A Review of Large Scale Energy Storage

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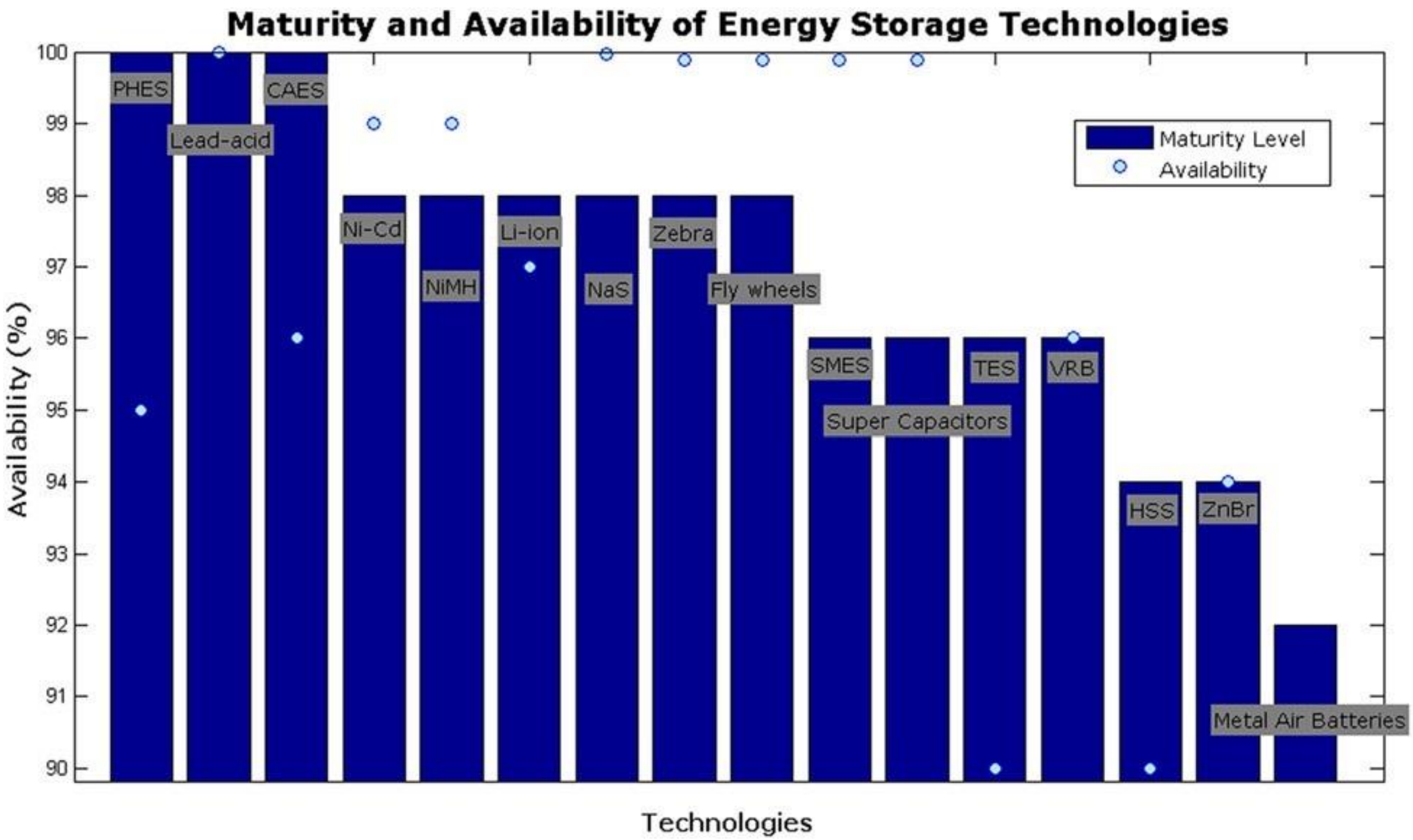
Introduction

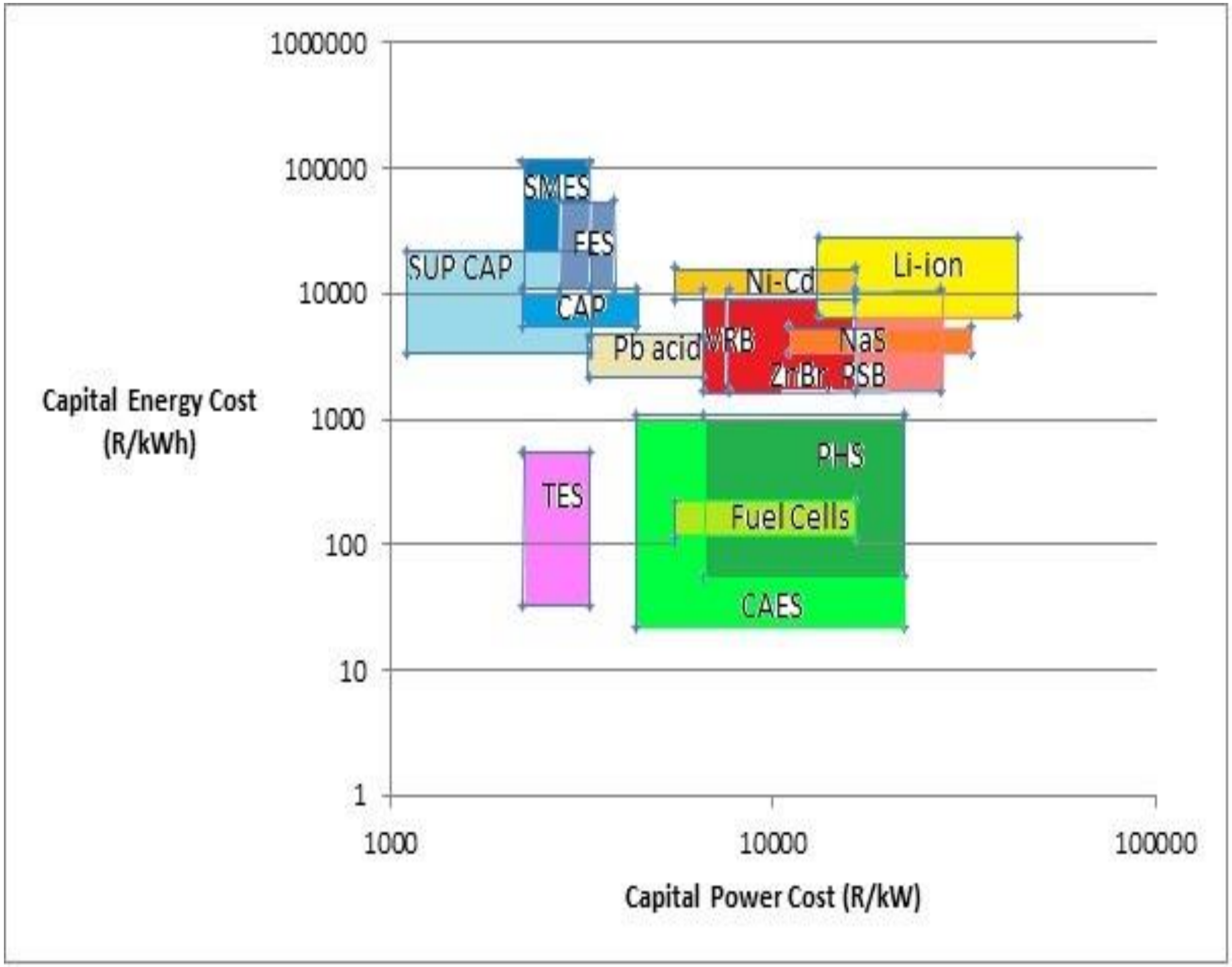
- Energy storage is needed to balance electricity supply and demand
- This study provides a comprehensive literature overview of large-scale energy storage technologies in the order of 10's to 100's of MWh that are available in the arena of energy storage in terms of capability performance parameters such as capital energy cost, capital power cost, energy density, power density, and round trip efficiency
- Capability graphs are generated showing performance and cost estimations of various large-scale energy storage technologies including thermal energy storage
- This study does provide a first cut mapping of the various energy storage technologies that are applicable on a large scale, however, a system of systems approach complimented with a thoroughly conducted techno-economic evaluation is crucial for the mapping of energy storage technologies in the context of an energy storage roadmap
- A thermal energy storage model is developed in order to compare it with other energy storage technologies

