II WORKSHOP DE

ENERGIAS

OCEÂNICAS E FLUVIAIS

Armazenamento de energia

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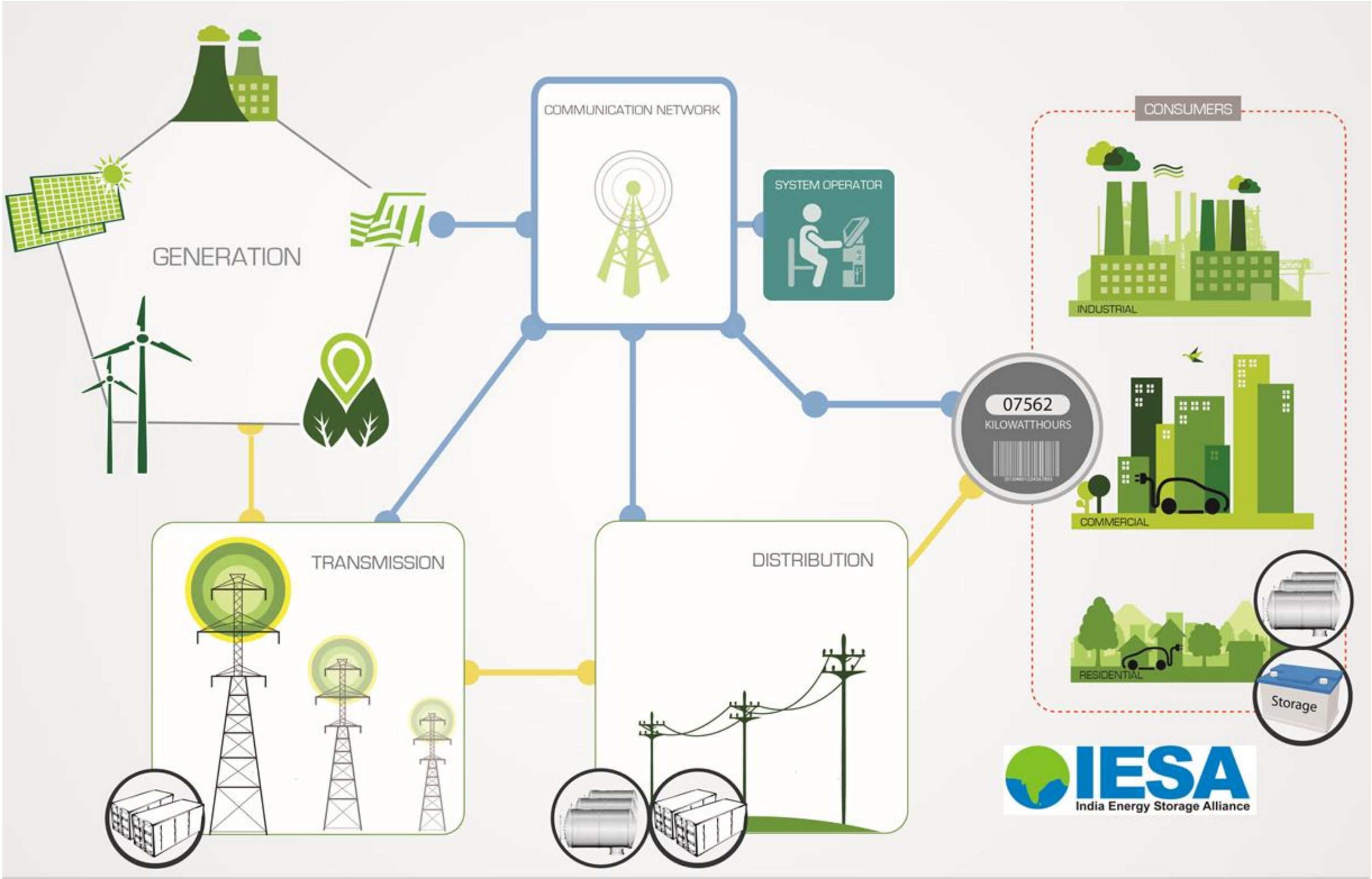
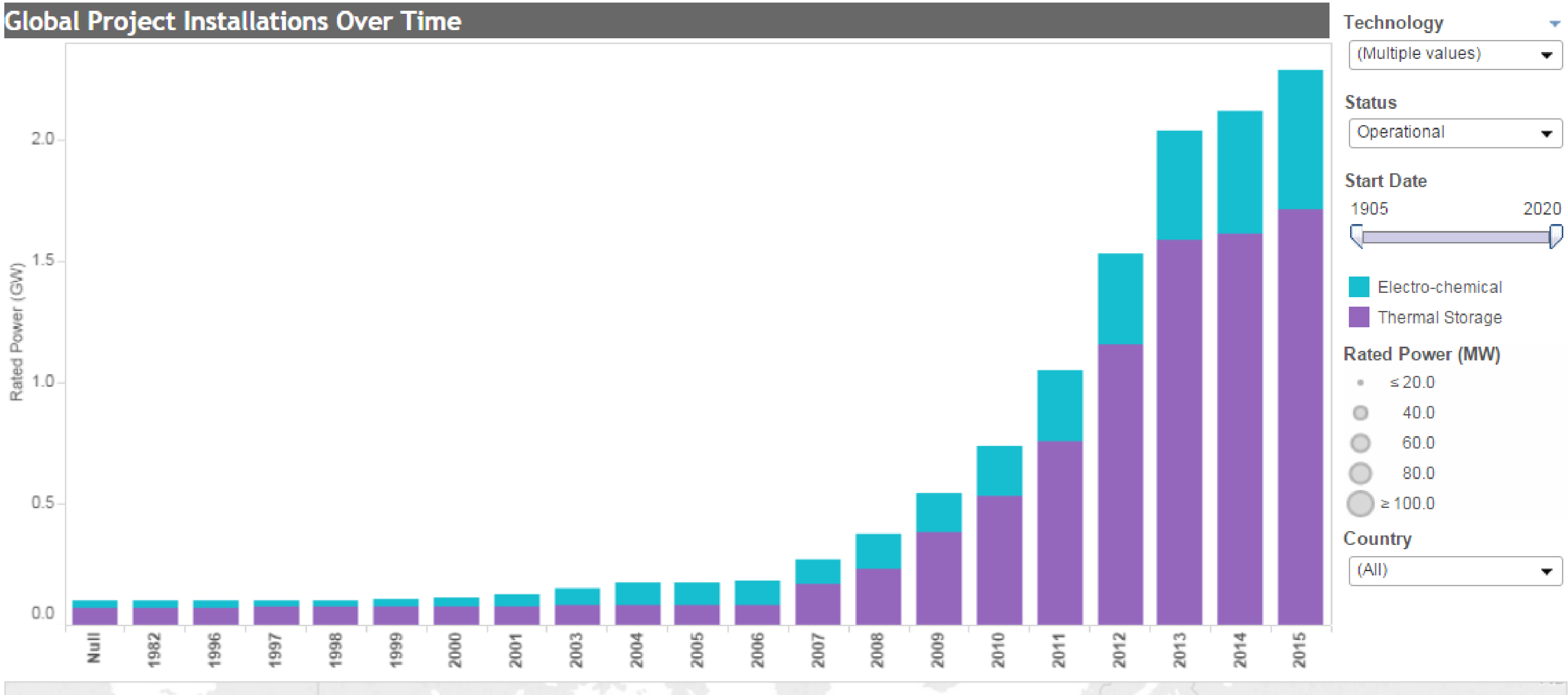
Instituto de Energia Elétrica

