell systems often use fuel cell stacks that utilize low-temperature PEM technology. Nevertheless, there are continuous endeavors to construct systems that use solid oxide fuel cell (SOFC) technology or directly employ methanol/water combinations.

Heat may be transformed into electricity by using a thermally regenerative electrochemical mechanism, which is done by the AMTEC (Alkali Metal Thermo-Electrochemical Energy Converters) device. The system has the capacity to convert heat inputs into direct electrical current with expected efficiencies ranging from 15% to 40%. The viability of the AMTEC concept has been shown, and more research is needed to verify its appropriateness for use in space power systems. In order to meet society's increasing energy demands in the future, it will be crucial to use efficient and cost-effective fuel cells, as well as advancements in energy storage and conversion technology. Continued research and progress in these areas will lead to the widespread adoption of environmentally benign and long-lasting energy sources, reducing our dependence on finite fuels and mitigating the effects of climate change.

CRediT Author Statement

The author reviewed the results and approved the final version of the manuscript.

Conflicts of Interest

The author declares no conflict of interest

Data Availability Statement

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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