Capability Graphs



Ferreira, H., Fulli, G., Garde, R., Kling, W., Lopes, J., 2013. Characterisation of electrical energy storage technologies. Energy 53, 288-298.

Capability Graphs



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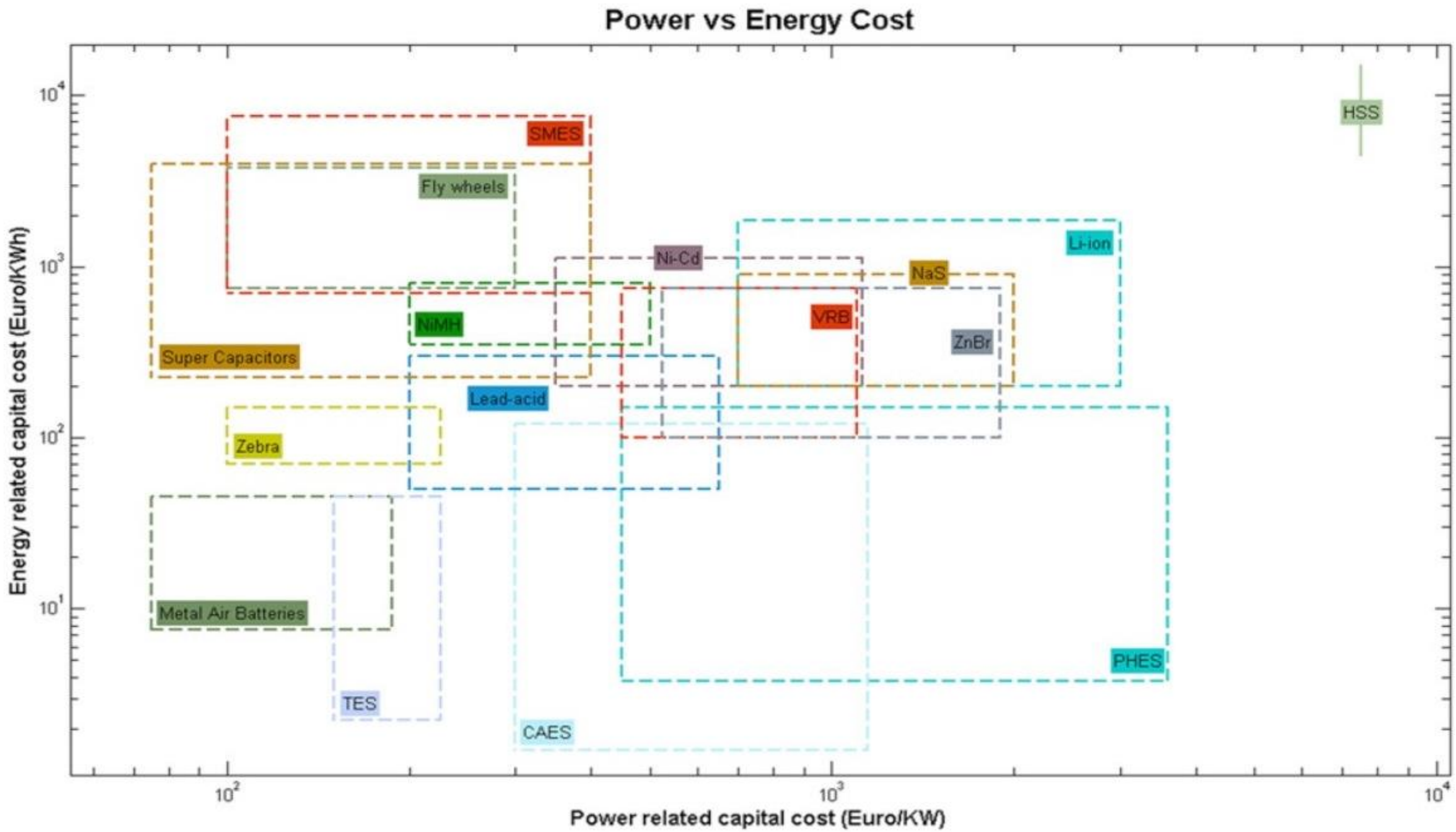