Introduction

Energy Storage in Modern Grids

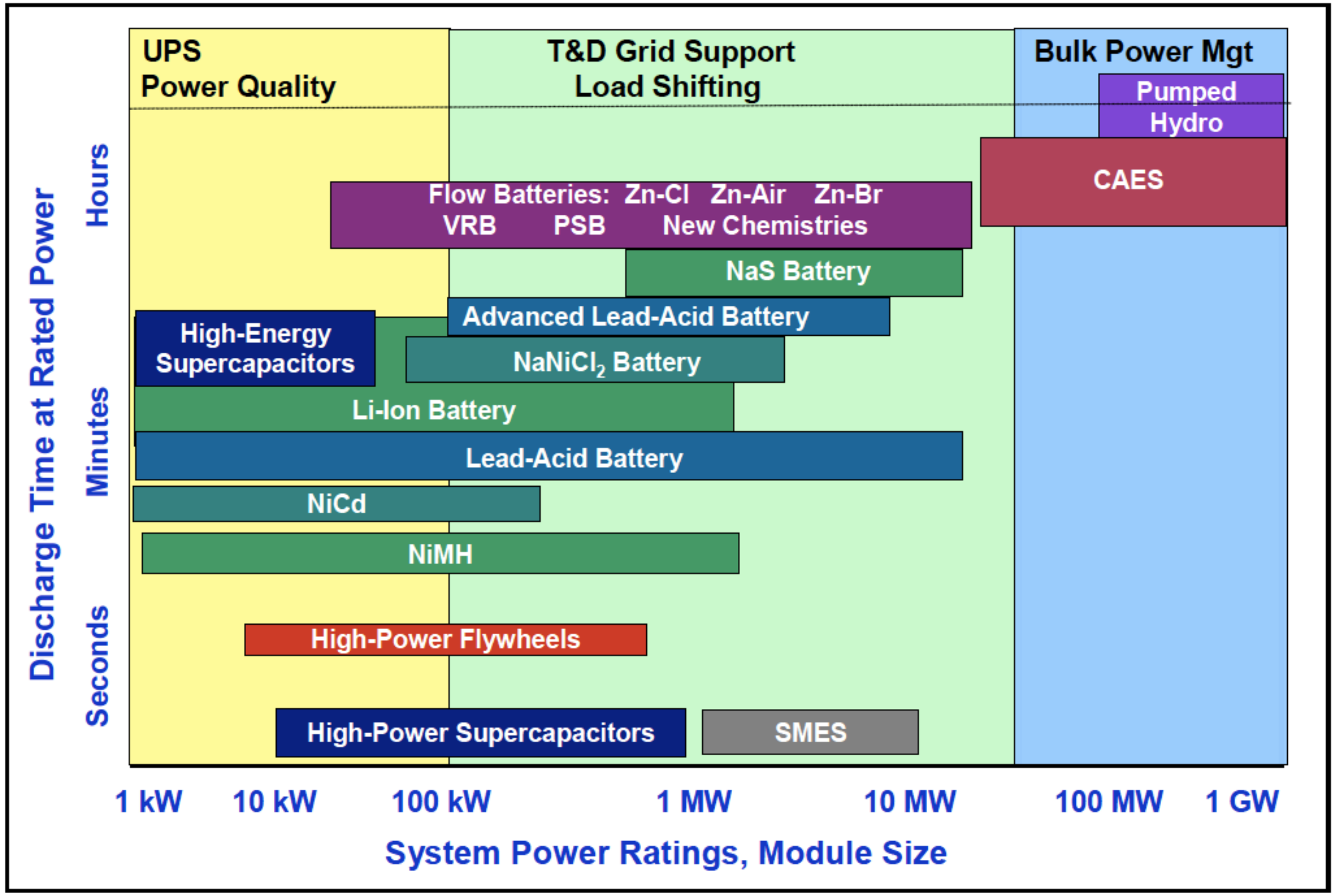


Emerging Energy Storage Technologies



Both Thermal and Electrochemical storage have been growing rapidly over the past decade. Renewable integration, ancillary services, demand side management and electric vehicles will probably foster energy storage markets in both developed and emerging nations.

Mapping Storage Technologies

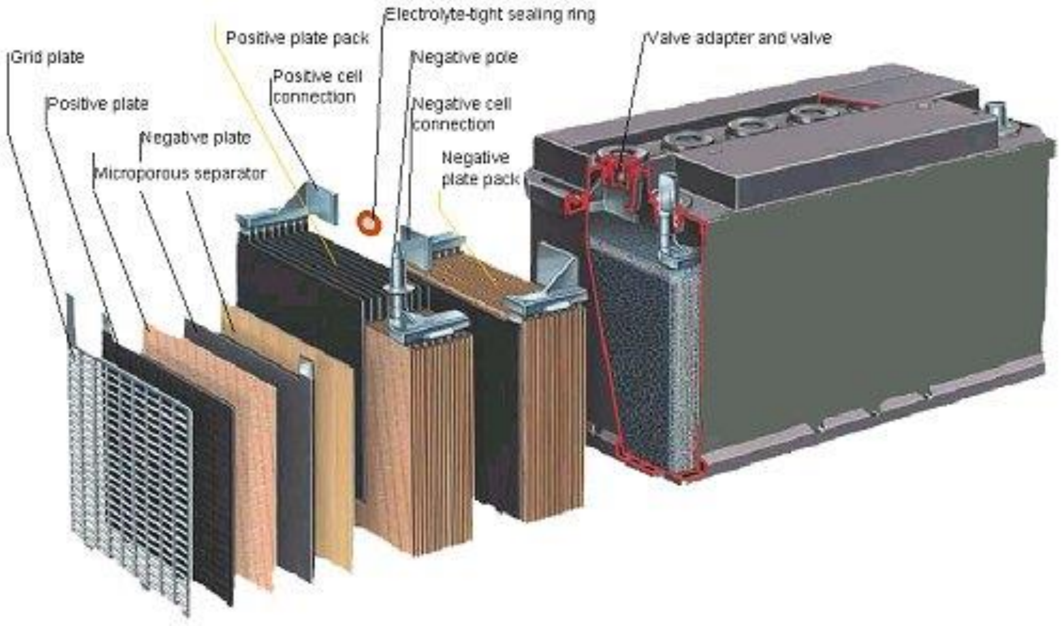


Advanced Lead Acid

Lead-Acid batteries consist of two electrodes: Lead and lead-dioxide immersed in sulfuric acid.

