CH2356 Energy Engineering

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Energy Storage

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Introduction

- Energy storage as a natural process is as old as the universe itself - the energy present at the initial creation of the Universe has been stored in stars such as the Sun, and is now being used by humans directly (e.g. through solar heating), or indirectly (e.g. by growing crops or conversion into electricity in solar cells).

- Storing energy allows humans to balance the supply and demand of energy.

- Energy storage systems in commercial use today can be broadly categorized as mechanical, electrical, chemical, biological, thermal and nuclear

Need for Energy Storage

- Many important renewable energy sources are intermittent, and generate when weather dictates, rather than when energy demand dictates.

- Many transportation systems require energy to be carried with the vehicle

Methods

- Batteries – limited due to small capacity and high cost
- Capacitor
- Thermal energy storage – manufacturing ice during non-peak hours and using ice during peak hours
- Chemical fuels, Hydrogen
- Flywheel, compressed air storage, pumped system storage

TABLE 12.1 Overview of Energy Storage Technologies and Their Applications

	Utility Shaping	Power Quality	Distributed Grid	Automotive
		Direct electric		
Ultracapacitors		✓		✓
SMES		✓		
		Electrochemical		
Batteries				
Lead–acid	✓	✓	✓	
Lithium ion	✓	✓	✓	✓
Nickel–cadmium	✓	✓		
Nickel–metal hydride				✓
Zebra				✓
Sodium–sulfur	✓	✓		
Flow Batteries				
Vanadium redox	✓			
Polysulfide bromide	✓			
Zinc bromide	✓			
Electrolytic hydrogen				✓
		Mechanical		
Pumped hydro	✓			
Compressed air	✓			
Flywheels		✓		✓
		Direct Thermal		
Sensible Heat				
Liquids			✓	
Solids			✓	
Latent Heat				
Phase change	✓		✓	
Hydration–dehydration	✓			
Chemical reaction	✓		✓	
		Thermochemical		
Biomass solids	✓		✓	
Ethanol	✓			✓
Biodiesel				✓
Syngas	✓			✓

Principal forms of stored energy

- The storage media can accept and deliver energy in three fundamental forms: **electrical**, **mechanical**, and **thermal**.

- Electrical and mechanical energy are both considered high-quality energy because they can be converted to either of the other two forms with fairly little energy loss (e.g., electricity can drive a motor with only about 5% energy loss, or a resistive heater with no energy loss).

Direct Electric Storage

- Ultra capacitors
- Superconducting magnetic energy storage (SMES)
  - store energy in the magnetic field created by the flow of direct current in a superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature.
  - SMES loses the least amount of electricity in the energy storage process compared to other methods of storing energy (efficiency greater than 95%)
  - due to the energy requirements of refrigeration and the high cost of superconducting wire, SMES is currently used for short duration energy storage

Mechanical Storage

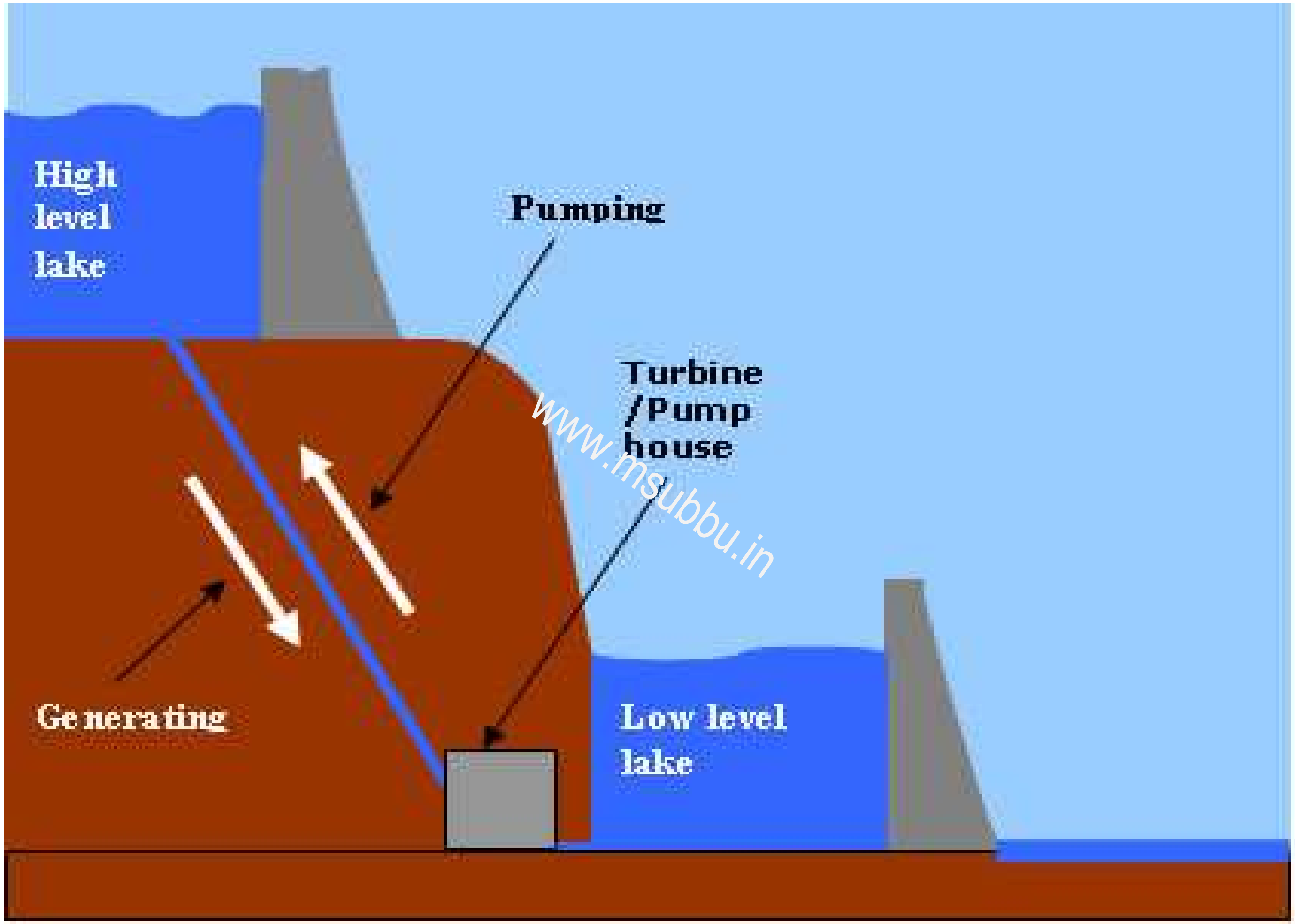
- Pumped hydro
- Compressed air
- Flywheel