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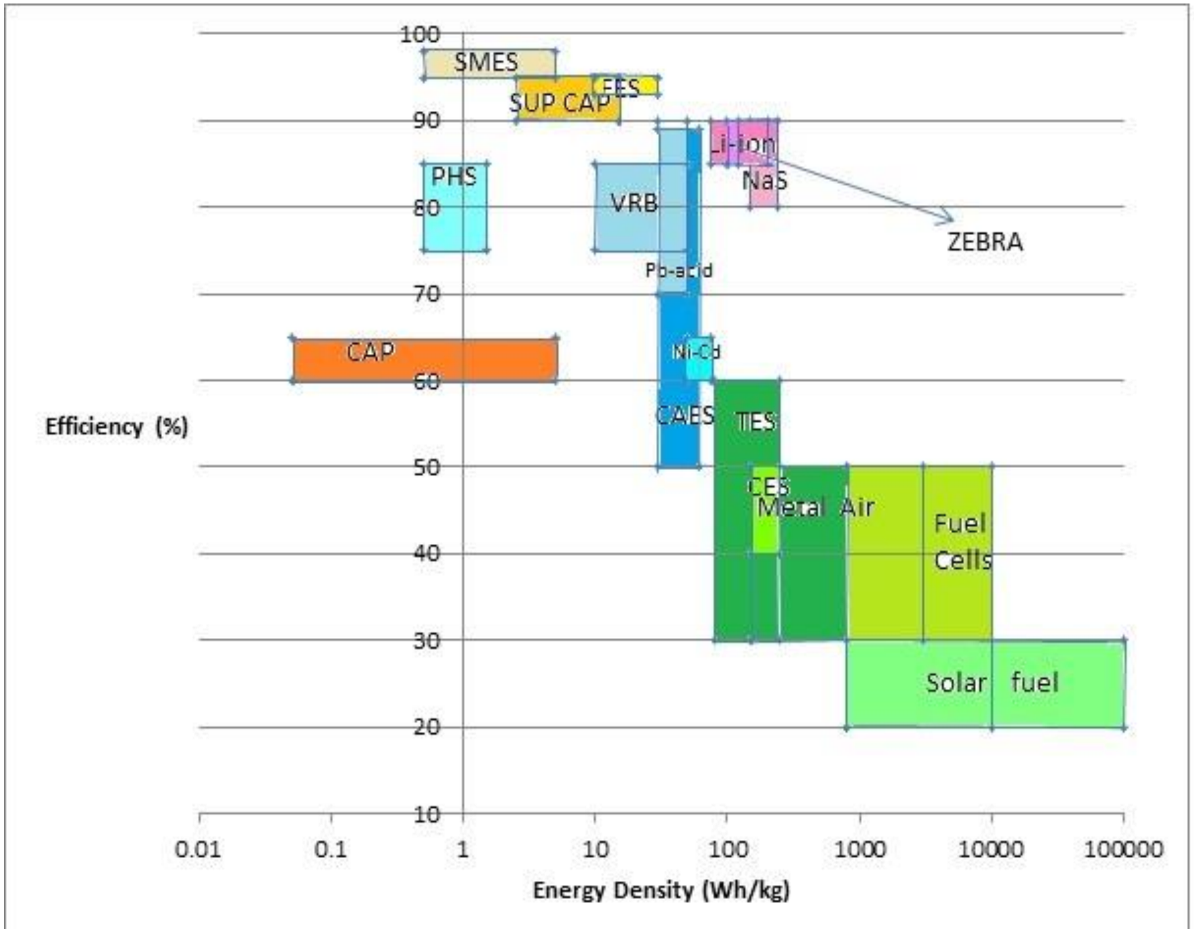

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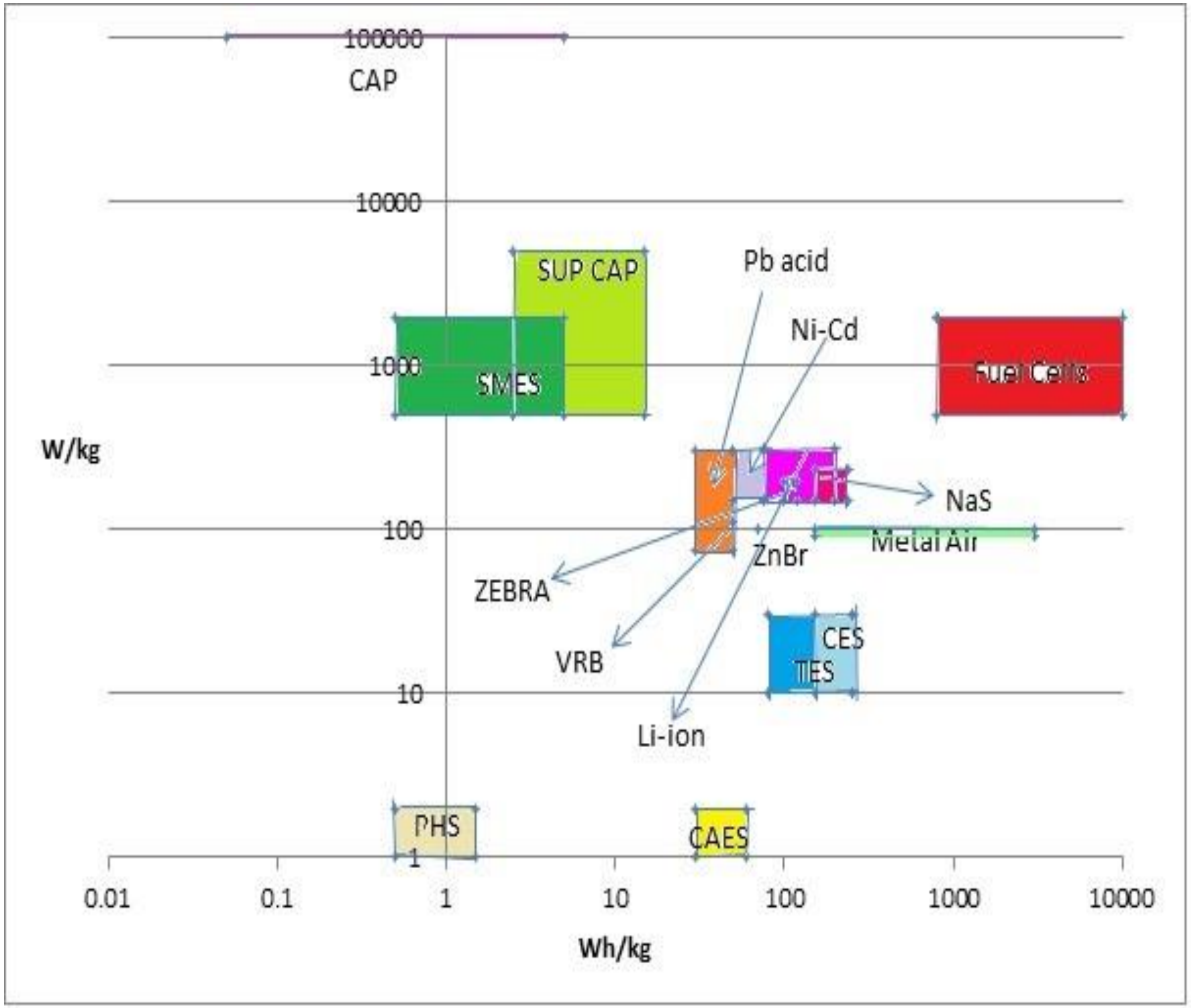

