CLEEN
Cluster for Energy and Environment

sgem
Smart Grids and Energy Markets

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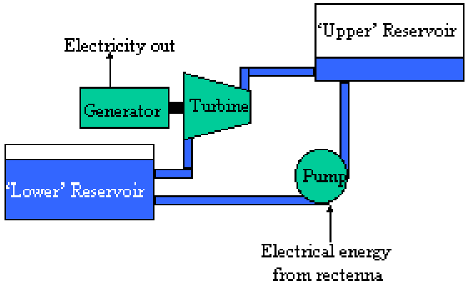

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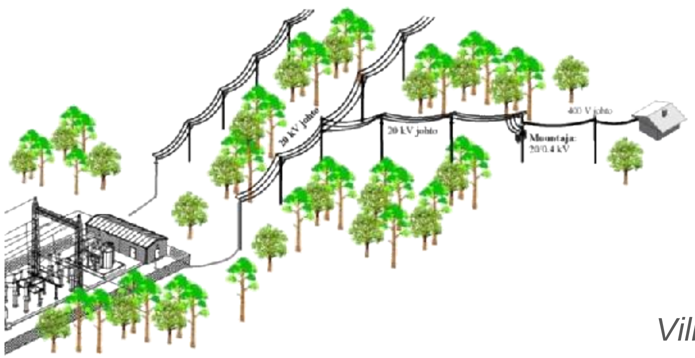
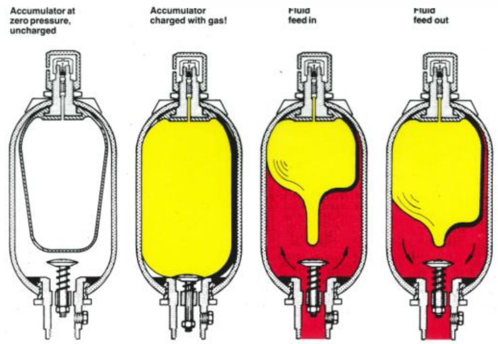
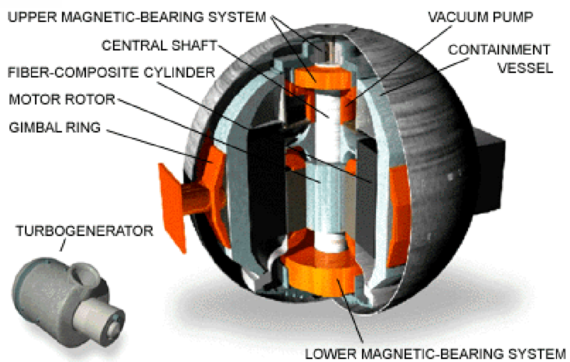
Energy Storages

Ville Tikka, Jukka Lassila, Henri Makkonen (LUT)







What is energy storage?

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- In energy storage energy is stored to be used at different time when it was generated
- Grid point:
  - Energy generated and stored during periods of low energy demand can be released to meet higher demand periods

- Storages can be mechanical, chemical or electronical
- Where can energy storages be used?
  - Large scale applications in transmision/distribution grid
  - Small scale applications in EV's and PHEV's

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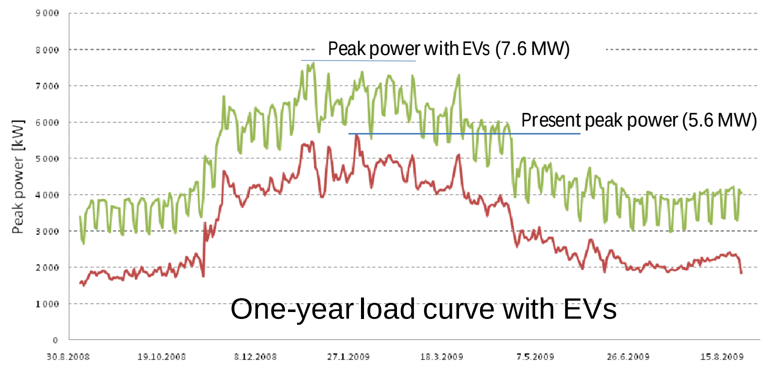
Why do we need energy storages?

- Increasing number of EV's, PHEV's, heat pumps, etc
  - → Increasing energy and power demand
  - High cap between base load and peak load
- Increasing amount renewables (wind, solar)
- **Load leveling**
- To improve **power quality**
- Storage solutions can be long or short period solutions
  - flywheel vs. pump station
    - voltage sag vs. load leveling
  - super capasitor vs. battery
    - momentary voltage sag vs. temporary voltage sag
- **Active resources**



Energy storages are one part of the Smartgrids

Many solutions storing energy

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- Suitable for grid
  - Batteries
    - Lead-acid, flow batteries, Ni-Cd, Li-ion, etc
  - Super capasitor
  - Flywheels
  - SMES (Superconducting magnetic energy storage)
  - Pumped-storage
  - Comprerssed air storage