Lead Acid

HITACHI Inspire the Next
Rolls Battery Engineering
LEOCH
Shin-Kobe Electric Machinery Co., Ltd.
HBL Batteries
EXIDE
ecoult energy storage solutions
EASTPENN
AXION POWER INTERNATIONAL INC.
energypower SYSTEMS
EnerSys Power/Full Solutions



Performance measure	Cycle Life	Energy Efficiency (%)
Market leader	1200	80
Best in class	2000	85

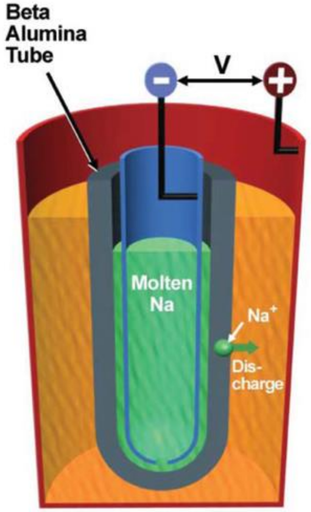
Sodium based battery - NAS

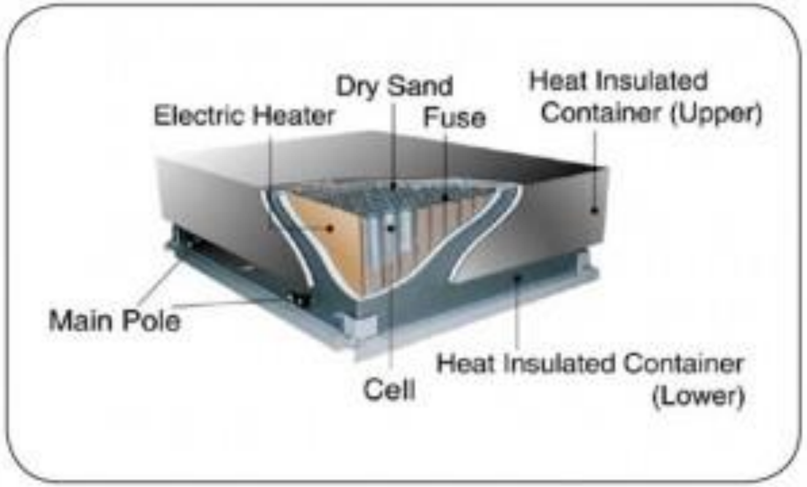
Sodium-sulfur (NaS) batteries use molten sodium and sulfur electrodes separated by a ceramic electrolyte

Sodium Based

NGK
FIAMM
SHARP
AQUION ENERGY

Performance measure	Cycle Life	Energy Efficiency (%)
Market leader	4000	70
Best in class	6000	85



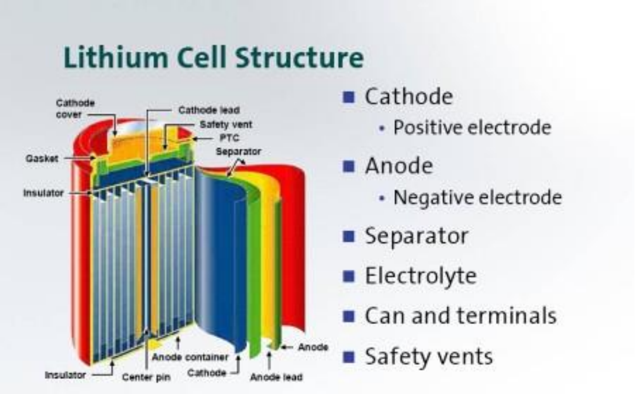


Li-ion

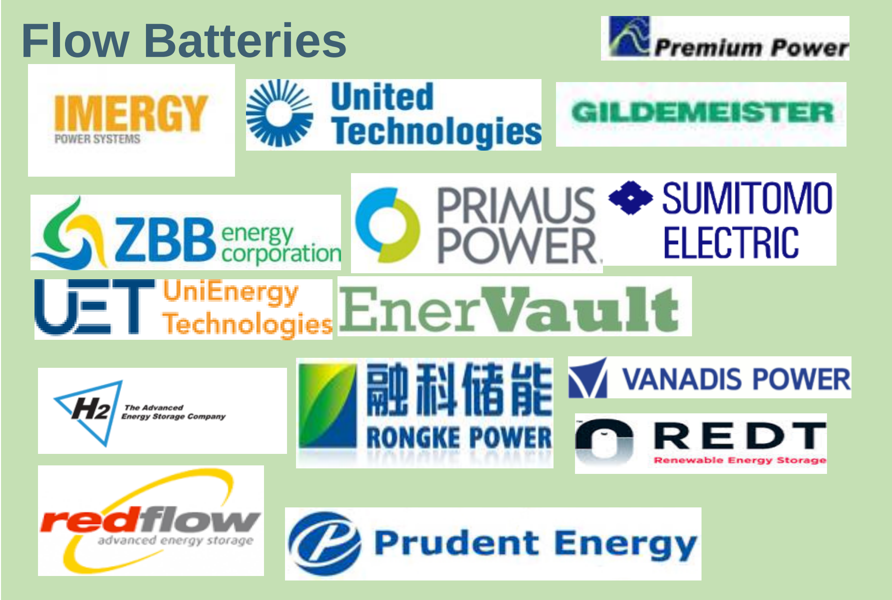
Li-ion battery uses graphite as the anode material and $LiFePO_4$ or $LiCoO_2$ or Lithium titanate or lithium nickel manganese cobaltate as the cathode.

Li-Ion Batteries

Performance measure	Cycle Life	Energy Efficiency (%)
Market leader	2000	90
Best in class	10,000+	95

