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4. Energy Materials and their Applications

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Abstract:

To fulfill the world's future energy needs, it is essential to develop new and innovative energy materials. It is also of utmost significance for energy applications in numerous technological fields. For effective and affordable energy conversion and storage, we are interested in creating novel materials and procedures. In order to develop materials and structures with specific functionalities for effective energy storage and conversion, our research focuses on low-cost, one-step synthesis and fabrication of electrodes with novel structures, in situ characterization, and multi-scale modeling of membranes, thin films, gradient porosity, and nanostructured electrodes with heterogeneous surfaces and interfaces. This covers the creation, assessment, and transfer of energy materials to applications. Photovoltaics (PV), solar fuels, biomass to liquid fuels, thermoelectric materials, battery electrode materials, hydrogen storage, and energy-saving catalysts for the chemical industry are just a few of the many energy-related subjects covered in this session. We shall talk about Energy Materials and Their Applications in this paper.

Keywords:

Energy Materials, Applications, Development, Novel Energy, Energy Storage, Gradient Porosity, Photovoltaics, Solar Fuels, Transmission, Nanomaterials, Macroscopic, Potential, Kinetic Energy.

4.1 Introduction:

Energy materials are a vast range of substances that can be used for energy transmission or conversion. Energy materials can also contribute to improving the efficiency or lowering the power consumption of current electronics. Engineering devices are just one area of research in energy materials. There are restrictions to the materials that are frequently employed in the industry to make next-generation optoelectronic devices. [1]

We must enhance the characterization of atomic-scale properties, control and reproducible growth processes, and rational design of nanomaterials in order to open up new opportunities in a variety of engineering applications, from photonics to energy production. Except for energy, which can only be indirectly viewed and quantified since it presents itself in diverse ways, every physical quantity may be accurately defined. As a result, work and energy share the same unit and are closely related. Since energy is a scalar physical quantity, its magnitude can be used to describe it in its entirety.

Additionally, it should be emphasized that the form may alter if research relating to energy shift from a macroscopic to a microscopic perspective, and vice versa. For instance, mechanical energy, such as friction, may only represent heat energy at the tiny scale. [2]

The attributes of energy can be used to further define it. Potential and Kinetic Energy are the two categories into which all others can be generically classified. When there are no frictional forces acting on the particle, the total of these two energy is always constant.