- Other energy ”storages”
  - Biofuels
  - Hydrogen
  - Spring, and many more

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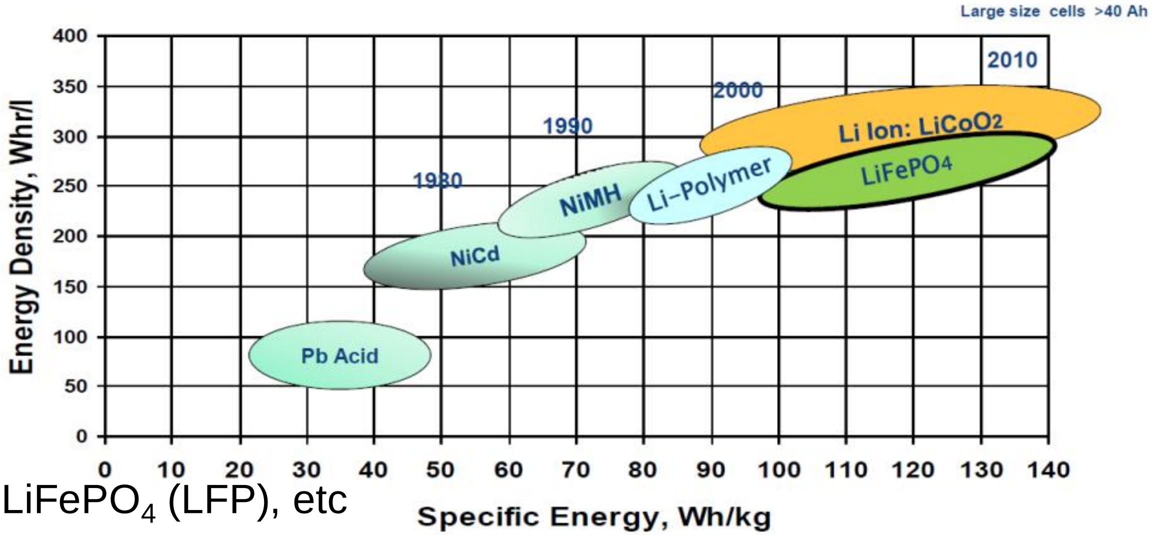
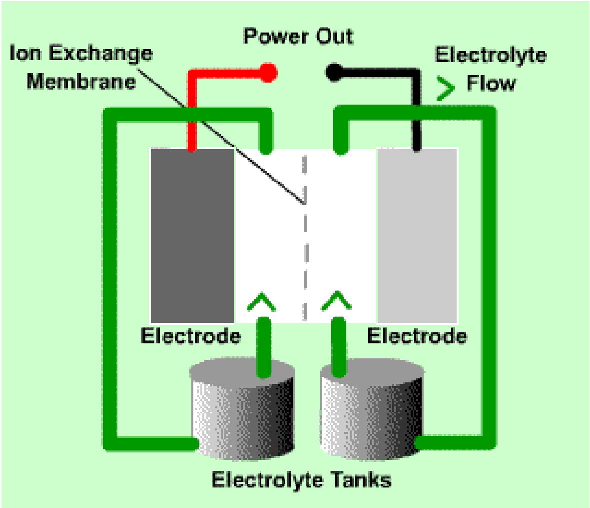
Batteries

- Lead acid
  - 20 Wh/kg
- NiCd, NiMH, NiZn
  - 40-80 Wh/kg
- Flow batteries
  - 10-70 Wh/kg
- Advanced lithium technologies
  - Lithium-titanate, lithium-iron oxide, $LiFePO_4$ (LFP), etc
  - <100 Wh/kg
  - Need for more complicated control electronics
  - High efficiency
- Lifetime few years or 500–2000 charge cycles
- Batteries can be used for small scale load leveling and to improve power guality
- 50–3000 €/kWh
- Future ?
  - Higher specific energy / lower price / higher cycle life
  →Revolutitionary small scale energy storages?



Alatalo, European Batteries 2010



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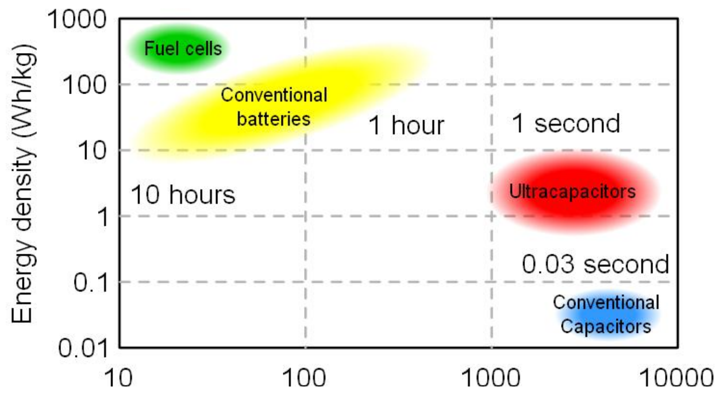
Super capacitors

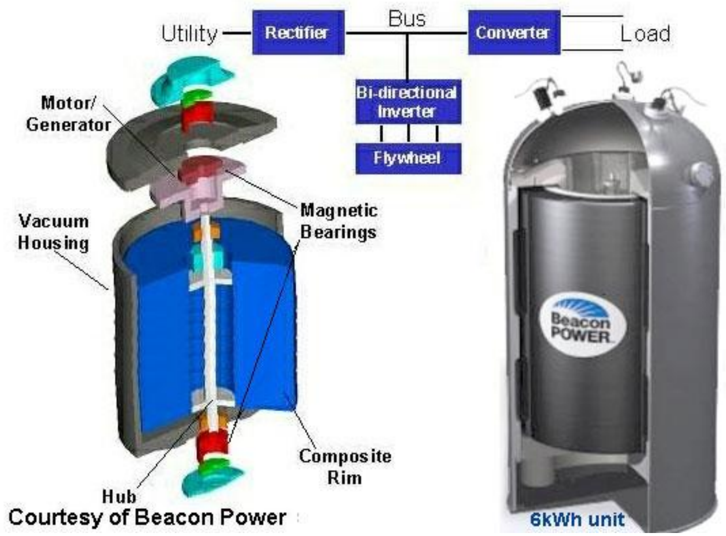
- High specific power compared to batteries
  - < 1000 W/kg
- Low specific energy
  - 1-10 Wh/kg
- Combined super capasitor and battery storage
  - < 1000W/kg (1-10 s)
  - < 100Wh/kg
  - Several k€/kWh, (2 k€/kW)
- Life cycle tens of years or tens of thousands cycles
- Near future
  - Capasitors with higher specific energy?
    - More than 80 Wh/kg