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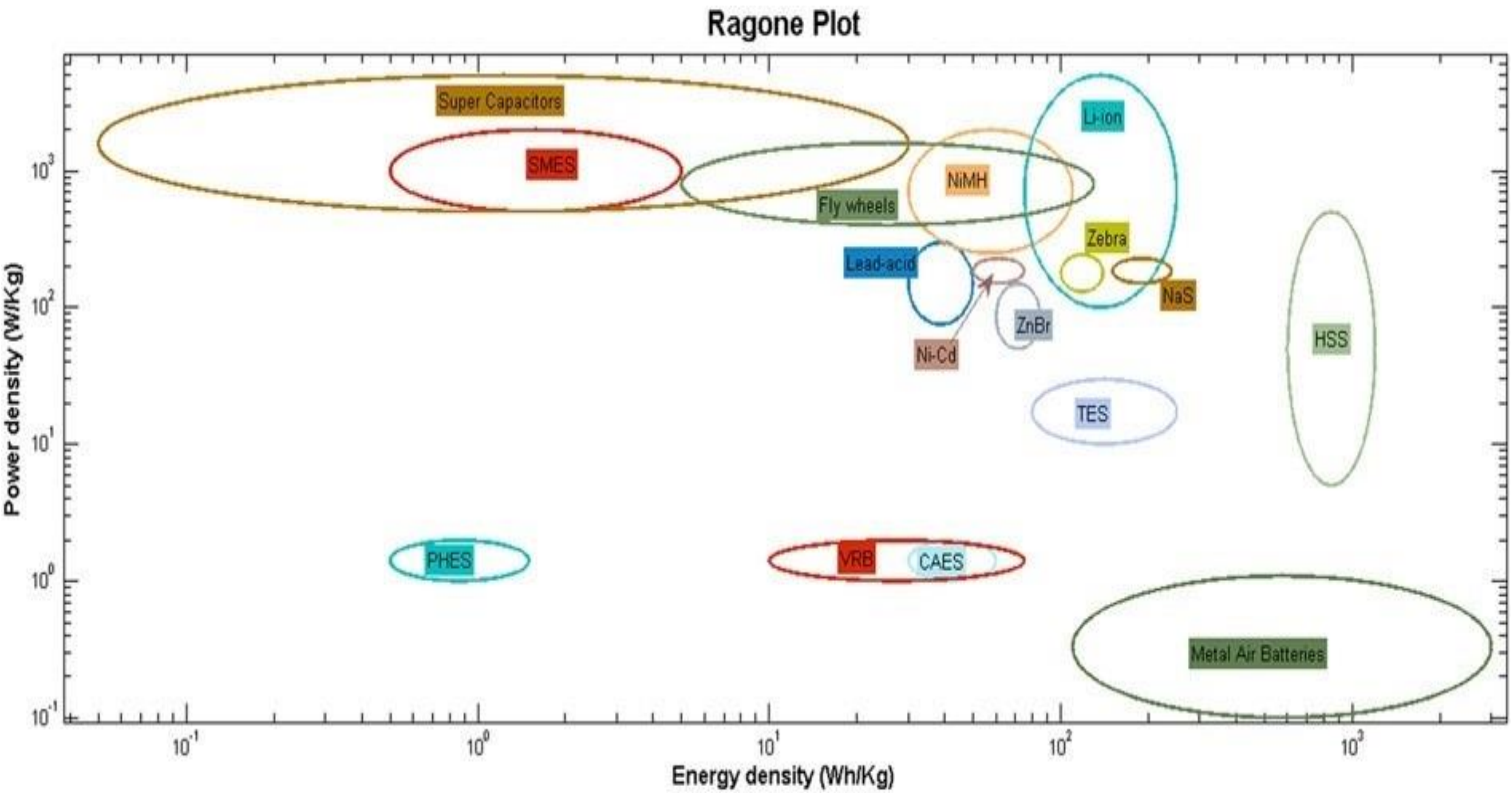