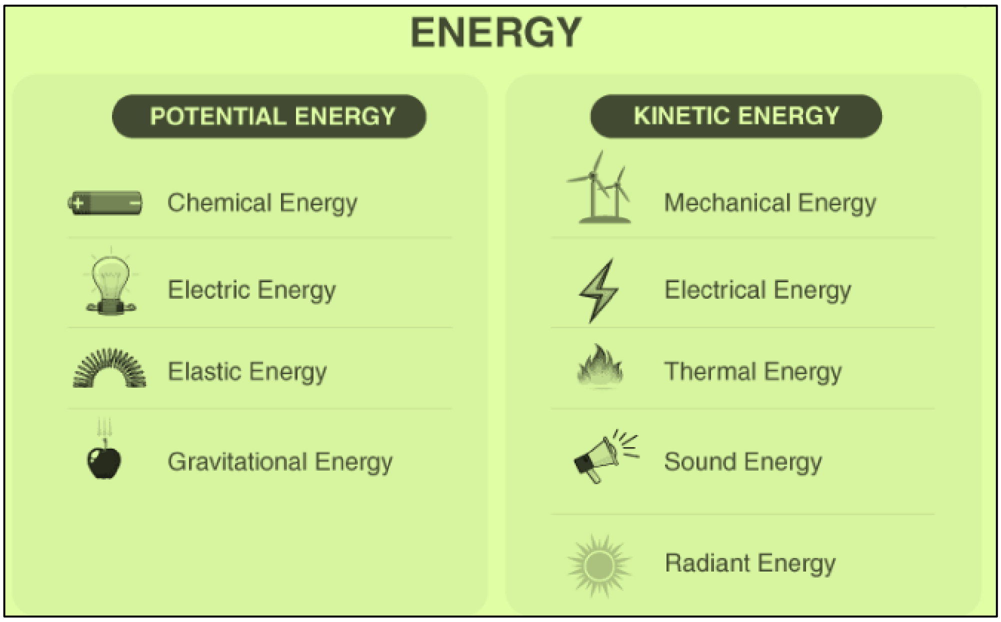

Figure 4.1: Types of Energy

Motion is what **kinetic energy** is. An object's kinetic energy increases with speed. Kinetic energy includes the energy of rivers (hydraulic energy) and the wind (wind energy). This energy can be used to operate a generator or to turn water mills, windmills, or pumps that are connected to turbines into mechanical energy.

Potential Energy is the energy that is held in both stationary objects and position. It is a potential kind of energy, as its name suggests, meaning that it only emerges when it is transformed into kinetic energy. For instance, when a ball is lifted, it gains potential energy (caused by gravity), which only manifests itself when it falls.

Chemical energy is the energy held in atom and molecule bonding. Chemical energy can be found in things like batteries, biomass, oil, natural gas, and coal. For instance, when humans burn wood in a fireplace or gasoline in a vehicle's engine, chemical energy is transformed into thermal energy.

Transverse waves of electromagnetic energy are known as **radiant energy**. Visible light, x-rays, gamma rays, and radio waves are all examples of radiant energy. One kind of radiant energy is light.

Mechanical energy is stored as tension in objects. Examples of mechanical energy that has been stored are compressed springs and stretched rubber bands.

The small, electrically charged electrons that generally flow through a wire are responsible for delivering electrical energy. An illustration of **electrical energy** in nature is lightning.

The energy that an object has due to its height or vertical position is known as **gravitational potential energy**. A book that is higher up on a bookshelf has more gravitational potential energy than a book that is lower down. [3]

The Energy Materials Team is working to create cutting-edge nanostructures and nanocomposites for 3-D integration, thermal control of electrical and photonic devices, and energy generation and storage. This activity's goal is to use nanomaterials in particular Energy-related applications while also doing applied research to close the knowledge gap between science and technology.