    → batteries vs. super capsasitors
- Power quality solutions



Flywheel, SMES

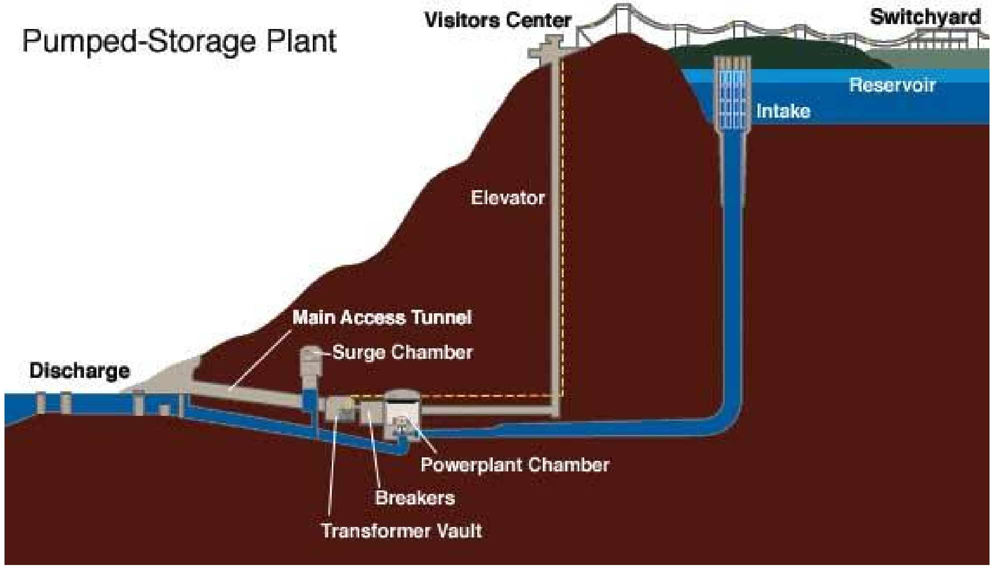
- **Flywheel**
  - Mechanical, store energy as angular momentum
  - High power, short period
  - Power quality management
  - 40 kW–1.6 MW
  - 5–120 s
  - Capacity < 100 kWh
  - 700–1000 €/kWh



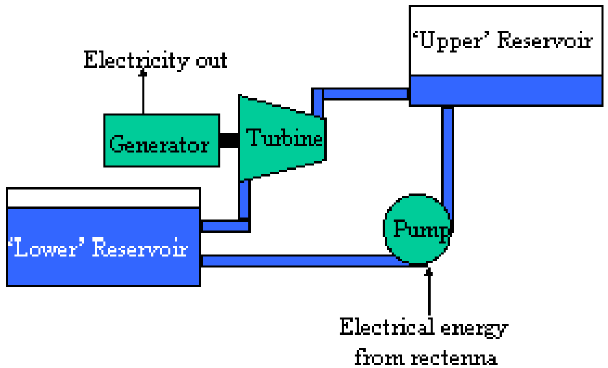
- **SMES** (Superconducting Magnetic Energy Storage)
  - No need for chemical or mechanical conversion for storing energy
  - Power quality management
  - Power up to 2 MW
  - Short period,1 s
  - Typical lifetime 20 years
  - System efficiency over 95%
  - 800-1800 €/kWh

Pumped-storage, “Hydro-storage”

- Mechanical storage
- Energy is stored by pumping water to higher ground
- Efficiency 50 – 87 %
- Power < 250MW
- Lifetime 30 years
- High capasity
- Most widespread high-energy storage technique
- Energy management



The upper reservoir (Llyn Stwlan) and dam of the Ffestiniog Pumped Storage Scheme in north Wales.



Compressed air energy storages, CAES

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- Mechanical storage
- Energy is strored in compresed air
    - Air tank, cavern
    - Adiabatic, diabatic or isothermal

- Needs gas fuel to operate
- Efficiency 40–73 %
- Power 15–400 MW
- Lifetime 35 years, 20 000–100 000 cycles
- 300–800 €/kWh
- Large scale load leveling and energy management