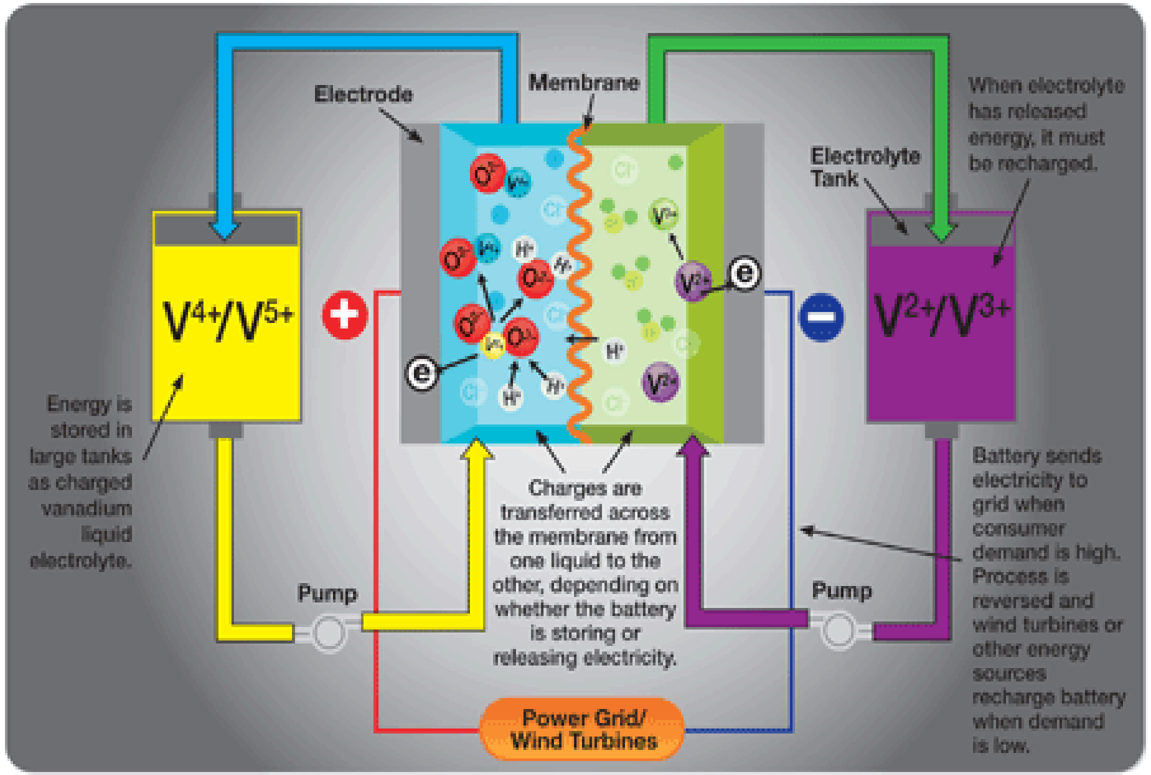


Flow Battery



Performance measure	Cycle Life	Energy Efficiency (%)
Market leader	5000	60
Best in class	10,000+	70

Flow batteries use liquid electrolytes with fixed cells to store and regenerate power. Various flow battery chemistries exist such as vanadium redox, zinc-bromine, iron - chromium etc.



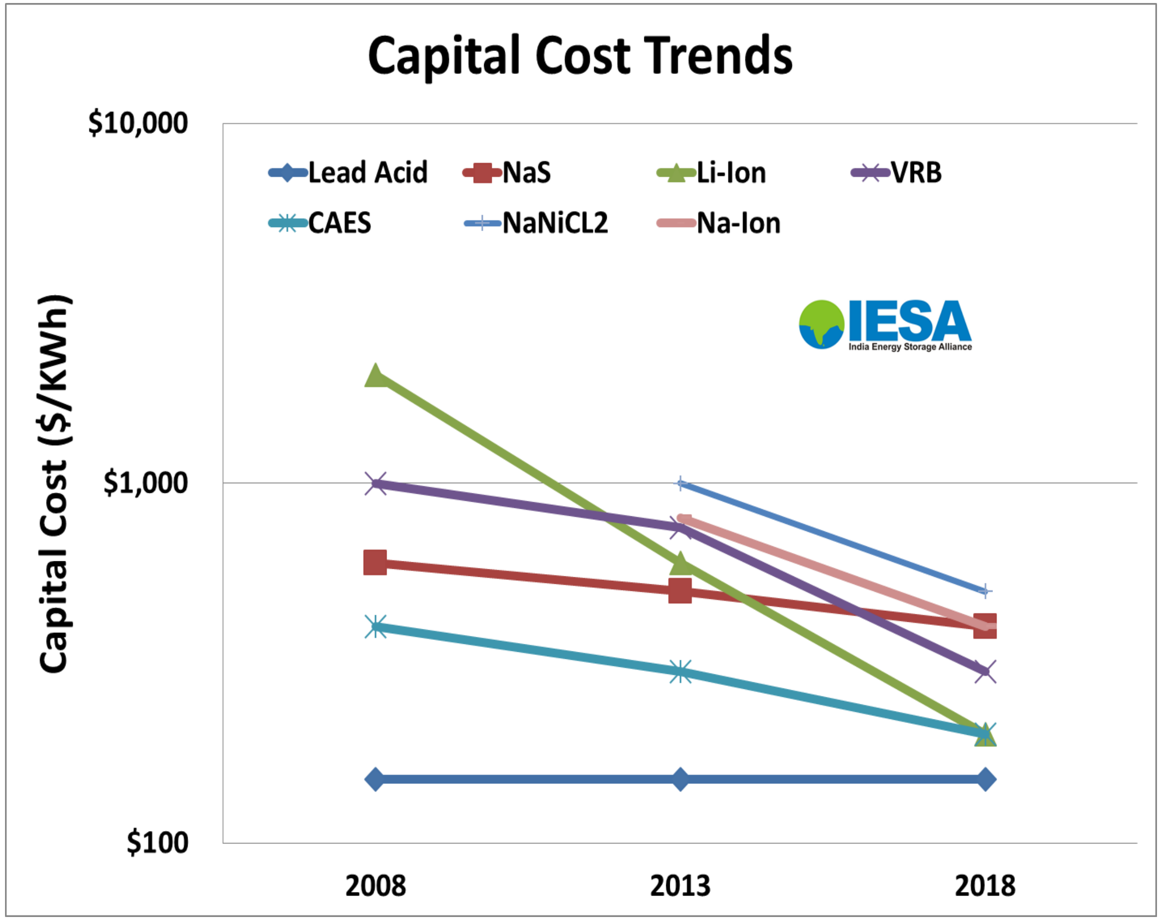
Typical System Configuration for Most Common Applications