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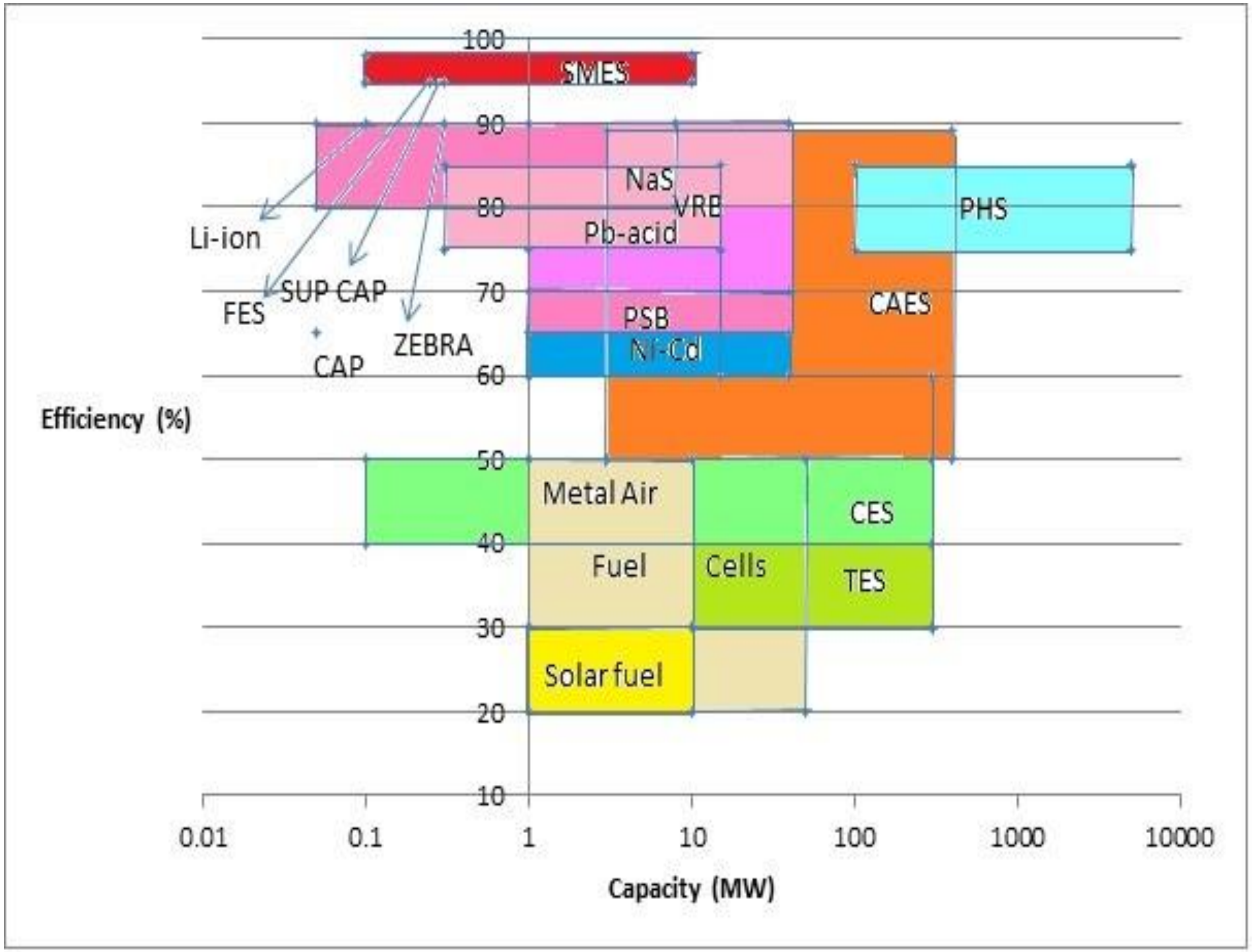

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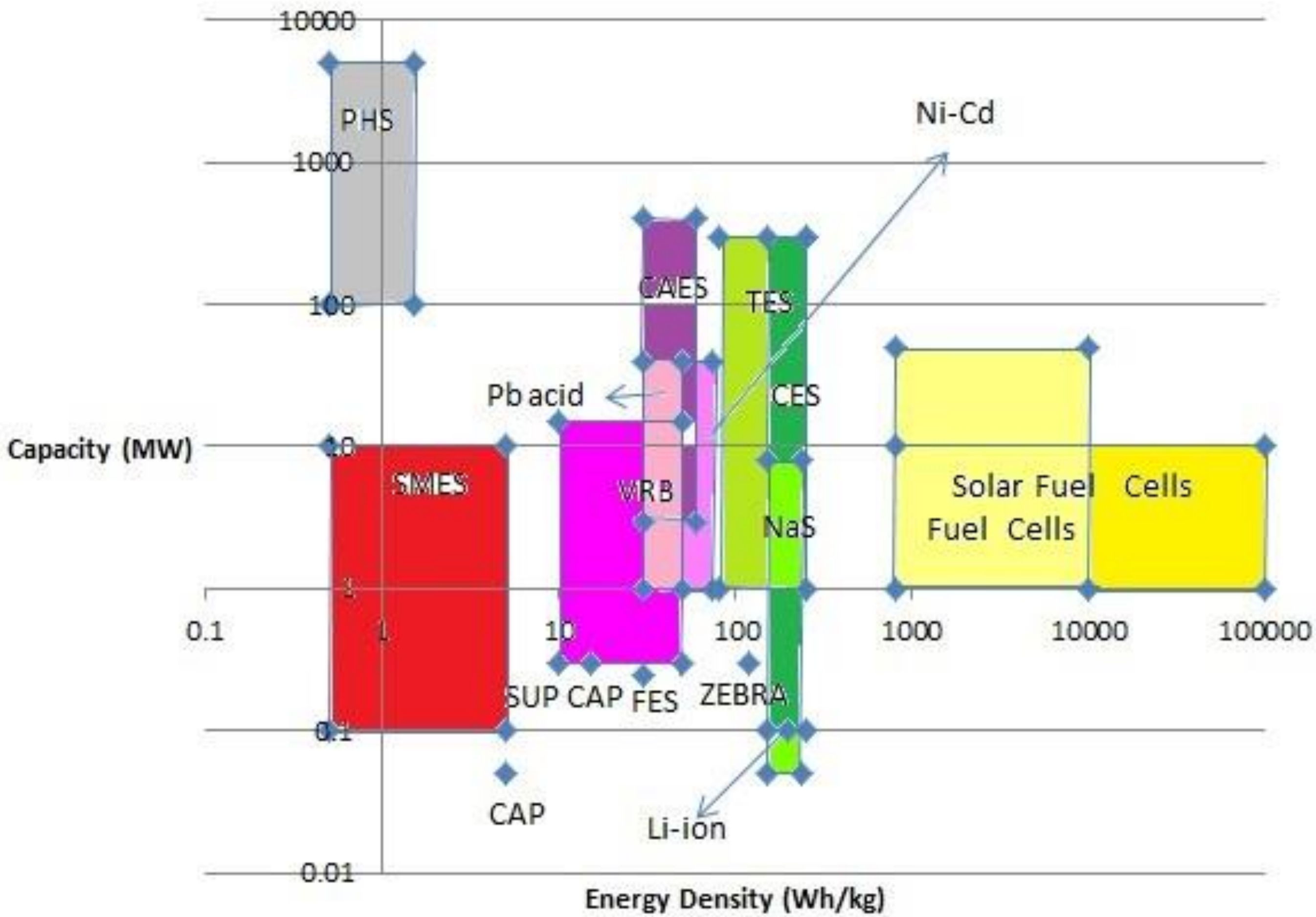