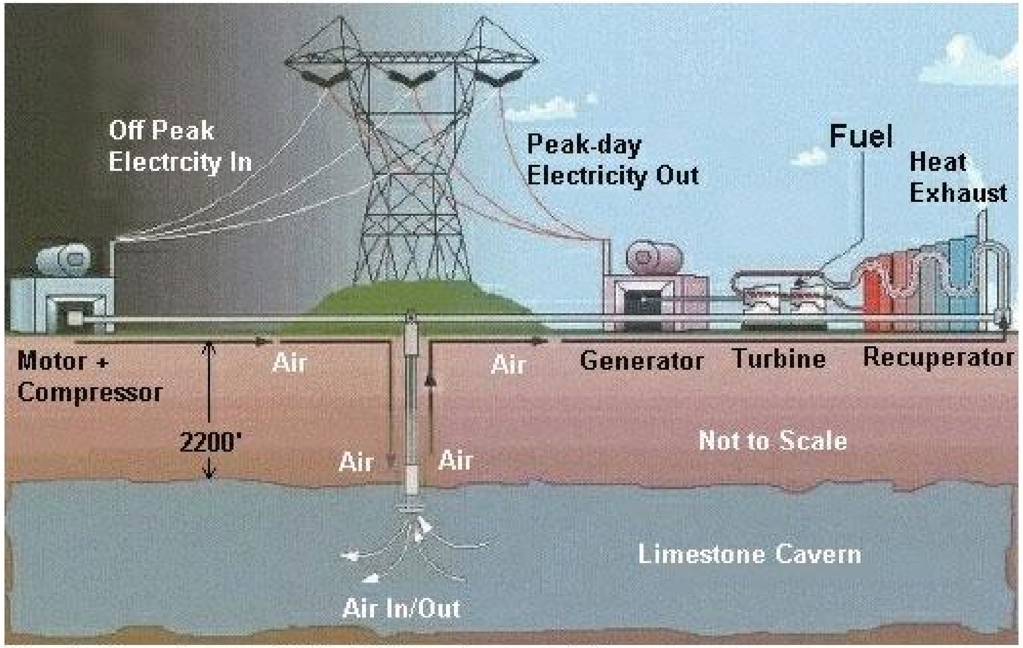

Photo Courtesy of CAES Development Company

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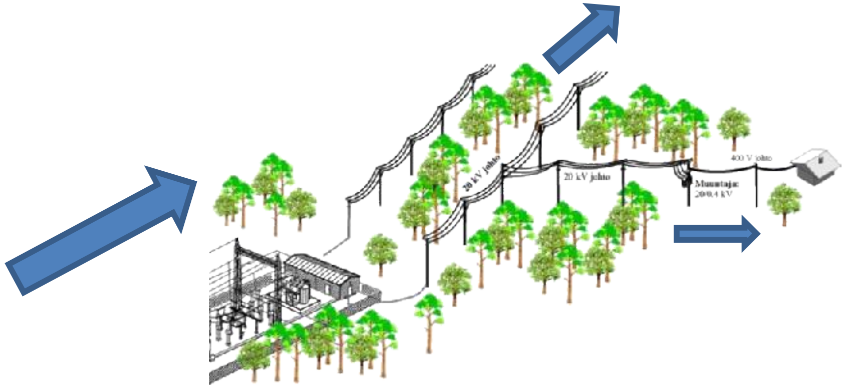
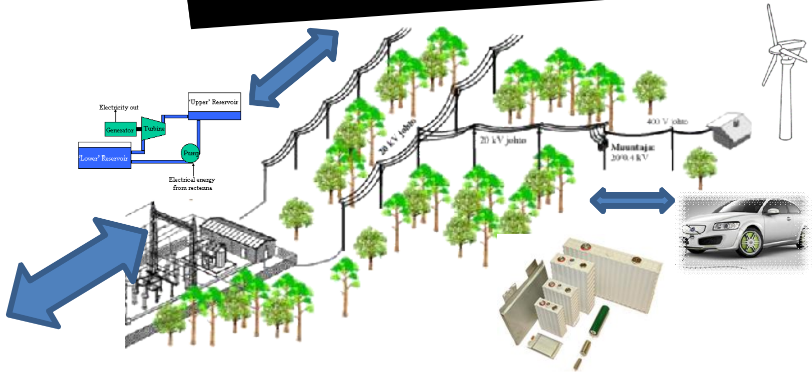
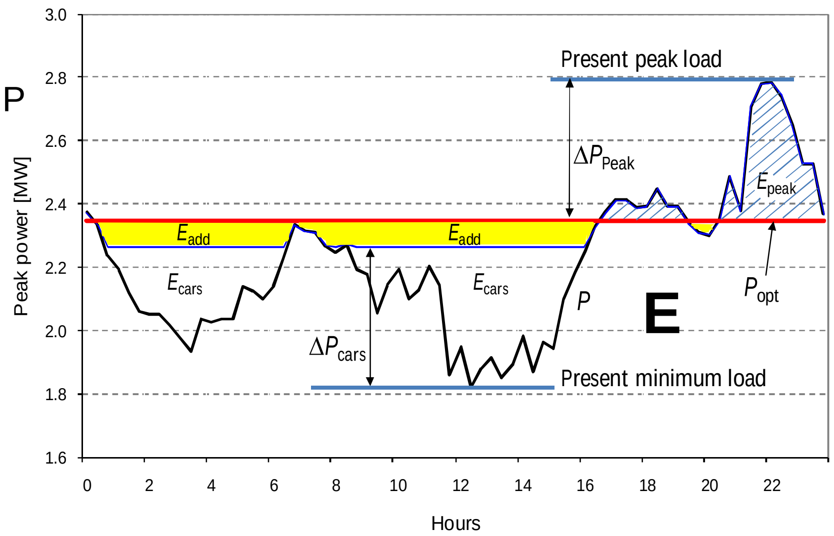
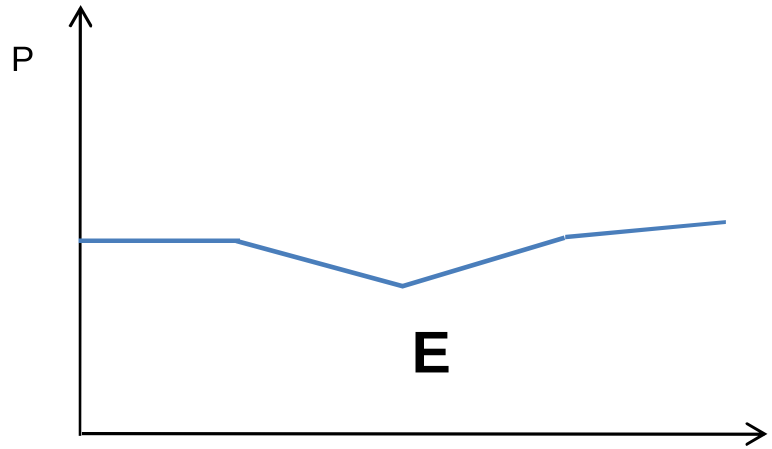
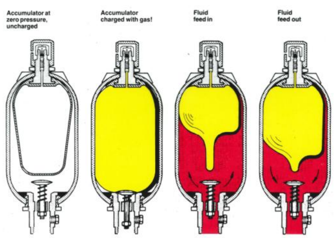
Load Leveling

