Enerji Depolama Metodları

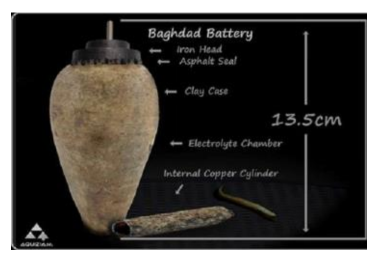
- Elektrokimyasal (bataryalar, sıvı elekrolit bataryaları)
- Elektriksel (Kapasitörler, süperkapasitörler, manyetik enerji depolama)
- Kimyasal (hidrojen, biyoyakıtlar, sıvı azot)
- Biyolojik (nişasta, glikojen)
- Mekanik (sıkıştırılmış hava, flywheel, hidrolik akü, hidro-elektrik)
- Isıl (buz, eriyik tuz, güneş havuzu vb)

Energy Storage Methods

- Electro-chemical (batteries, flow batteries)
- Electrical (capacitors, supercapacitors, superconducting magnetic energy storage)
- Chemical (hydrogen, biofuels, liquid nitrogen)
- Biological (starch, glycogen)
- Mechanical (compressed air, flywheels, hydraulic accumulator, hydro-electric)
- Thermal (ice, molten salt, solar pond, etc)

Batarya Tarihi

- Italian physicist Alessandro Volta invented the first electrochemical cell in 1792.
- İtalyan fizikçi Alessandro Volta 1792 yılında ilk elektrokimyasal hücreyi üretmiştir.



- Hücre = cell

- In 1800 , he invented the first battery with many cells.
- 1800 yılında ise çok hücreli ilk bataryayı üretmiştir.

Battery Types

- Primary Batteries
  - Disposable batteries
  - Can not be reliably recharged
  - Chemical reactions not reversible
- Secondary Batteries
  - Rechargeable batteries
  - Can be charged with a *charger*
  - *Lead-acid, NiCd, Nzn, NiMH, Li-ion*
  - Lower total cost compared to disposable batteries

Cell types

- Galvanic cells
- Electrolytic cells
- Fuel cells
- Flow cells (rechargeable fuel cell)
- Voltaic piles

Applications of Electrical Energy Storage

- Ground transportation
- Aerospace (aircrafts, space vehicles)
- Renewable energy – solar and wind
- Grid energy storage
- Consumer electronics (computers, cell phones)
- Tools and others

Ground transportation applications of electrical storage

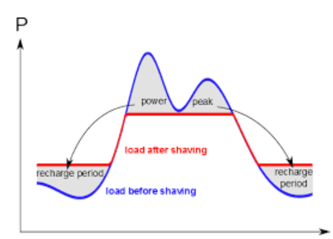
- Hybrid electric vehicles
- Plug-in electric vehicles
- Motorized wheelchairs
- Golf carts
- Electric bicycles
- Forklifts
- Automobile starters

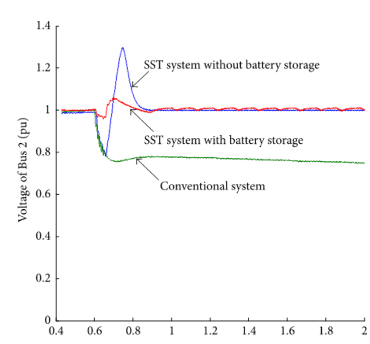
Aerospace application of electrical storage

- Auxiliary power unit
- Start systems of engines
- Emergency power
- Emergency lightning
- Hybrid electric propulsion
- All electric propulsion

Renewable energy

- Solar and wind power is intermittent
  - Load leveling: used to store energy for peak load periods. Reduce the need for peak power plants
  - Storing power from photovoltaic arrays during the day and use at night
  - Transient assist : use of stored energy for stabilizing the network during transients





Grid energy storage applications

- Electric supply applications
  - Electric energy time shift
  - Electric supply capacity
- Ancillary service applications
  - Load following
  - Area (frequency) regulation
  - Electric supply reserve capacity
  - Voltage support
- Power system applications
  - Transmission support and congestion relief
  - Transmission and distribution upgrade deferral
  - Substation on-site power

- Consumer applications
  - Time of use energy cost management
  - Demand charge management
  - Electric service reliability
  - Electric service power quality
- Renewable integration applications
  - Renewable energy time shift
  - Renewable capacity firming
  - Wind generation grid integration
- Community energy storage applications

Consumer electronics

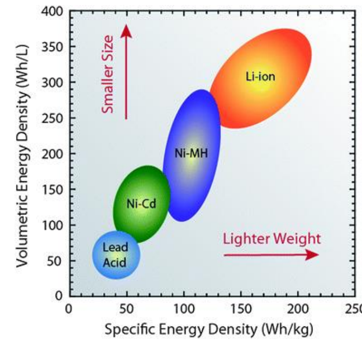
- Cell phones
- Laptop computers
- Cordless phones
- Cameras
- Toys
- Health systems
- etc