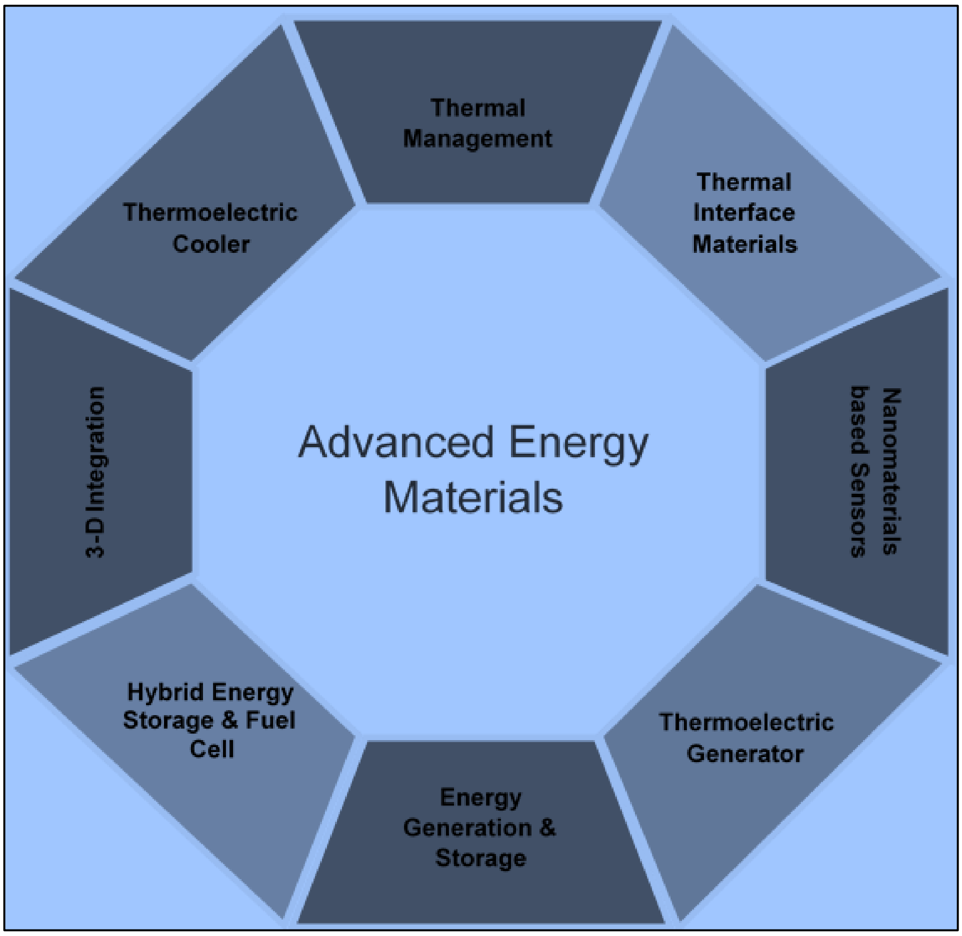

Figure 4.2: Advanced Energy Materials

The advances in material science have a major impact on the development of energy storage and conversion technologies. Researchers today stand at a position that could be rich in enormous chances to eradicate the energy and environmental problems thanks to new equipment for creating and studying innovative materials for green energy and the quick accumulation of knowledge about them.

Indeed, there has been significant improvement in the use of green energy, including solar energy, biofuels, and wind power. In addition to harnessing green energy, the light-emitting devices are revolutionizing the lighting industry by being energy-efficient. Although colleagues are making an effort in these areas, the achievements are still far below the expectations. [4]

Energy materials are components for machinery that harvests energy from resources as efficiently as possible. Therefore, all materials used in technology to transform primary energy into energy carriers that reach consumers as secondary energy and ultimately into energy that is actually used for human purposes, such as air conditioning, a comfortable lifestyle, transportation, and the production of goods, are considered energy materials.