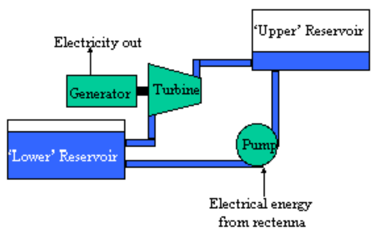




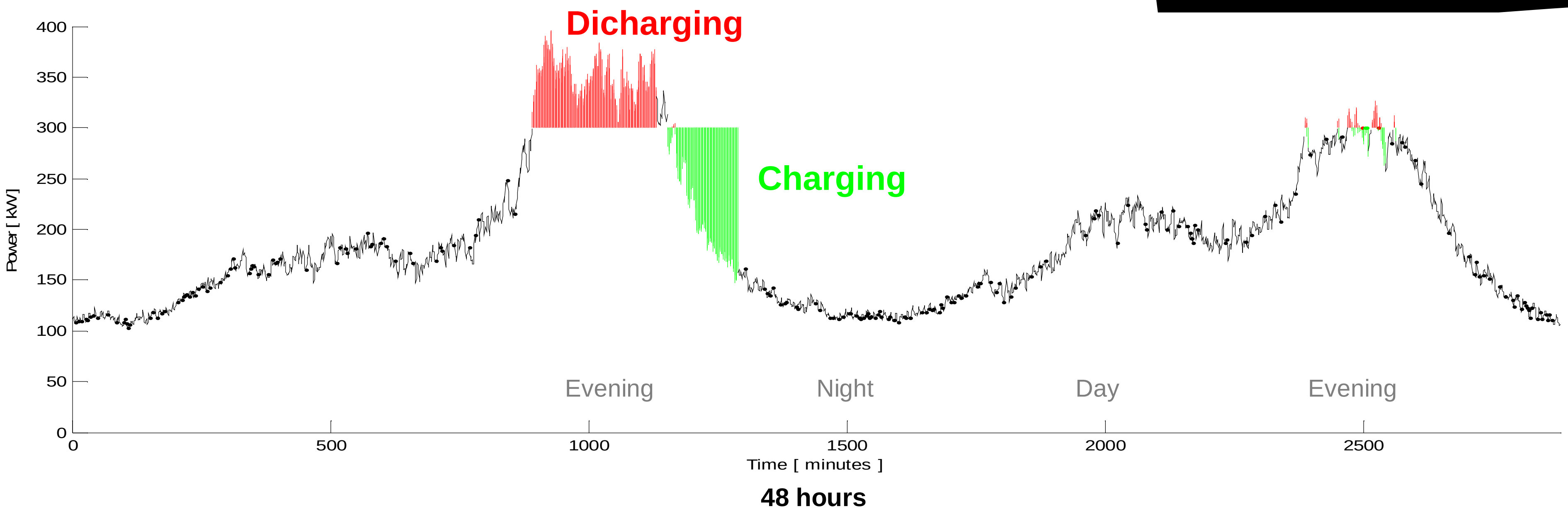


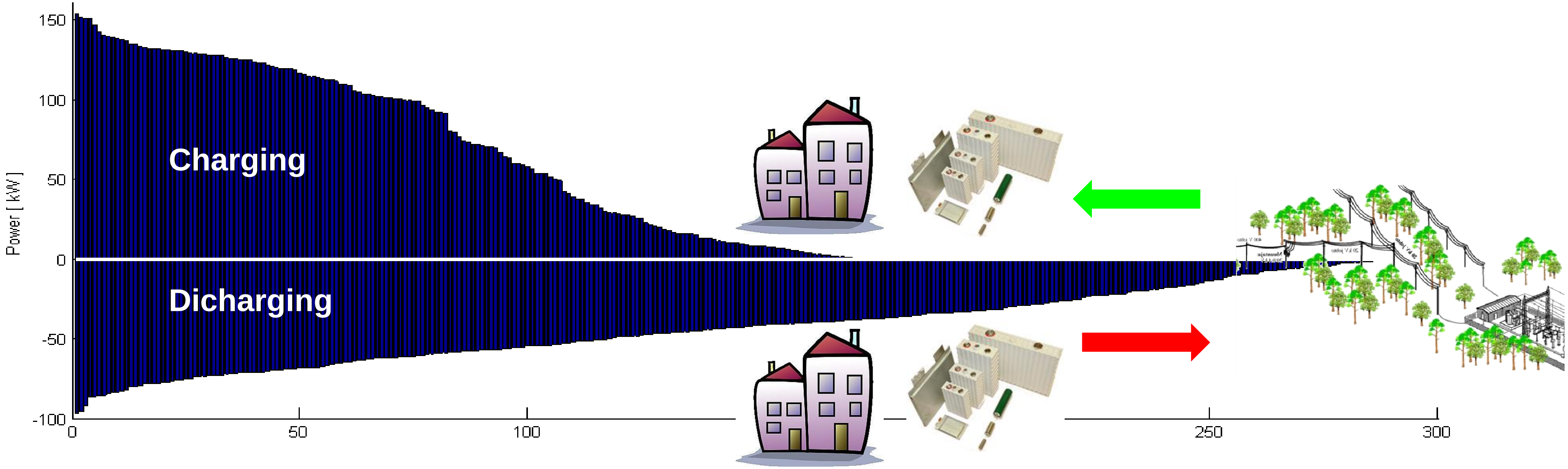






Load Leveling





