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ANALYSIS OF MODERN ENERGY STORAGE METHODS FOR RENEWABLE SOURCES

The increasing global focus on renewable energy sources (RES), such as solar, wind, and hydroelectric power, has led to a growing need for efficient energy storage solutions. These renewable sources are intermittent, meaning their energy production is not constant, making energy storage crucial for grid stability and energy reliability. This article provides a brief overview of the current energy storage technologies used for renewable energy applications.

1. Batteries. Batteries are the most common and well-known method of energy storage. Among the most widely used are lithium-ion batteries, which offer high energy density, long lifespan, and relatively fast response times. These batteries are typically used in both residential and industrial applications, providing storage for excess energy generated during periods of high production. However, the high cost of lithium-ion batteries and environmental concerns regarding their disposal remain challenges to their widespread use.

Other battery technologies include sodium-ion, flow batteries, and solid-state batteries, which are being researched for their potential to provide lower-cost, more sustainable energy storage options. For instance, flow batteries are suitable for large-scale storage due to their ability to store large amounts of energy for extended periods, although their energy density is lower than that of lithium-ion batteries.

2. Pumped Hydro Storage (PHS). Pumped hydro storage is one of the oldest and most established methods of large-scale energy storage. It works by pumping water from a lower reservoir to an upper one during periods of low energy demand

and then releasing the water through turbines to generate electricity when demand is high. While this method offers high energy storage capacity and long discharge durations, its geographical limitations and environmental impact make it unsuitable for all locations.

3. **Compressed Air Energy Storage (CAES).** Compressed Air Energy Storage (CAES) involves storing compressed air in underground caverns or other sealed containers. When electricity is needed, the compressed air is released, heated, and expanded to generate power through turbines. CAES can be implemented at a larger scale than batteries and has the potential for high efficiency and cost-effectiveness. However, the technology is still limited by the availability of suitable sites for underground storage and the energy losses in the compression and expansion processes.

4. **Thermal Energy Storage (TES).** Thermal energy storage involves storing energy in the form of heat, which can later be converted to electricity or used directly for heating. Molten salt is a commonly used material for storing heat in concentrated solar power (CSP) plants. The salt is heated by the solar energy collected, and the stored heat is later used to generate steam for electricity production. Thermal storage is particularly useful in solar power applications where energy generation is often needed during periods without sunlight.

5. **Hydrogen Storage** Hydrogen storage is an emerging technology in the renewable energy field. Surplus renewable energy can be used to produce hydrogen through electrolysis, splitting water into hydrogen and oxygen. The hydrogen can be stored and later converted back to electricity in fuel cells or used directly as fuel in various industries. This technology offers high energy density and long-term storage capacity, though it is still in the early stages of development, with challenges regarding storage, transportation, and overall efficiency.

6. **Flywheel Energy Storage.** Flywheel energy storage systems use a rotating mass (flywheel) to store mechanical energy. The flywheel is accelerated to a high speed using electricity, and the energy is stored in its rotational motion. When energy is needed, the flywheel's rotational speed is decreased, converting mechanical energy back into electricity. Flywheels offer fast response times and high cycle efficiency, making them ideal for short-term energy storage and stabilizing grid frequency. However, they are limited by their energy storage capacity and duration.

Conclusion. The need for efficient energy storage solutions is critical as the world transitions to renewable energy sources. While technologies like batteries and pumped hydro are already in use, emerging technologies such as hydrogen storage, flywheels, and thermal storage hold promise for the future. Each storage method has its strengths and limitations, and their widespread adoption will depend on continued research, technological advancements, and the integration of storage systems into modern energy grids. The future of energy storage will play a key role

in enabling the full potential of renewable energy, ensuring reliability and sustainability in the global energy landscape.