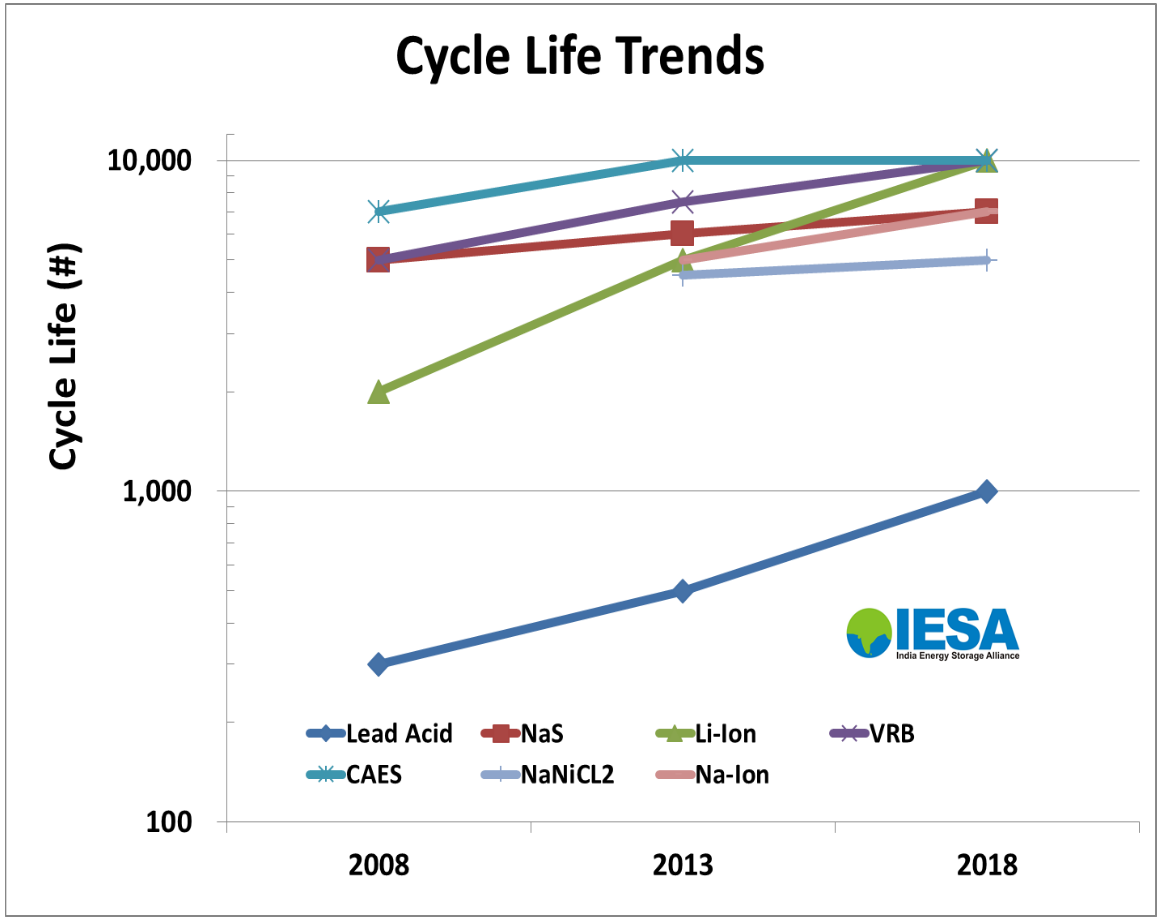
Segments / Applications	Sub Segments	Power Rating	Duration	DOD	Type of cycles	No of cycles / Year
Renewable Energy Integration	Wind Smoothing	1 MW- 20 MW	15 min - 1 h	<60%	Shallow	<18,000
	Wind Firming	1 MW-20 MW	4-6 h	>80%	Deep	<500
	Solar	3 KW-2 MW	3-6 h	>80%	Deep	<350
Load shifting or energy arbitrage	Commercial	10 KW - 2 MW	2-4 h	>80%	Mix	<400
	Industrial	500 KW - 5 MW	2-4 h	>80%	Mix	<400
Off grid applications	Rural Microgrid (households)	1KW - 5 kW	2-8 h	>80%	Mix	<400
	Rural Schools / Hospitals	1 KW - 10 kW	2-8 h	>80%	Mix	<400
Replacement of DG	Telecom Towers	2 KW - 5 kW	2-4 h	>80%	Mix	<700
	Commercial	10 KW - 2 MW	2-4 h	>80%	Mix	<400
	Industrial	500 KW - 5 MW	2-4 h	>80%	Mix	<400
Transmission or Distribution Deferral	Utilities	1-20 MW	4-6 h	>80%	Mix	<100
Frequency support	Utilities / IPP	1 MW- 20 MW	15 min – 1 h	<60%	Shallow	<18,000
Reactive Power Management	Utility / C&I	3 KW - 10 MW	15 min – 1 h	N.A.	N.A.	N.A.