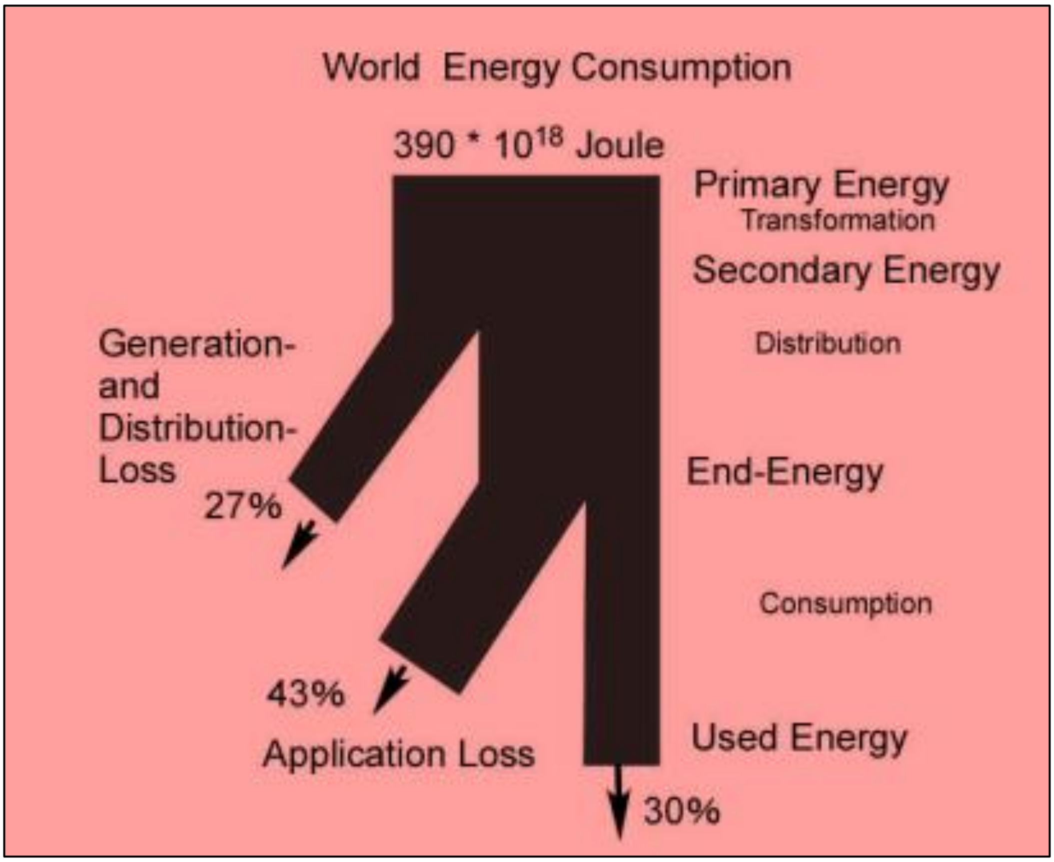

Figure 4.3: Future energy materials face a challenge in reducing energy loss during production, distribution, and use.

Figure 4.3 demonstrates how much energy is lost throughout each stage of energy transformation using current technologies. Only 63% of the primary energy, which is contained in fuels or comes from renewable sources, is supplied to consumers as secondary energy. The losses result from heat dissipation, inadequate equipment, inefficient technology, transportation or storage losses, among other things.

Fuel cells are being developed by materials scientists in an effort to replace electricity and gasoline as the primary energy sources in many applications. Currently, energy is carried by electricity and gasoline. [5]

4.2 The Numerous Energy Uses in Daily Life:

4.2.1 Residential Uses of Energy:

These are the most fundamental energy uses when discussing home use. You can work from home on your laptop or computer, watch television, wash your clothes, heat and light your house, take a shower, operate appliances, and cook.

The majority of consumers are unaware that there are options, businesses, and innovations that can support them in monitoring and reducing their energy usage.

4.2.2 Commercial Uses of Energy:

Energy is used for business purposes in the commercial sector. This includes power utilized by businesses and companies throughout our cities for computers, fax machines, workstations, copiers, to mention a few, as well as heating, cooling, and lighting of commercial buildings and spaces.

In order to combat the waste culture existing at our workplaces, energy conservationists should launch energy-saving campaigns.

4.2.3 Transportation:

Energy is the only factor that influences transportation in any way. The transportation sector consumes over seventy percent of all petroleum. The transport sector encompasses all types of vehicles, including motorbikes, trucks, buses, and personal automobiles.

Aircraft, railroads, ships, and pipelines are all included. If we take into account the uses and address them individually, worldwide efforts at energy conservation can be achieved.

materials pertaining to energy applications, such as:

- Alternative Energy Vectors
- Thermoelectric
- Semiconductors
- Photovoltaics (PV)
- Fuel Cells
- Energy Storage.

Materials for potential future energy uses can include, among others, polymeric, complex oxide, nanoionics, caloric, and porous materials. [6]

Energy-related materials may contribute to improving the efficiency or lowering the power consumption of current technology. Engineering devices are just one area of research in energy materials.

The term "energetic material" refers to a fairly broad category of substances, ranging from low explosives like gunpowder, dynamite, and TNT to basic automotive fuels like gasoline and diesel.

- Solar Energy
- Solar Systems Integration
- Concentrating Solar Thermal for Electricity, Chemicals, and Fuels
- Photovoltaic Materials, Devices, Modules, and Systems
- Renewable Energy
- Energy Storage & Grid Modernization
- Fossil & Nuclear Energy
- Bioenergy
- Geothermal
- Renewable Fuels
- Solar Thermal
- Batteries & Fuel Cells
- Electric Grid

- Grid Scale Storage
- Superconductors
- CO2 Capture, Storage & Conversion
- Combustion
- Enhanced Oil Recovery
- Natural Ga
- Unconventional Oil & Gas

On earth, energy comes in a variety of ways. The elemental source of energy on earth is said to be the sun. Energy is seen as a quantifiable property in physics that may be transferred from an item to carry out work. Thus, we might characterize energy as the capacity to engage in any kind of physical action. As a result, the simplest way to describe energy is as the capacity for work. [7]

Energy "can neither be created nor destroyed but can only be converted from one form to another," according to the rules of conservation of energy. The SI unit for energy is called a joule.