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Power flow and use of storages in the grid

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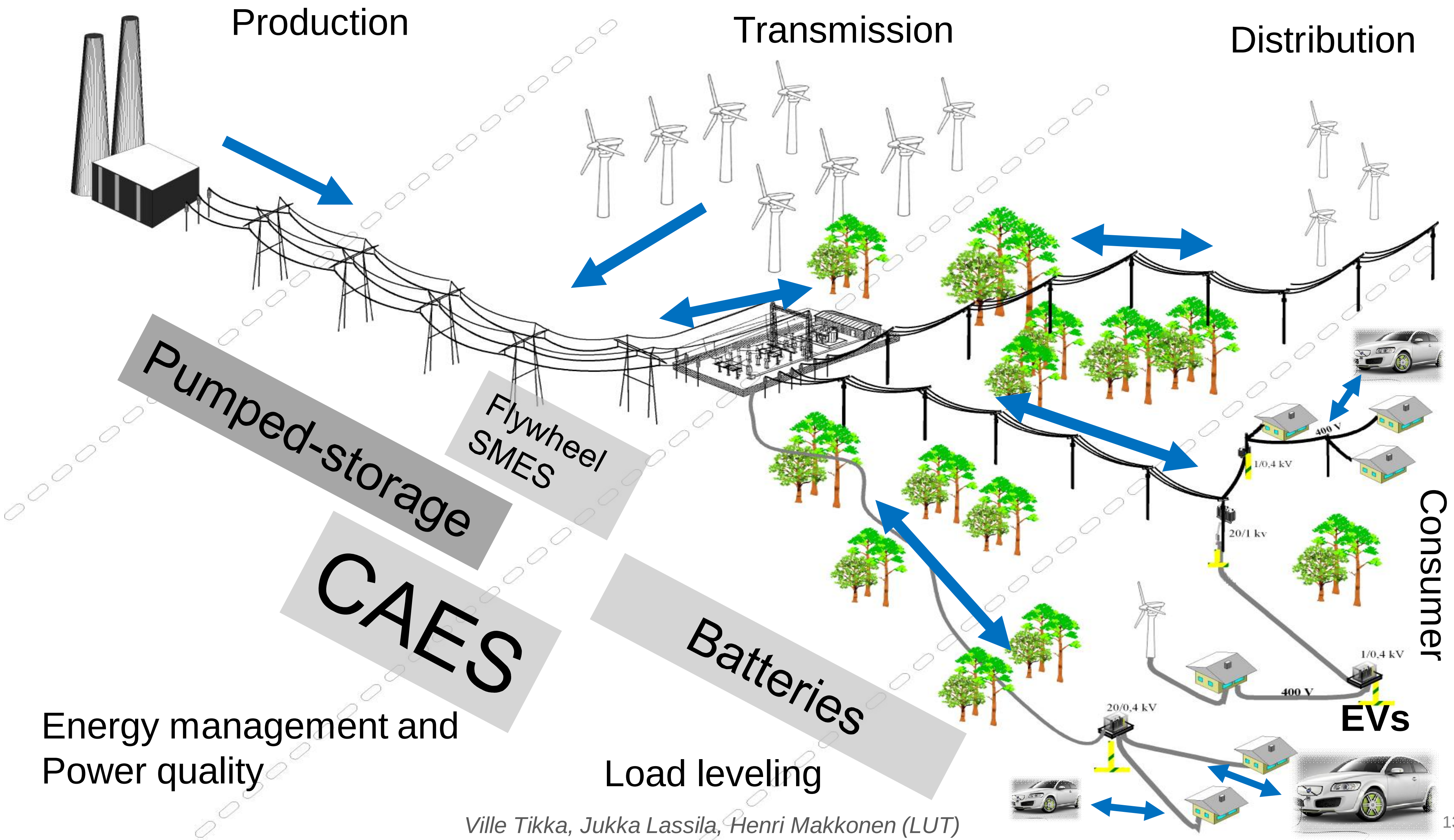

