Solar Energy Storage Systems Review

Yu Hou[1], Ruxandra Vidu[2] and Pieter Stroeve[2]
[1] Department of Mechanical and Aerospace Engineering, University of California, Davis
[2] Department of Chemical Engineering and Materials Science, University of California, Davis

ABSTRACT:
Solar energy can provide an abundant source of renewable energy (electrical and thermal). However, because of its unsteady nature, the storage of solar energy will become critical when a significant portion of the total energy will be provided by solar energy. In this paper, current solar energy storage technologies are reviewed. Storage methods can be classified into categories according to capacity and discharge time. New developments in solar energy storage require advances in chemical engineering and materials science. Life cycle assessment (LCA) is an important tool to evaluate energy consumption and environmental impact of renewable energy processes. LCAs of some of the storage methods are reviewed. It is important to note that, while using renewable energy sources such as solar power, storage methods based on non-recyclable materials or methods that consume significant amounts of energy may undermine the effort to reduce energy consumption.

Classification According to Storage	
Electrical energy storage	Directly electricity storage in devices such as capacitors or super-conducting magnetic devices. Those storage methods have the advantage of quickly discharging the energy stored.
Mechanical energy storage	Storage of electrical energy in the form of kinetic energy such as flywheel or potential energy such as pumped hydroelectric storage (PHS) or compressed air energy storage (CAES).
Chemical energy storage	Storage in chemical energy form as in batteries, fuel cells and flow batteries. Chemical energy storage usually has small losses during storage.
Classification according to usage	
Bulk Energy Storage	Bulk energy storage has discharge power range from 10-1000 MW, discharge time are from 1-8 hours and stored energy range of 10-8000 MWh. The applications of such storage are in load leveling and spinning reserve.
Distributed Generation	Distributed generation storage has discharge power range from 100-2000 kW, discharge time range from 0.5-4 hours, and stored energy range of 50-8000 kWh. The application of such storage is in peak shaving and transmission.
Power Quality	Power quality storage has discharge time range from 0.1-2 MW, discharge time 1-30 seconds and stored energy range from 0.028-16.67 kWh. The applications are end-use power quality and reliability.

Characteristics of Commercial Battery Units Used in Electric Utilities

Battery type		Capacity (MW/ MWh)	Efficiency (%)	Cost ($/kWh)	Life span (Cycles)	Depth of discharge (%)	Operating temperature (°C)	Energy Density (Wh/kg)
Lead acid	Flooded type	10/40	72~78	74.2~223	1000~2000	70	-5~40	25
	Valve regulated	0.3/0.58	72~78	74.2~223	200~300	80	-5~40	30~50
Nickel Cadmium (NiCd)		27/6.75	72~78	297~890	3000	100	-40~50	45~80
Sodium Sulphur (NaS)		9.6/64	89	N.A.	2500	100	325	100
Lithium ion		N.A.	100	1040~1480	3000	80	-30~60	90~190
Metal Air		N.A.	50	74.2~297	<100	N.A.	-20~50	450~650
Flow battery	Regenerative fuel cell (PSB)	15/120	75	534~1480	N.A.	N.A.	0~40	N.A.
	Vanadium Redox (VRB)	1.5/1.5	85	534~1480	10,000	75	0~40	30~50
	Zinc	¼	75	534~	N.A.	N.A.	0~40	70

Electrical Energy Storage

Pumped hydro- electric storage (PHS) has the largest storage capacity that is commercially available. The basic idea is simple: use the excess electrical energy generated at off-peak hours to pump water from a lower reservoir to a higher reservoir.

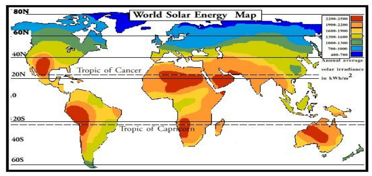
Flywheel energy storage systems store energy in the form of angular momentum. During peak time, energy is used to spin a mass via a motor. At discharge, the motor becomes a generator that produces electricity.