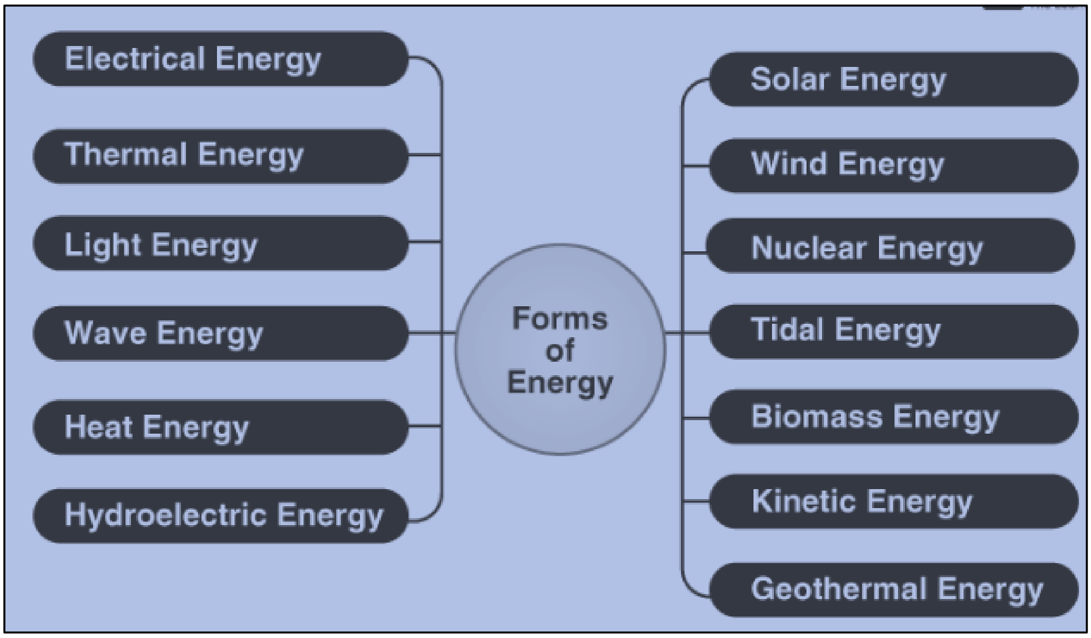

Figure 4.4: Forms of Energy

4.3 Units of Energy:

The unit of measurement for energy in the International System of Units is joule. James Prescott Joule is honored with the name of the energy unit. The energy used to apply a force of one newton over a distance of one meter is measured in joules, a derived unit.

However, there are also additional units outside of the SI that are used to measure energy, including ergs, calories, British Thermal Units, kilowatt-hours, and kilocalories, which need to be converted before being expressed in the SI system. [8]

Due to its abundance, low cost, high specific heat, and high density, water is regarded as one of the greatest materials that may be utilized to store thermal energy in the form of sensible heat. Additionally, if water is employed in the solar thermal system as the heat transfer fluid, a heat exchanger is avoided. Water has traditionally been used in commercial applications to store thermal energy in liquid-based systems.