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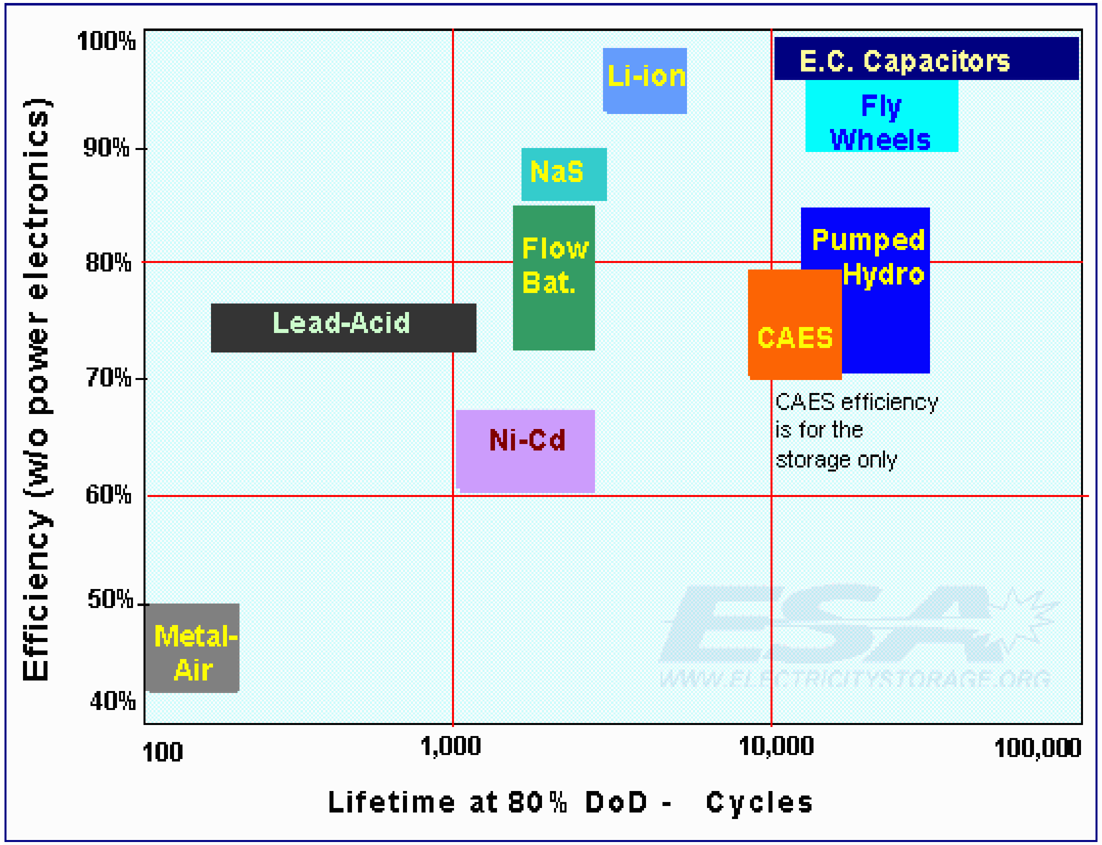
Conclusion

- Several alternatives for energy storing
- Using energy storages causes additional losses but give possibility to flat power peaks and release network capacity

- If feasibility can be proved…
  - → **Smart Grid revolution**
  - – Less need for peak capacity
  - – Power quality improvement
  - – More efficient grid system

Network capacity and electricity price **vs.** Cost of energy storing



www.electricitystorages.org

Conclusion

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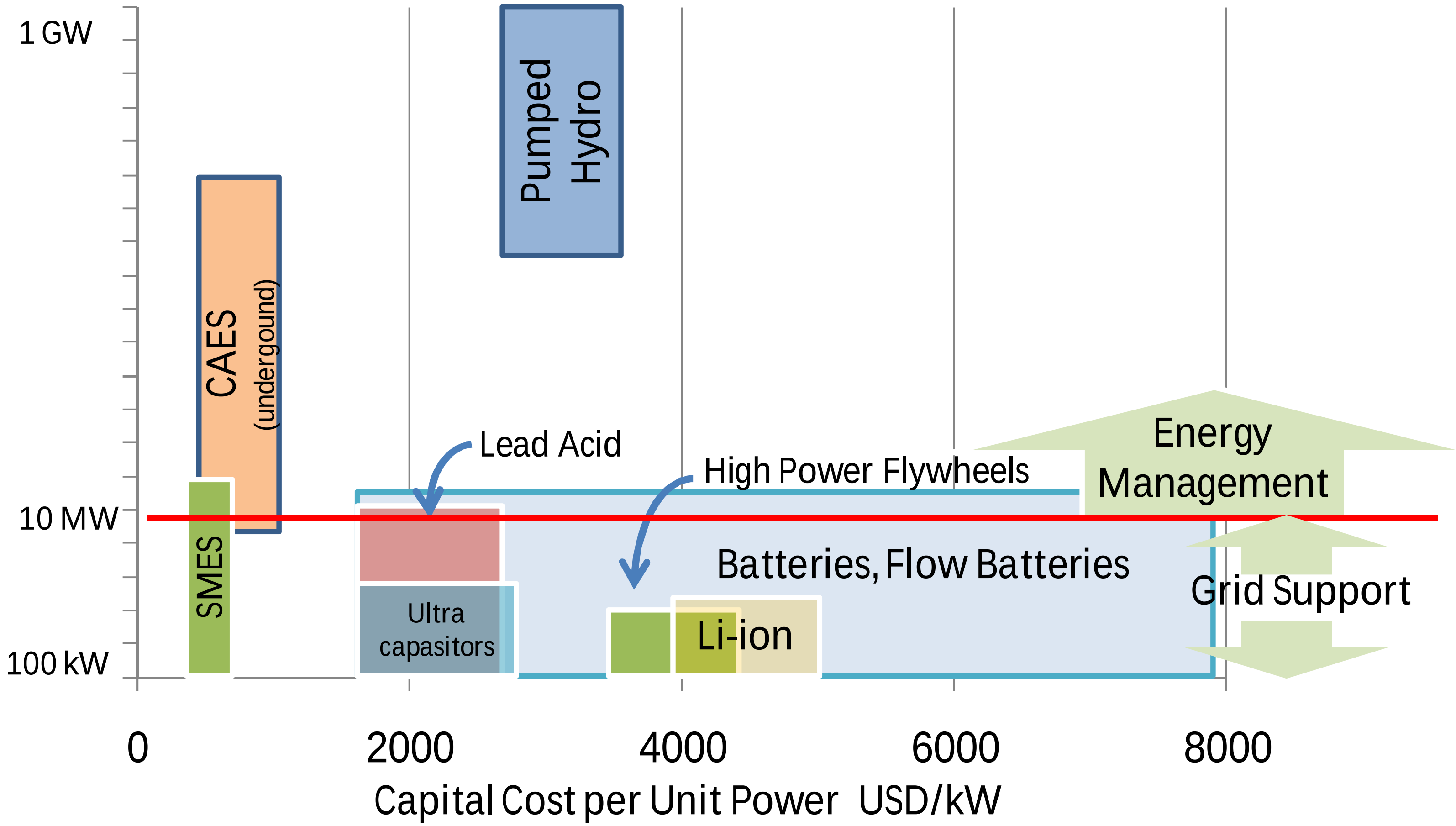
Storage capital costs per unit power