Costing

Energy Storage Technology	Capital Power Cost (ZAR/kW)	Capital Energy Cost (ZAR/kWh)
TES	2,000 - 3,000[a] 2,000 - 3,000[g]	30 - 500[a], < 500[h] 600[g] 600 – 800[i]
PHS	6,000 - 21,000[a] 27,000 - 46,000[b] 21,000 - 43,000[C] 14,000[f] 7,000 - 54,000[g]	1,000[a] 5,000[b] 2,000[g]
CAES	4,000 - 21,000[a] 11,000[b] 9,000 - 11,000[c] 7,000 - 8,000[f] 4,000 - 19,000[g]	1,000[a] 1,000[b] 2,000[g]
NaS	11,000 - 32,000[a] 33,000 - 35,000[b] 1,000 - 21,000[c] 20,000 - 24,000[f] 10,000 - 30,000[g]	3,000 - 5,000[a] 6,000[b] 5,000[f] 3,000 - 13,000[g]
Li-ion	43,000[a] 12,000 - 17,000[b] 27,000 - 32,000[c] 27,000 - 37,000[f] 11,000 - 45,000[g]	27,000[a] 46,000 - 66,000[b] 14,000[f] 30,000[g]
Zn/Fe Redox	Current: 24,000[d] Next generation: < 16,000[d]	< 5,000[d]
VRB	33,000 - 40,000[b] 32,000 - 43,000[c] 35,000[e] 7,000 - 16,000[a] 17,000 - 34,000[f] 7,000 - 17,000[g]	7,000 - 8,000[b] 4,000 - 6,000[e] 7,000 - 20,000[f] 1,700 - 11,000[a] 1,000 - 10,000[g]
Pb-acid	16,000 - 22,000[c] 19,000 - 21,000[b] 3,000[a] 19,000 - 28,000[f] 3,000 - 10,000[g]	4,000[a] 5,000[b] 3,000[f] 4,000[g]

a - [5], b - [13], c - [14], d - Vizn Energy Systems Inc., e - [7], f - [17], g - [6], h - NEST, i - Novatec Solar

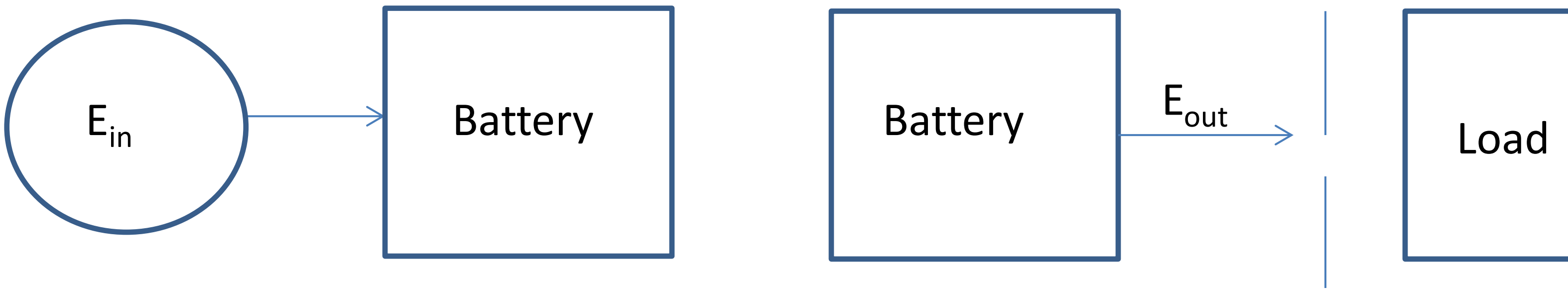
Thermal Energy Storage Model

- The charging and discharging process of batteries, fuel cells, flywheels, and CAES including the discharging mechanism of thermal energy storage systems (TES) is well understood and defined from a physics standpoint in the context of comparing these systems
- The challenge lays in comparing the charging process of batteries, fuel cells, flywheels, and CAES with the charging process of TES systems for CSP plants
- The source of energy for all these systems is electrical energy for comparison purposes
- The metric that is proposed for comparison is the round trip efficiency, which in this context is simply defined as the ratio of desired output to desired input i.e. E_{out}/E_{in}

Charging and Discharging Processes of Batteries, Fuel Cells, Flywheels, CAES, and TES (Block Diagrams)