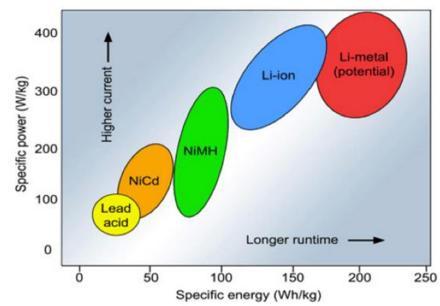
Tools and others

- Uninterruptable power supplies
- Blowers
- Hand held drills

Battery chemistry comparisons

- Specific energy is the storage capacity that a battery can hold in watt-hours per mass (kilogram) (Wh/kg)
- Specific power is the battery’s ability to deliver power in watts per mass (kilogram) (W/kg)
- Energy density is the energy capacity of the battery per volume (Wh/l)



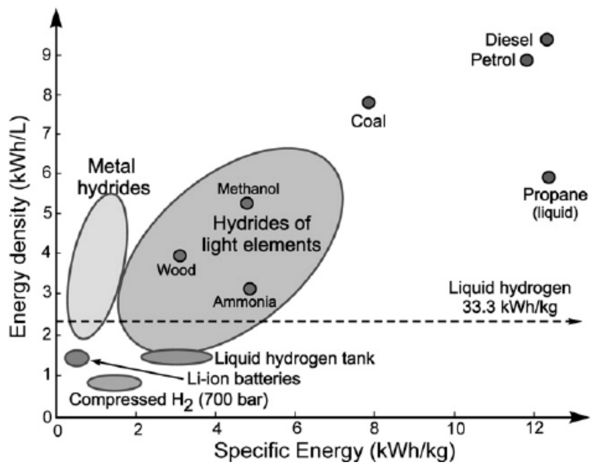


Energy storage capacity and peak power capability of various storage options

- Pumped hydro
- Compressed air energy storage
- Batteries
  - NaS
  - Lead acid
  - NiCd
  - Flow batteries
  - Lithium ion
  - NiMH
- Flywheels
- Electrochemical capacitors

Energy

Power

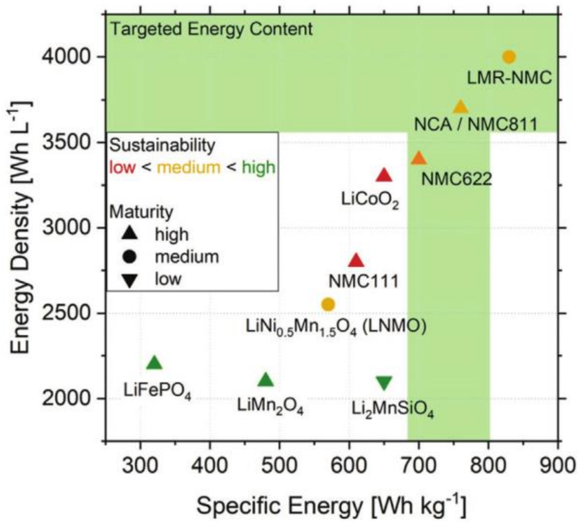


Battery electrochemistry comparisons

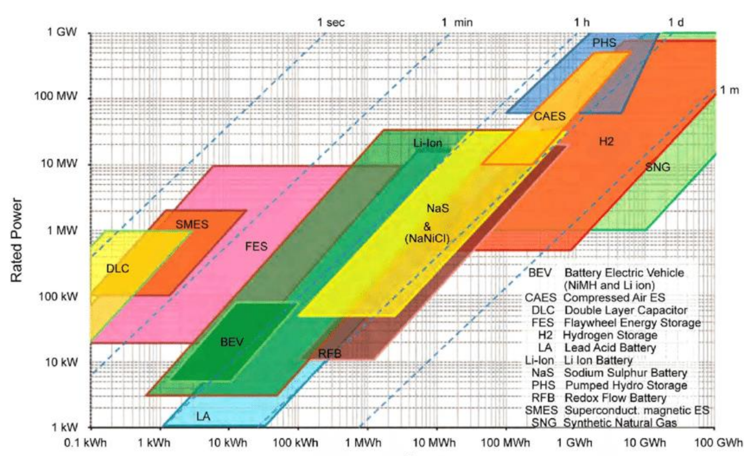
Specifications	Lead-Acid	NiCd	NiMH	Li-Ion		
				Cobalt	Manganese	Phosphate
Specific energy density (Wh/kg)	30 – 50	45 – 80	60 – 120	150 – 190	100 – 135	90 – 120
Internal resistance (mΩ/V)	<8.3	17 – 33	33 – 50	21 – 42	6.6 – 20	7.6 – 15.0
Cycle life (80% discharge)	200 – 300	1,000	300 – 500	500 – 1,000	500 – 1,000	1,000 – 2,000
Fast-charge time (hrs.)	8 – 16	1 typical	2 – 4	2 – 4	1 or less	1 or less
Overcharge tolerance	High	Moderate	Low	Low	Low	Low
Self-discharge/month (room temp.)	5 – 15%	20%	30%	<5%	<5%	<5%
Cell voltage	2.0	1.2	1.2	3.6	3.8	3.3
Charge cutoff voltage (V/cell)	2.40 (2.25 float)	Full charge indicated by voltage signature	Full charge indicated by voltage signature	4.2	4.2	3.6
Discharge cutoff volts (V/cell, 1C*)	1.75	1	1	2.5 – 3.0	2.5 – 3.0	2.8
Peak load current**	5C	20C	5C	> 3C	> 30C	> 30C
Peak load current* (best result)	0.2C	1C	0.5C	<1C	< 10C	< 10C
Charge temperature	-20 – 50°C	0 – 45°C	0 – 45°C	0 – 45°C	0 – 45°C	0 – 45°C
Discharge temperature	-20 – 50°C	-20 – 65°C	-20 – 65°C	-20 – 60°C	-20 – 60°C	-20 – 60°C
Maintenance requirement	3 – 6 months (equalization)	30 – 60 days (discharge)	60 – 90 days (discharge)	None	None	None
Safety requirements	Thermally stable	Thermally stable, fuses common		Protection circuit mandatory		
Time durability				>10 years	>10 years	>10 years
In use since	1881	1950	1990	1991	1996	1999
Toxicity	High	High	Low	Low	Low	Low