Table 4.1 displays The following are Selected Materials for Sensible Heat Storage:

Table 4.1: Material for Sensible Heat Storage

Phase	Medium	Temp Rang [°C]	Density Kg/m³	Specific Heat J/kg K
Solid	Rock	7-27	2560	879
	Brick	17-37	1600	840
	Concrete	7-27	2100	880
	Sand	7-27	1550	800
	Soil	7-27	2040	1840
Liquid	Water	7-97	1000	4180
	Engine Oil	Up to 157	888	1880
	Ethanol	Up to 77	790	2400
	CalorieaHT43	12-260	867	2200
	Butanol	Up to 118	809	2400
	Other Organic	Up to 420	800	2300

Materials used in energy harvesting and energy storage systems, such as thin film solar cells and batteries, behave differently depending on their morphology and composition at the nano- and micro-scale. We examine these features at various length scales using focused ion beam (FIB) milling along with scanning and transmission electron microscopy (SEM/TEM). [9]

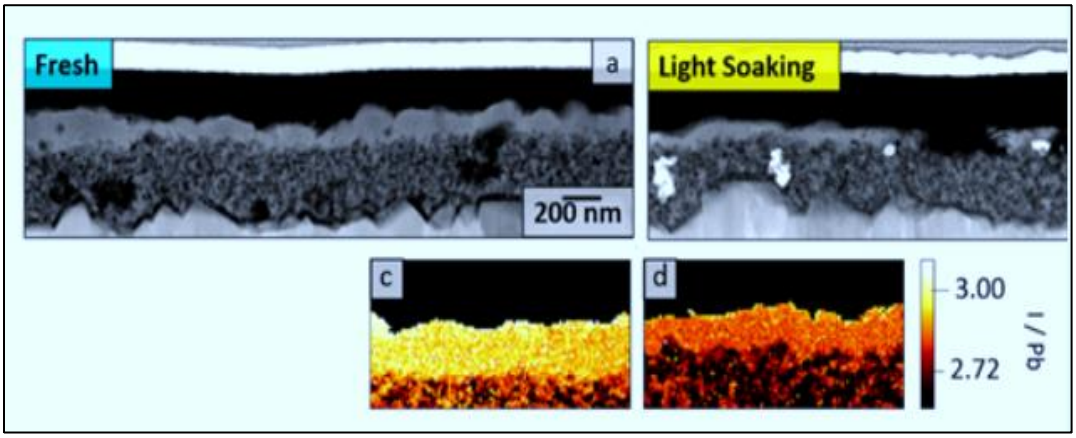

Figure 4.5: Caption: a) HAADF STEM images for a large area fresh cell and b) for a cell after 200h of light soaking. (c) Calculated atomic ratio maps for iodine/lead in the fresh and (d) stressed cells obtained from energy dispersive X-ray spectroscopy (EDX).

4.4 Energy Storage:

Energy storage is a frequently underutilized yet crucial energy technology. It can improve energy systems' functionality and increase their effectiveness, economics, dependability, and environmental impact. It is essential for making many renewable energy sources more widely used. [10]

The recent Long-term Energy Plan for Ontario, which calls for the purchase of 50 MW of energy storage capacity by the end of 2014, recently highlighted this surge in interest in energy storage.

As a result, the Independent Electricity System Operator (IESO) and Ontario Power Authority (OPA) jointly developed an energy storage procurement framework, which received endorsement from the province's energy minister.

To encourage a better understanding of and experience with a variety of energy storage technologies, the procurement framework allows for

- The services that energy storage systems can offer,
- The advantages they offer operations and
- The best way to incorporate storage into electricity markets.

The following are some of the energy storage's advantages, which are frequently extremely substantial:

Energy storage enables peak needs to be lowered or transferred to periods of lower demand when energy consumption varies dramatically over time, frequently with large economic benefits.

Energy storage is particularly useful for eliminating mismatches between times of energy supply and demand and for bridging those periods between energy supply and demand.

Energy storage is especially helpful for bridging periods between energy supply and energy demand, and reducing the mismatches between periods of energy supply and demand.

The use of energy storage significantly improves the performance of energy systems that utilise intermittent energy sources.

Through the use of energy storage, operational performance flexibility can be improved.

Utilizing energy storage can lessen the environmental effects of burning fossil fuels.

There are numerous different kinds of energy storage technologies and systems (see Figure 6). Chemical, electrical, thermal, thermochemical, mechanical, and other classifications can be used to separate these.