E_{in}, E_{out} - Electrical Energy

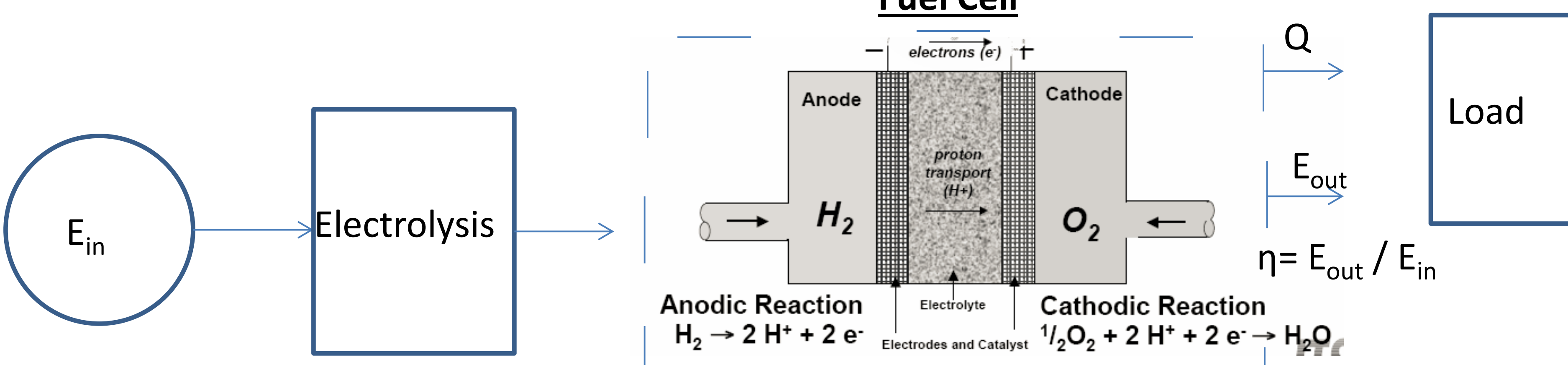
Battery



Charging **Discharging** $\eta = E_{out} / E_{in}$

E_{in} **No Storage** $E_{out,ns}$

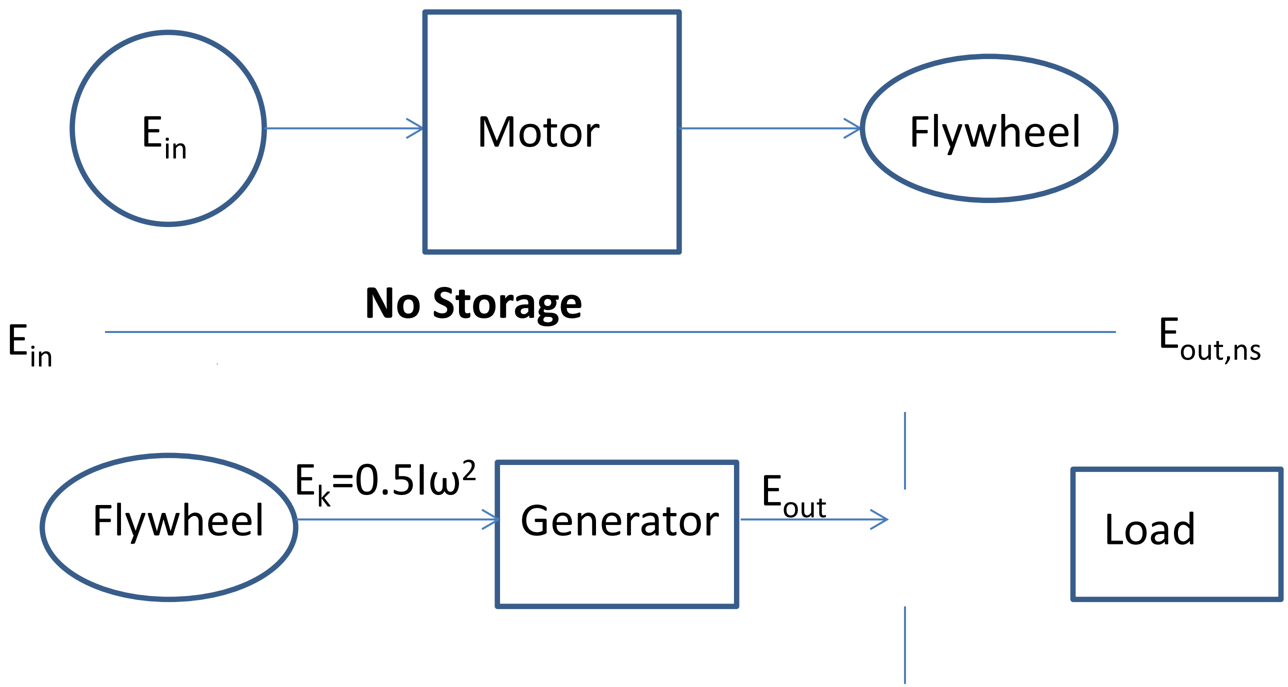
Fuel Cell



Charging **Discharging**

Charging and Discharging Processes of Batteries, Fuel Cells, Flywheels, CAES, and TES (Block Diagrams)