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Energy Storages

Storage Technologies	**Main Advantages** (relative)	**Disadvantages** (Relative)	**Power** Application	**Energy** Application
Pumped Storage	High Capacity, Low Cost	Special Site Requirement		●
CAES	High Capacity, Low Cost	Special Site Requirement, Need Gas Fuel		●
Flow Batteries: PSB VRB ZnBr	High Capacity, Independent Power and Energy Ratings	Low Energy Density	◐	●
Metal-Air	Very High Energy Density	Electric Charging is Difficult		●
NaS	High Power & Energy Densities, High Efficiency	Production Cost, Safety Concerns (addressed in design)	●	●
Li-ion	High Power & Energy Densities, High Efficiency	High Production Cost, Requires Special Charging Circuit	●	○
Ni-Cd	High Power & Energy Densities, Efficiency		●	◐
Other Advanced Batteries	High Power & Energy Densities, High Efficiency	High Production Cost	●	○
Lead-Acid	Low Capital Cost	Limited Cycle Life when Deeply Discharged	●	○
Flywheels	High Power	Low Energy density	●	○
SMES, DSMES	High Power	Low Energy Density, High Production Cost	●	
E.C. Capacitors	Long Cycle Life, High Efficiency	Low Energy Density	●	◐

www.electricitystorages.org

Storage Type	Power	Duration of Discharge	Efficiency (%)	Lifetime	Total Capital Cost (USD/kW)
CAES (100-300 MW, Underground)	15-400 MW	2-24 hrs	54 (Eff_{NG}=1)* 76(Eff_{NG}=0.54)* 88(Eff_{NG}=0.39)*	35 years	600-750
Pumped Hydro	250 MW >1 GW	12 hrs	87	30 years	2700-3300 Upgrade:300**
Li Ion	5 MW	15 min to several hrs	90 (DC)	15 years	4000-5000
Lead Acid	3-20 MW	10 sec to several hrs	75-80 (DC) 70-75 (AC)	4- 8 years	1740-2580
NaS	35 MW	8 hrs	80–85 (DC)	15 years	1850-2150***
VRB Flow Cell	4 MW	4-8 hrs	75–80 (DC) 63–68 (AC)	10 years	7000-8200
ZnBr Flow Cell	40-100 kW, 2 MW	2-4 hrs	75–80 (DC) 60–70 (AC)	20 years	5100-5600
High Power Flywheel	750-1650 kW	15 sec to 15 min	93	20 years	3695-4313
ZEBRA	<10 MW	Up to 8 hrs	80-85 (DC)	Over 1500 cycles shown	1500-2000***
Fe/Cr Flow Battery	<10 MW	2-4 hrs	50-65	20 years	200-2500***
Zn/Air	20 kW-10 MW	3-4 hrs	40-60	a few hundred cycles	3000-5000***
SMES	1-3 MW	1-3 sec	90	>30,000 cycles	380-490
SMES****	100 MW-200 MW	100 sec (MWh) 0.5-1h (100MWh) 5-10 hr (GWh)	90	>30,000 cycles	700-2000
Ultra capacitors	10 MW	Up to 30 sec	90	>500,000 cycles	1500-2500

**For CAES, the following round-trip efficiency is usually used:*

$$\eta = \frac{1.0 \ kWh}{(4220/3600) * Eff_{NG} + 0.67}$$

where Eff_{NG} is 1.00 for natural gas, 0.54 for NGCC, 0.385 for simple GT. When Eff_{NG} =1.00, and the round-trip efficiency is equivalent to the conventional energy efficiency.
*** Based on an interview for manufacturers*
**** Projected*
*****Estimated by RASMES (Research Association of SMES, Japan)*

IEA, 2009, http://www.iea.org/papers/2009/energy_storage.pdf

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Electricity storage association, www.electricitystorage.org

IEA, http://www.iea.org/papers/2009/energy_storage.pdf

Raili Alanen & Hannu Hätönen, VTT, 2006 Sähkön laadun ja jakelun luotettavuuden hallinta - State of art –selvitys, ISBN 951.38.6604.1