Source: batteryuniversity.com. The table values are generic, specific batteries may differ.
*"C" refers to battery capacity, and this unit is used when specifying charge or discharge rates. For example: 0.5C for a 100 Ah battery = 50 A.
**Peak load current = maximum possible momentary discharge current, which could permanently damage a battery.

Battery electrochemistry comparisons



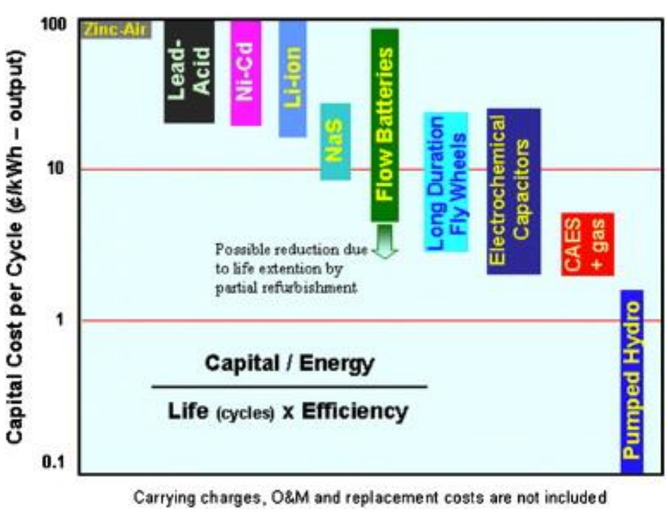
Energy storage technology comparisons



Energy storage technology comparisons

Storage system	Cycling efficiency	lifetime	cost	complexity	Energy capacity	Peak power capacity
Lead acid battery	75-85%	<500	+	Low	Low	Low
Li-ion battery	85-95%	<4000	+++	Low	High	High
NiMh battery	80-90%	500-1000	++	Low	Medium	Medium
Ultra capacitor	>99%	1000000	++	Low	Lowest	Medium
Battery/UC	>95%	<15000	+++	Moderate	Medium	High
Flywheel	80%	<50000	+++	Moderate	Lowest	Medium
Compressed air	75-80%	10000	++++	Moderate	Medium	High
Compressed hydraulic	85-90%	15000	++++	Moderate	Medium	High
Pumped hydro	70-85%	20-30 years	++++	Moderate	Highest	High to Highest
Redox flow battery	70-80%	<15000	++++	High	High	Highest
Hydrogen	30-50%	<20000	+++++	High	High	Highest

Cost per cycle comparisons of energy storage systems



- While the capital cost is an important economic parameter for a complete economic analysis, the total ownership cost is a more meaningful index for a complete economic analysis.

Ders içeriği

Konular
Giriş
Enerji depolama metodları
Batarya elektrokimyalarına giriş
Kurşun asit bataryalar
Lithium ion bataryalar
Süper kapasitörler
Nikel Metal Hydrid bataryalar
Batarya sistem entegrasyonu
Otomotiv batarya uygulamaları
Şebekeye bağlı enerji depolama sistemleri ve uygulamaları
Havacılık uygulamaları
Bataryaların modelleme ve simülasyonu
Gelecek elektrik enerjisi depolama uygulamaları

Ders içeriği -2

Konular
Enerji depolama sistemleri araştırmaları
Bataryaların ölçümü, tahmini ve korunması
Şarj üniteleri
Batarya geri dönüşümü
Batarya standartları ve testleri
Süper kapasitörler

- **Sorular ??**