Landscape

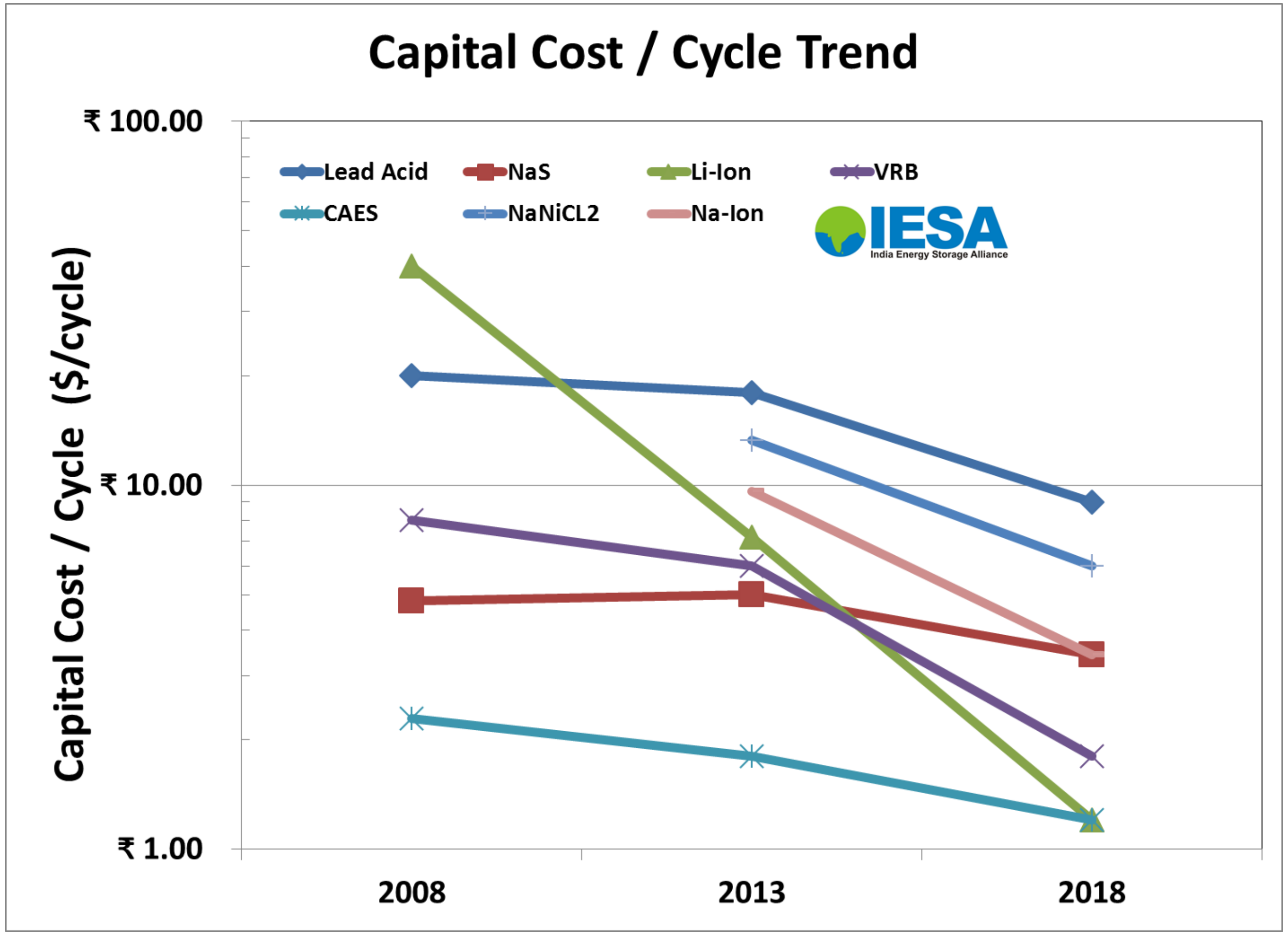

IPPs / Project Developers
AES Energy Storage
EDISON INTERNATIONAL
SPINDLE GRID REGULATION, LLC
Invenergy
stem
Xcel Energy
DUKE ENERGY
AMERICAN ELECTRIC POWER
firstwind
NEXTera ENERGY
res
SolarCity
PCS / Inverter Supplier
SIEMENS
Beacon POWER
DYNAPOWER COMPANY
Parker
ABB
BOSCH
EATON
PRINCETON POWER SYSTEMS
Sodium Based
NGK
FIAMM
SHARP
AQUION ENERGY
Compressed Air
DRESSER-RAND
LightSail Energy
SustainX
GENERAL COMPRESSION
Flywheel
Beacon POWER
temporal POWER
Lead Acid
ecoult
EASTPENN
EXIDE
EnerSys
energypower
AXION POWER
Li-Ion Batteries
NEC
BYD
TESLA
Panasonic
TOSHIBA
electrovaya
SAMSUNG
SAFT
altairnano
ALEVO
Kokam
LG Chem
ATL
Flow Batteries
IMERGY
United Technologies
GILDEMEISTER
ZBB energy corporation
PRIMUS POWER
SUMITOMO ELECTRIC
UET UniEnergy Technologies
EnerVault

Key Trends


Capital Cost Trends
$10,000
$1,000
$100
Capital Cost ($/KWh)
Lead Acid
NaS
Li-Ion
VRB
CAES
NaNiCL2
Na-Ion
IESA
India Energy Storage Alliance
2008
2013
2018


Cycle Life Trends
10,000
1,000
100
Cycle Life (#)
IESA
India Energy Storage Alliance
Lead Acid
NaS
Li-Ion
VRB
CAES
NaNiCL2
Na-Ion
2008
2013
2018

Cost/Cycle Evolution



Global Deployments

Global Deployments

Technology Types

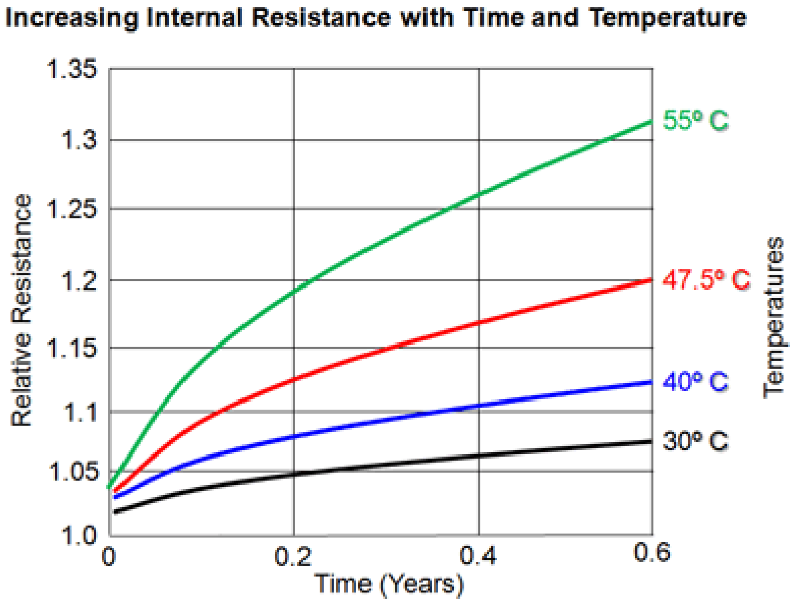
Technology Type	Projects	Rated Power (MW)
Compressed Air Energy Storage	3	7
Pumped Hydro Storage	350	181190
Thermal Storage	220	3275
Electro-chemical	991	3297
Hydrogen Storage	13	20
Liquid Air Energy Storage	2	5

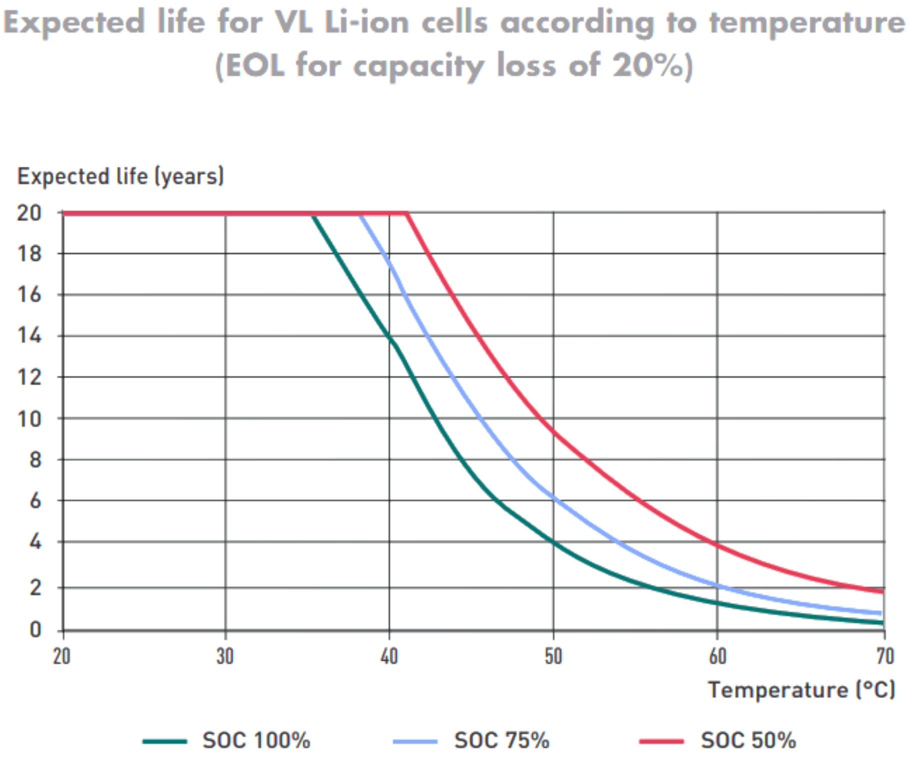
Calendar Life vs Cycle Life

Calendar Life

Calendar aging comprises all aging processes that lead to a degradation of a battery cell independent of charge/discharge cycling:

- ✓ **Temperature;**
- ✓ **Time;**
- ✓ **State-of-charge (SOC).**





Calendar Life

Recoverable capacity when storing Li-ion for one year at various temperatures

Temperature	40% charge	100% charge
0°C	98% (after 1 year)	94% (after 1 year)
25°C	96% (after 1 year)	80% (after 1 year)
40°C	85% (after 1 year)	65% (after 1 year)
60°C	75% (after 1 year)	60% (after 3 months)

Cycle Life

Cycle life is expressed in terms of the number of charge and discharge cycles that can be achieved depending on what level the battery is discharged (Depth of Discharge - DoD)

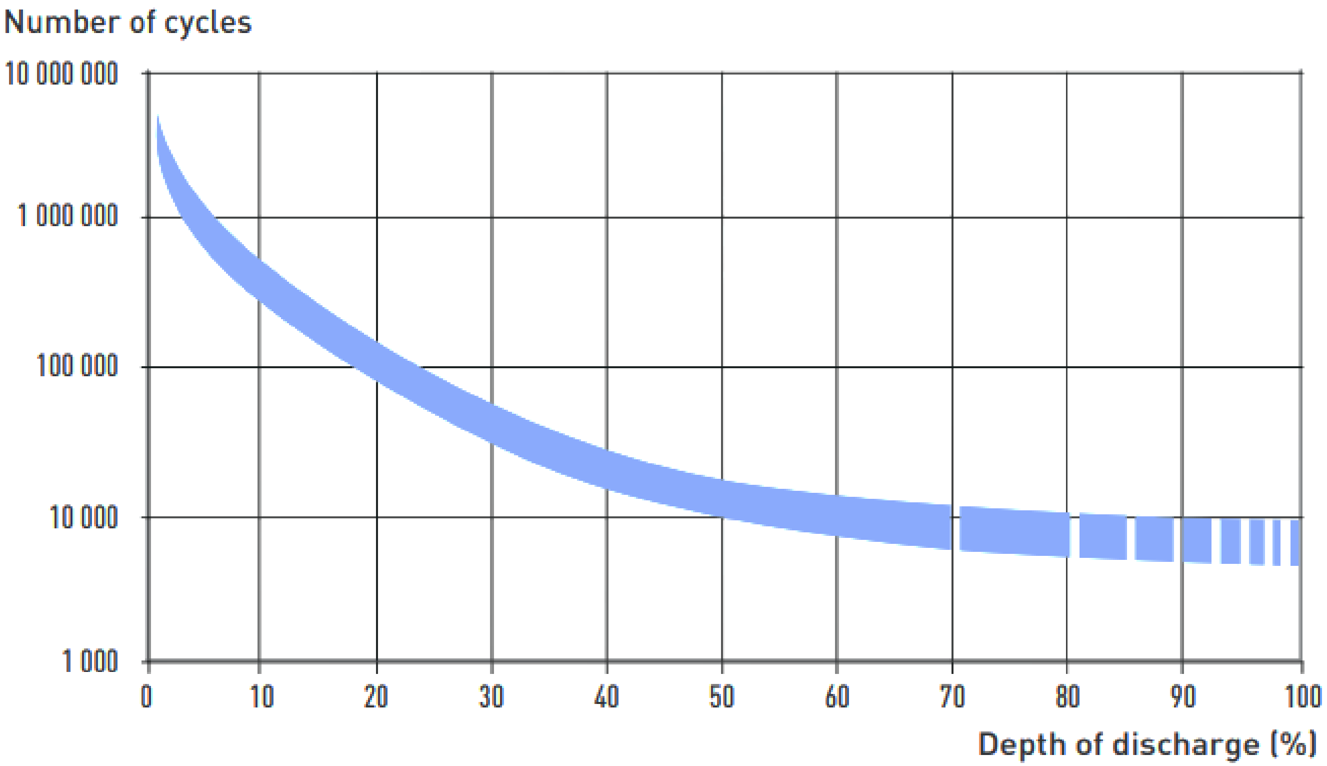
BESS	# Cycles	Capacity (MW)
ZnBr	>2000	0.05-2
Pb-acid	100-1000	0.001-50
NiCd	1000-3000	0.001-40
Li-ion	1000-5000	0.001-40
NaS	2000-4500	0.5-50
ZEBRA	>2500	0.001-1