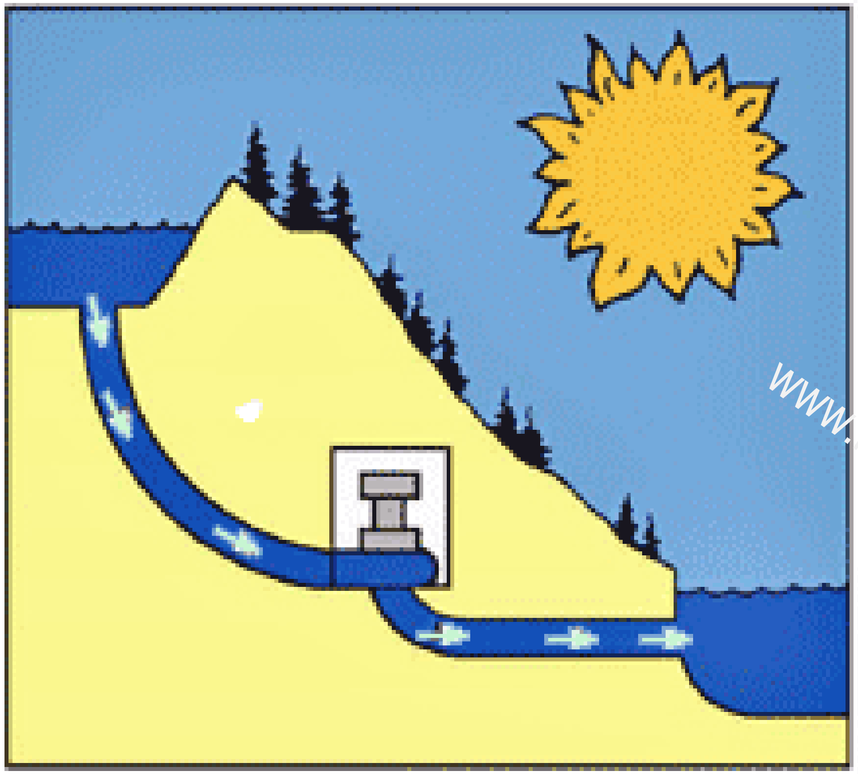
Pumped Hydro

- Pumped hydro is the oldest and largest of all of the commercially available energy storage technologies, with existing facilities up to 1000 MW in size.