Charging Process of a Flywheel Energy Storage

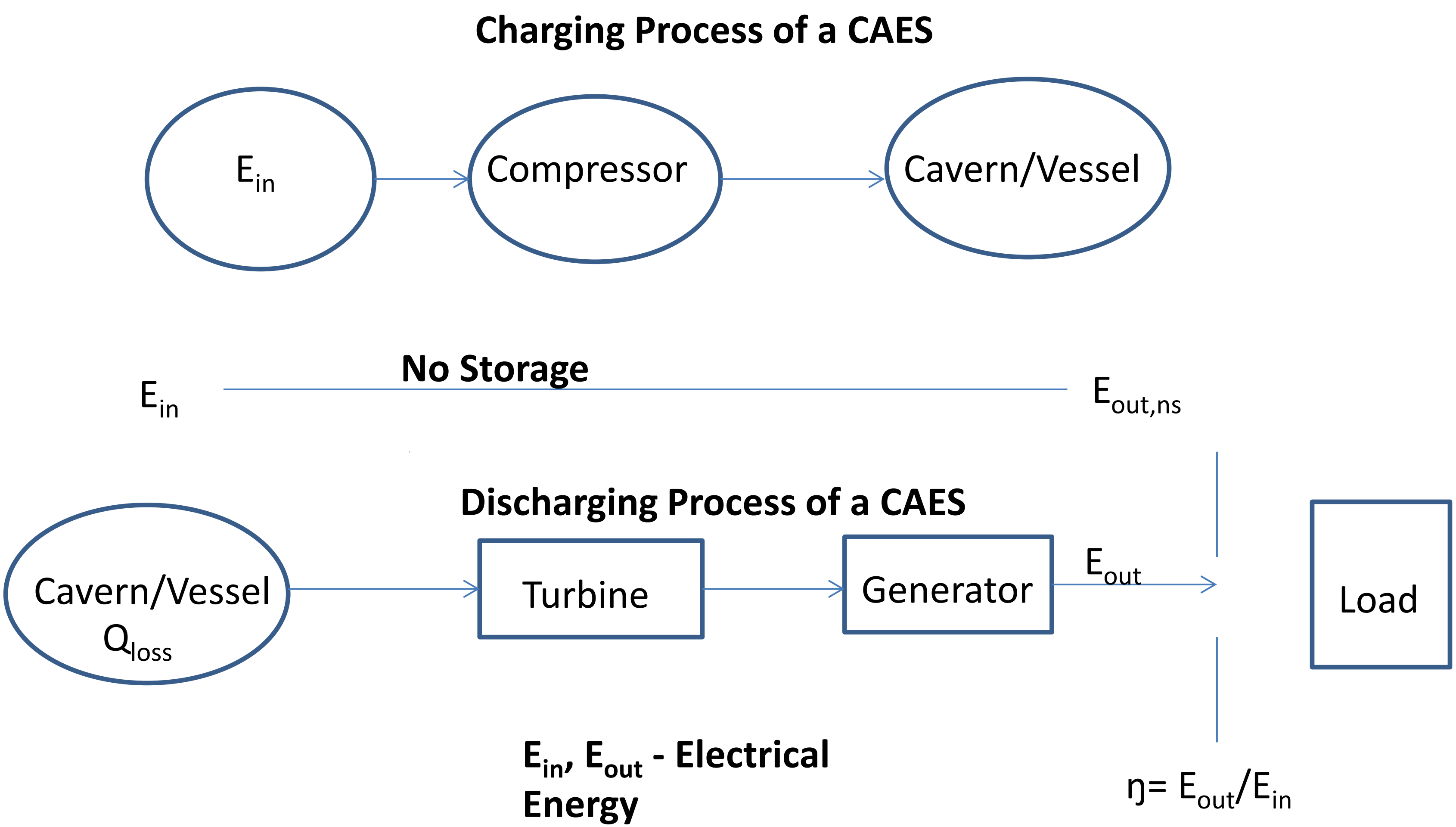


E_{in}, E_{out} - Electrical Energy

$\eta = E_{out}/E_{in}$

Discharging Process of a Flywheel Energy Storage

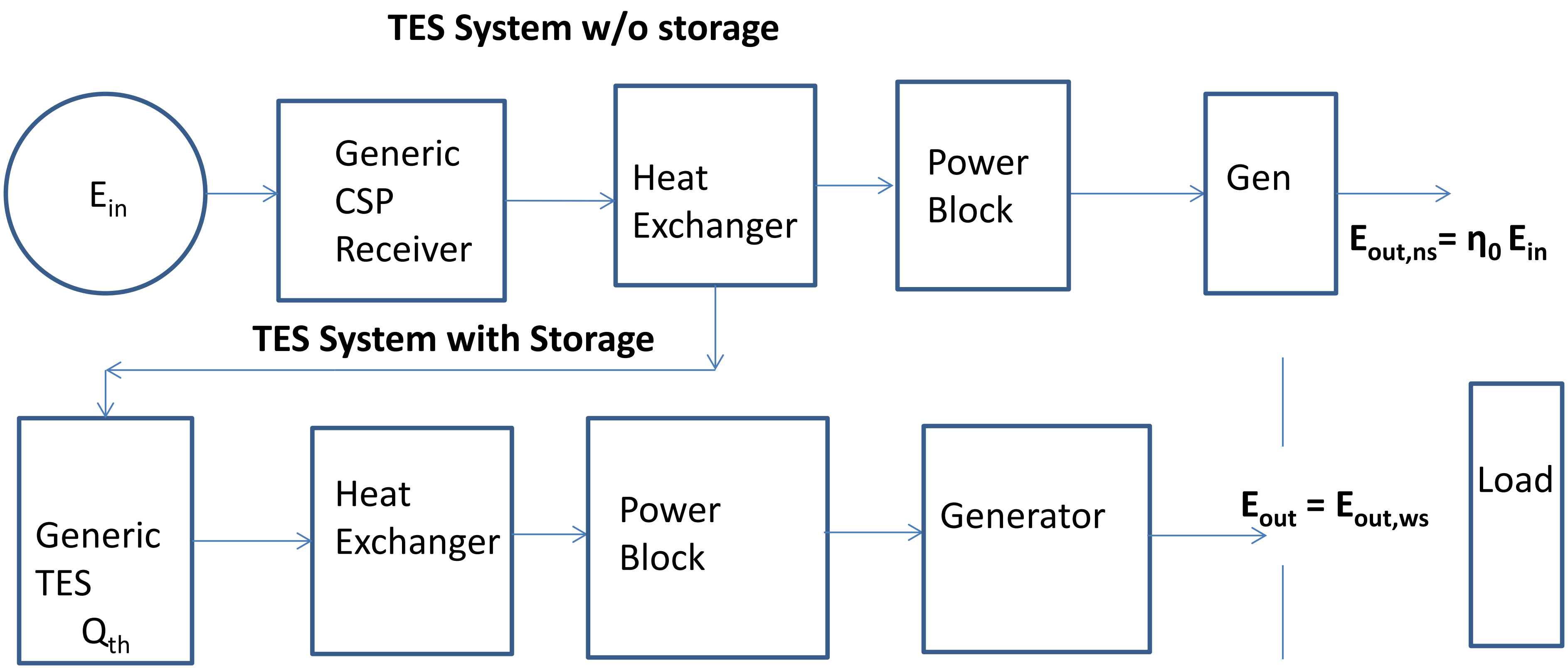
Charging and Discharging Processes of Batteries, Fuel Cells, Flywheels, CAES, and TES (Block Diagrams)



Important Points

- $E_{in} = E_{out,ns}$ for battery, fuel cell, flywheel, and CAES diagrams shown in the previous slides, whereby the ns in the subscript stands for no storage
- $E_{out} = E_{out,ws}$, ws stands for with storage
- The metric, round trip efficiency can be defined as $\boldsymbol{\eta = E_{out,ws} / E_{out,ns}}$

Charging and Discharging Processes of Batteries, Fuel Cells, Flywheels, CAES, and TES (Block Diagrams)



$\eta_1 = E_{out}/E_{in}$

E_{in} – Solar Energy , E_{out} - Electrical Energy

Now you are comparing apples with apples → $\eta = \eta_1/\eta_0 = E_{out,ws}/E_{out,ns}$

Conclusion

- According to the capability graphs generated in this report, thermal energy storage, compressed air energy storage, pumped hydro storage, flow batteries, lithium ion, and sodium sulphur are suitable for large scale storage in the order of 10’s to 100’s of MWh.

- Metal air batteries have a high theoretical energy density equivalent to that of gasoline along with being cost efficient. However, the technology is still in the developmental stage along with solar fuel and cryogenic energy storage.

- Compressed air energy storage has the lowest capital energy cost in comparison to other energy storage technologies. However, this technology requires special geological sites such as those in USA. Advanced adiabatic CAES has a high round trip efficiency similar to pumped hydro storage and is a promising technology for the future.

- Flywheels, super conducting magnetic storage, super capacitors, capacitors, pumped hydro storage have very low energy density while compressed air energy storage, cryogenic energy storage, thermal energy storage, and batteries have relatively high energy density.

Conclusion

- The cycle efficiencies of SMES, capacitors, super capacitors, PHS, CAES, batteries, and flow batteries are greater than 60% compared to other storage technologies.

- Pumped hydro storage accounts for 99% of the total installed energy storage. However, it has very high capital cost; long construction times; requires special sites; has very low energy density; and has the least LCOE.

- A plethora of research areas in thermal storage include molten salt storage, rock, cryogenic energy storage, room temperature ionic liquids, and the use of phase change materials. A techno-economic evaluation of energy storage technologies is required.

- Li-ion battery is a major candidate in future large scale energy storage systems.

Conclusion

- NaS batteries have been commercialized in Japan, but lack of multiple manufacturers will stagnate the growth in the near future according to Frost & Sullivan.

- According to the International Energy Workshop held in 2013, thermal energy storage roadmap requires the need to determine the maturity of thermal energy storage technologies in terms of the push and pull; legal and technological framework readiness; breakthrough technologies in high temperature thermal energy storage such as Phase Change Materials (PCM) i.e. liquid metals, liquid glass, quartz glass, and thermochemical energy storage; favourable electricity tariffs; consider needs for future energy systems complimented with a rolling-plan vision for the year 2050 deployment.

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Questions