Cycle Life

Cycle life depends on

- ✓ **<u>DoD</u>**
- ✓ Charging level
- ✓ Temperature

Cycle life at + 25°C/+ 77°F



Li-ion

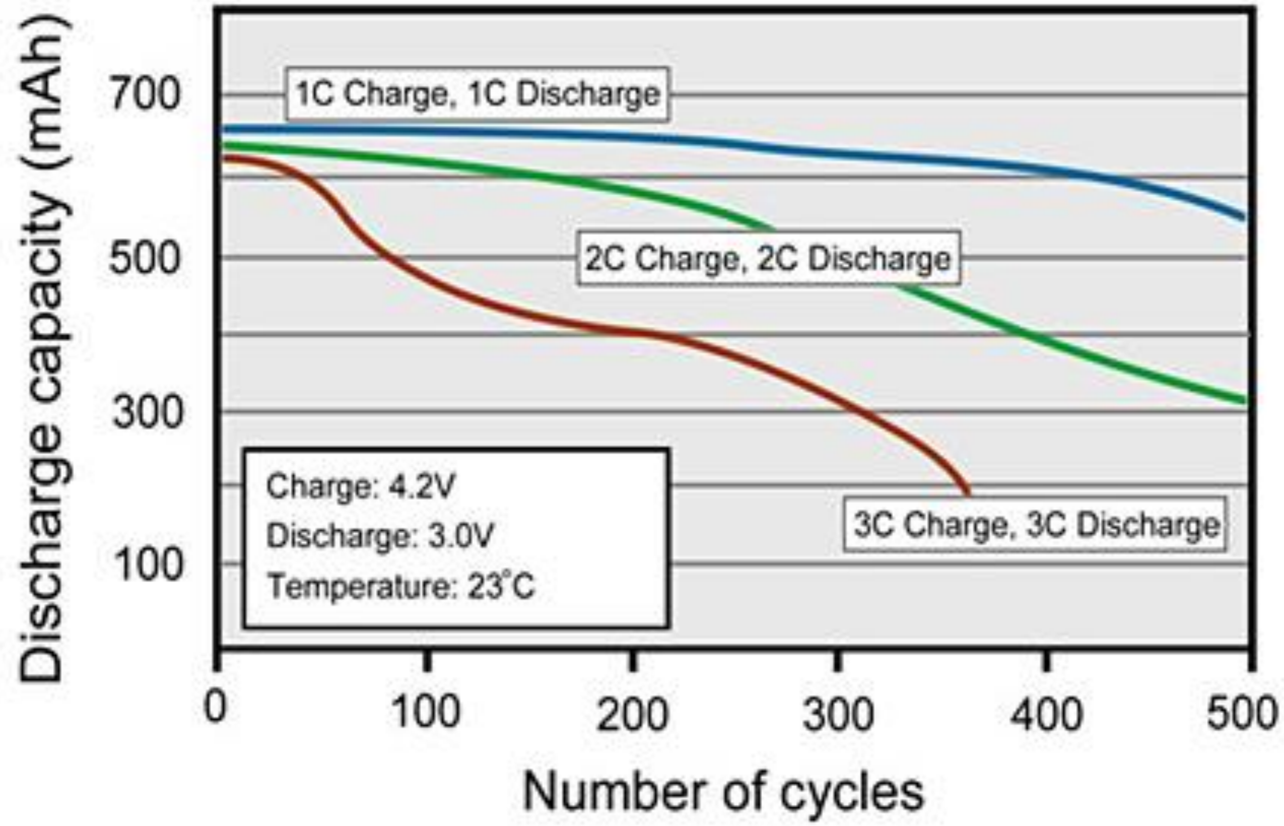
Energy applications 70% capacity at EOL

Cycle Life

Cycle life depends on

- ✓ **DoD**
- ✓ Charging level
- ✓ Temperature

C-rate	Time
5C	12 min
2C	30 min
1C	**1h**
0.5C or C/2	2h
0.2C or C/5	5h
0.1C or C/10	10h



Cycle Life

Cycle life depends on

- ✓ DoD
- ✓ **Charging level**
  - Pb-acid: a periodic fully saturated charge is essential to prevent sulfation
- Temperature

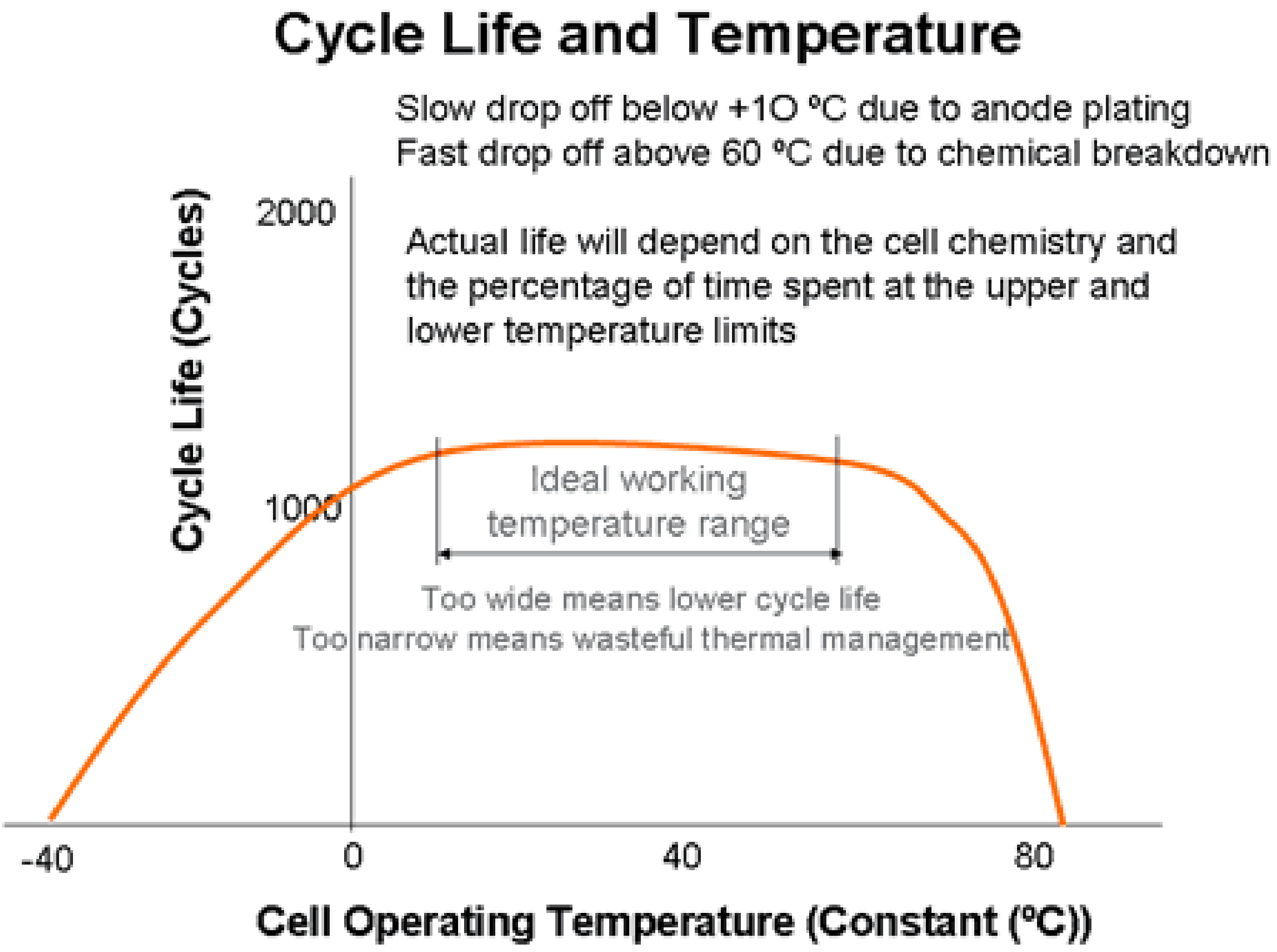
Li-ion battery

Charge Level (V/cell)	Discharge Cycles	Available SOC
4.30	150–250	110–115%
4.25	200–350	105–110%
4.20	300–500	100%
4.15	400–700	90–95%
4.10	600–1000	85–90%
4.05	850–1500	80–85%
4.00	1200–2000	70–75%
3.90	2400–4000	60–65%

Cycle Life

Cycle life depends on

- ✓ DoD
- ✓ Charging level
- ✓ **Temperature**



Final Remarks

Conclusions

- Energy storage technologies are rapidly gaining adoption for several grid applications;
- Pumped Hydro, Thermal Storage and Lead Acid batteries have been used for grid support and back up applications for 100+ years;
- In recent years, Li-Ion batteries are gaining rapid adoption for short duration applications, and reduction in prices and improvements in performance are also enabling its use for applications such as peak load management and renewable integration;
- Advanced Lead Acid and Flow batteries are also promising significant improvements in the next years which may enable their utilization in newer applications;
- Regulatory intervention & business model innovation is expected to foster the wide adoption of energy storage in the upcoming years.

Conclusions

- Each battery system has unique characteristics (restrictions!) in terms of:
  - ✓ Depth of discharge;
  - ✓ Charging level ;
  - ✓ Loading;
  - ✓ Exposure to adverse temperature.

- BESS Management Systems play a fundamental role in maximizing storage lifetime at the expense of added losses for the overall system;
- It is possible to simulate the behavior of the BESS in practical applications to determine the expected EoL.

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