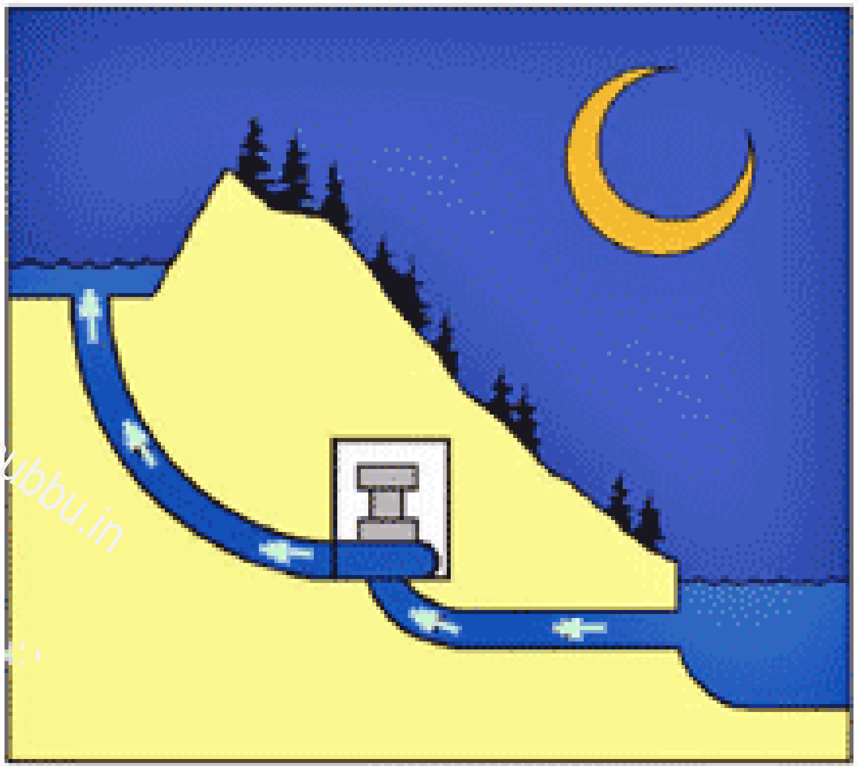
- Conventional pumped hydro uses two water reservoirs, separated vertically. Energy is stored by moving water from the lower to the higher reservoir, and extracted by allowing the water to flow back to the lower reservoir

- Pumped hydro is most practical at a large scale with discharge times ranging from several hours to a few days. There is over 90 GW of pumped storage in operation worldwide, which is about 3% of global electric generation capacity


High
level
lake
Pumping
Turbine
/Pump
house
Generating
Low level
lake



Daytime: Water flows downhill through turbines, producing electricity



Nighttime: Water pumped uphill to reservoir for tomorrow's use

Compressed Air

- A relatively new energy storage concept that is implemented with otherwise mature technologies is compressed air energy storage (CAES).
- CAES facilities must be coupled with a combustion turbine, so are actually a hybrid storage/generation technology.
- A conventional gas turbine consists of three basic components: a compressor, combustion chamber, and an expander. Power is generated when compressed air and fuel burned in the combustion chamber drive turbine blades in the expander.

Flywheel

- A **flywheel** is a mechanical device with a significant moment of inertia used as a storage device for rotational energy.

- Flywheels resist changes in their rotational speed, which helps steady the rotation of the shaft when a fluctuating torque is exerted on it by its power source

Thermal Storage

- Sensible heat
- Latent heat

Sensible Heat Storage

- Sensible heat storage in a liquid is, with very few exceptions, accomplished with water. Water is unique among chemicals in having an abnormally high specific heat of 4.186 kJ/kg.K, and furthermore has a reasonably high density. Water is also cheap and safe. It is the preferred choice for most non-concentrating solar thermal collectors

- When a larger temperature range than that afforded by water is required, mineral, synthetic, or silicone oils can be used instead. The tradeoffs for the increased temperature range are higher cost, lower specific heat, higher viscosity (making pumping more difficult), flammability, and, in some cases, toxicity

- For very high temperature ranges, salts are usually preferred that balance a low specific heat with a high density and relatively low cost.

Latent heat storage

- Latent heat is absorbed or liberated by a phase change or a chemical reaction and occurs at a constant temperature.

- The latent heat, E_s, stored through a phase change is:

$$E_s = \lambda M;$$

where M is the mass of material undergoing a phase change (kg), and λ is the latent heat of phase change

Latent heat storage - Phase change systems

- Practical energy storage systems based on a material phase change are limited to solid–solid and solid–liquid phase changes
- Solid–solid phase changes occur when a solid material reorganizes into a different molecular structure in response to temperature. One particularly interesting example is lithium sulfate (Li_2SO_4) which undergoes a change from a monoclinic structure to a face-centered cubic structure at 578^{o}C, absorbing 214 J/g in the process, more than most solid–liquid phase changes
- Fatty acids and paraffins received particular attention in the 1990s

TABLE 12.4 Melting Points and Heats of Fusion for Solid–Liquid Phase Changes

	Melting Point°C	Heat of Fusion J/g
Aluminum bromide	97	42
Aluminum iodide	191	81
Ammonium bisulfate	144	125
Ammonium nitrate	169	77
Ammonium thiocyanate	146	260
Anthracine	96	105
Arsenic tribromide	32	37
Beeswax	62	177
Boron hydride	99	267
Metaphosphoric acid	43	107
Naphthalene	80	149
Naphthol	95	163
Paraffin	74	230
Phosphoric acid	70	156
Potassium	63	63
Potassium thiocyanate	179	98
Sodium	98	114
Sodium hydroxide	318	167
Sulfur	110	56
Tallow	76	198
Water	0	335

Source: From Kreith, F. and Kreider J.F., *Principles of Solar Engineering*, Taylor & Francis, 1978. With permission

Thermo-chemical Energy Storage

- Biomass solids
- Ethanol
- Bio-diesel
- Syngas from biomass