Batteries, hydrogen storage, flywheels, compressed gas storage, pumped storage, magnetic storage, capacitor storage, chemical storage, thermal energy storage (both sensible and latent), thermochemical energy storage, organic and biological energy storage, and others are examples of specific types of energy storage.

Even though a lot of energy storage is developed and commercially available, new storage technologies are constantly being researched, and existing ones are constantly being improved. Some technologies, like thermal energy storage, are currently both marketable and the subject of in-depth research. [11]

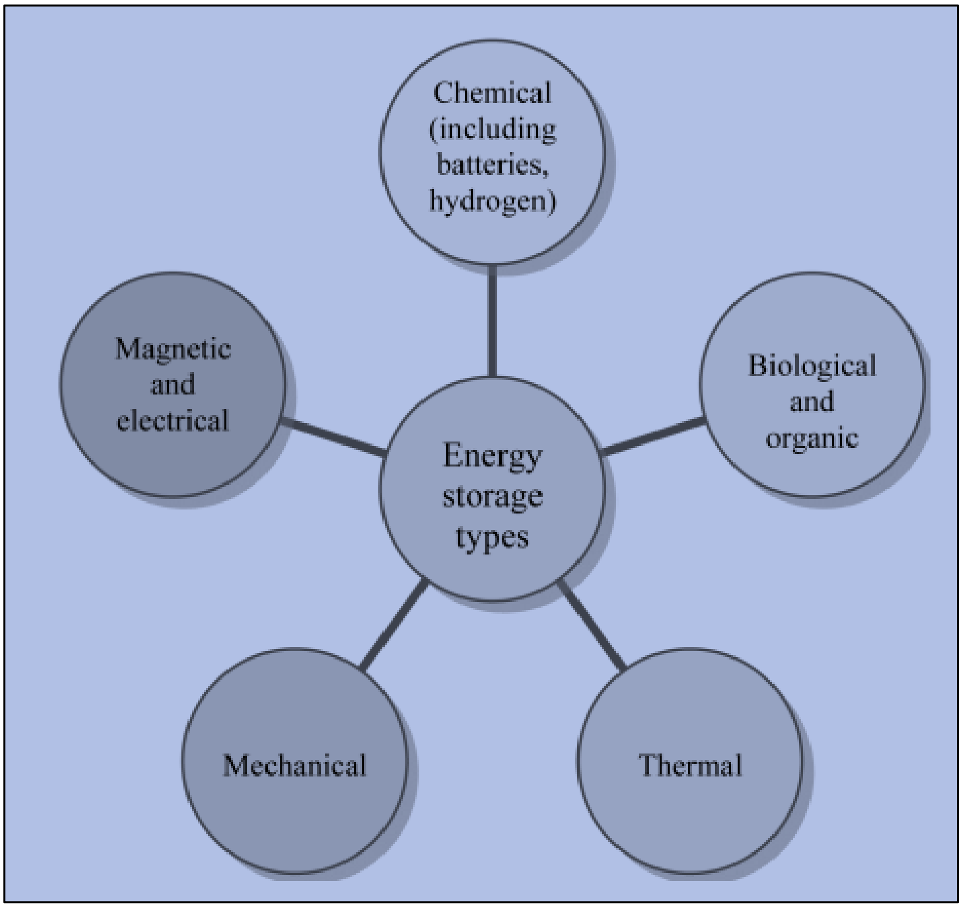

Figure 4.6: Energy storage types classified by type of stored energy.

4.5 Conclusion:

Energy materials are components for machinery that harvests energy from resources as efficiently as possible. Our society is mostly driven by energy. Various energy producing techniques can also be harmful to the environment. Depending on the amount of theory and technology available at the time, the understanding of porous energy materials displayed distinct characteristics in various eras.

The design and optimization of their structures and operational parameters remain difficult and call for additional work from the industrial and academic sectors despite the rise in breakthrough materials and energy technologies.

Thus, converting all materials into virtual data spaces rather than relying just on experimental research has steadily gained interest.

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