Compressed air energy storage (CAES)- the idea of the system is to use the off-peak excess electricity to compress air. At a later time, the compressed air can be used along with a gas turbine to generate electricity.

Battery and fuel cells are electrochemical cells that converts stored chemical energy to electrical energy.

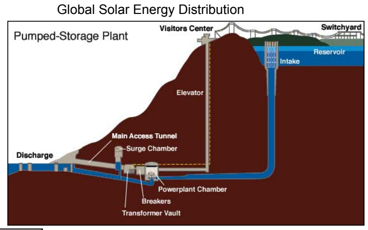
Superconducting magnetic energy storage (SMES) method stores electrical energy in a magnetic field that is generated by direct current.

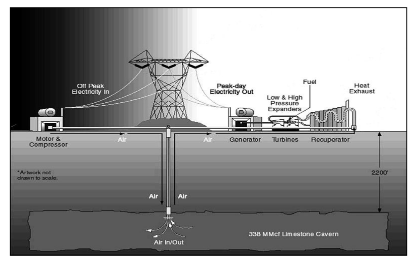
Capacitors store energy in the form of electrical potential created by the two sides of the capacitors. The two plates are charged during the off peak hour to create potential and discharged during peak hour.



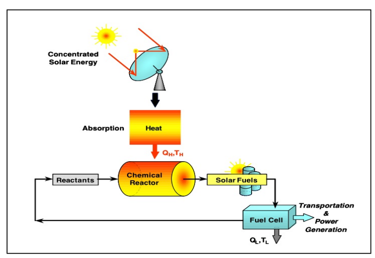
Global Solar Energy Distribution

location	facility	capacity (MW)
Virginia	Bath County	2772
New Jersey	Mt. Hope	2000
California	Castaic Dam	1566
Michigan	Ludington	1872
California	Pyramid Lake	1495





CAES System

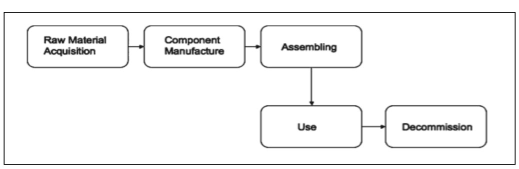


Solar Fuel Production and Storage

Life cycle assessment

Life cycle assessments (LCAs) are investigations performed to characterize and quantify the cradle-to-grave environmental impacts of certain products and services. LCA accounts for the materials, resources, and energy that enters the system, as well as the waste and pollution that leaves the system.

LCA studies such as those presented above should also be performed for all other storage methods. The studies can provide us a more realistic indication, with regard to the efficiency and environmental impact of each storage method, and may reveal additional information, such as the production of raw materials and co- products of the process, which could be important.



Thermal Energy Storage

Sensible Heat. Changing the temperature of materials (liquid or solid) by using solar energy generated at its peak hour, energy is stored by the temperature difference of the material with the original temperature.

Phase Change Material Storage (PCMS). When a material undergoes a phase change, heat is absorbed or released. Energy can be stored or released by change phases of the storage materials

Sorption is the fixation or capture of a gas or a vapor (sorbate) by a solid or liquid substance (sorbent). When heat is introduced to the system, AB is split into compounds A and B, energy is stored as the chemical potential of A and B with negligible loss. When A and B are mixed, A is fixed onto B to form AB, releasing heat.

Solar Fuel. Using optical devices, scattered sunlight can be concentrated and the heat generated from concentrated solar power can be used to carry out endothermic chemical transformation to produce storable and transportable fuels.

Conclusion

Solar energy storage methods are urgently needed, because of the increased demand and unsteady nature of solar power. The implementation of proper energy storage remains crucial to achieve energy security and to reduce environmental impact. It is difficult to compare different types of storage methods using only one factor. It should be noted that some materials needed for certain storage methods are scarce, such as ruthenium for capacitors and lithium for batteries. While using renewable energy sources such as solar power, storage methods based on nonrenewable resources may undermine the initial effort to resolve the energy problem

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