Industrial batteries. Features Summary.

Chapter 2 - Industrial Battery Types

Note: To read Chapter 1, please visit: https://www.norwatt.es/noticia-industrial-batteries--features-summary---chapter-1---acronyms-es.html

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For the industrial use, the most common battery types available are:

2.1 <u>**Lead-acid batteries:**</u> Can be Flooded or sealed:

Lead-acid battery was invented in 1859 by Gaston Plante and was the first rechargeable battery, and it's the more used worldwide even actually.

Typical uses:

- In short discharge: start of thermal engines.
- In charge discharge cycles: motive power (EV or HEV).
- In long discharges: PV or communication applications.

Discharge - $PbO_2 + 2H_2SO_4 + 2e- \rightarrow 2H_2O + PbSO_4 + SO_4^{2-}$

Charge: $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$

Positive cathode: PbO_2
Negative Anode: Pb
Electrolyte: Diluted H_2SO_4

Lead-acid batteries are composed of a Lead-dioxide cathode, a sponge metallic Lead anode and a Sulphuric acid solution electrolyte.

Main advantages:

- Low-cost
- Simple manufacture
- Low cost per watt-hour
- High specific power, capable of high discharge currents
- Good performance at low and high temperatures
- No block-wise or cell-wise BMS required
- Most mature technology
- High recovery value.

Main disadvantages:

- Weight (with some exceptions were the weight can be useful)
- Sudden blackout possibility
- Low energy density per unit mass
- Slow charging: Fully saturated charge takes 14–16 hours
- Need for storage in charged condition to prevent sulphating.
- Watering requirement for flooded type
- Environmental impact
- Lead pollution risks in the industrial chain.
- Short cycle life

Characteristic	Lead- Acid Batteries
Nominal voltage per cell	2V
Specific energy (Wh/kg)	30-40
Energy density (Wh/L)	50-90
Cycle life (to 80% original capacity at 100% DOD)	200-300 (up to 400 at 80% DOD) Traction special types – 1500 up to 1500 cycles
Calendar life (years)	2 to 8
Ambient temperature during charge (°C)	-40-50 ºC (only some special types)
Ambient temperature during discharge (°C)	40-60 ºC (only some special types)
Self-discharge capacity loss per month	4-8 %
Memory effect	No
Toxic metals	Lead
Battery management system required	No

2.2 **<u>NiCd batteries</u>:** Only flooded

Nickel Cadmium battery was invented in 1899 by Waldemar Jungner.

Typical uses:

In short discharge: start of thermal engines

In long discharges: Rectifiers or back up applications: UPS, substations, railway, planes.

Cd + 2NiOOH + 2 H_2O <-> 2Ni(OH)+ $Cd(OH)_2$

Positive cathode: NiOOH

Negative Anode: Cd

Electrolyte: KOH

These type of batteries use nickel hydroxide Ni(OH)2 for the cathode, cadmium Cd for the anode and an alkaline potassium hydroxide for the electrolyte.

Main advantages:

- Economically priced per cycle
- Long life
- High resistance to abuse
- Long shelf life; can be stored in a discharged state, needing priming before use
- Wide range of operation temperature
- Good low-temperature performance
- Availability in a wide range of sizes and performance options
- Reliable chemistry

Main disadvantages:

- Low in energy density per unit mass
- Cadmium is a toxic metal; cannot be disposed of in landfills
- High self-discharge; needs recharging after storage

- Low cell voltage of 1.20 V
- Memory effect
- Environmentally unfriendly

Characteristic	NiCd Batteries
Nominal voltage per cell	1,2 Vdc
Specific energy (Wh/kg)	35-80
Energy density (Wh/L)	100-150
Cycle life (to 80% original capacity at 100% DOD)	300-1000
Calendar life (years)	15 -20
Ambient temperature during charge (°C)	0-40 ºC
Ambient temperature during discharge (°C)	-20-70 ºC
Self-discharge capacity loss per month	15-20%
Memory effect	Yes
Toxic metals	Cadmiun
Battery management system required	No

2.3 **Nickel–Metal Hydride** (Ni–MH) Battery

Development was sponsored by Mercedes and Volkswagen for use in EV.

The Ni–MH Battery for EV, HEV or satellite applications (initially).

$NiOOH + MH <-> Ni(OH)_2 + M$

Positive cathode: $Ni(OH)_2$

Negative Anode: MH

Electrolyte: KOH

These cells use nickel hydroxide Ni(OH)2 for the cathode. Hydrogen is used as the active element in a hydrogen-absorbing anode.

Main advantages:

- Good energy density.
- Simplified incorporation into products currently using nickel–cadmium batteries because of the many design similarities between both.
- Greater service advantage over other primary battery
- Greater service advantage at extreme low-temperature operation (–20°C)

Main disadvantages:

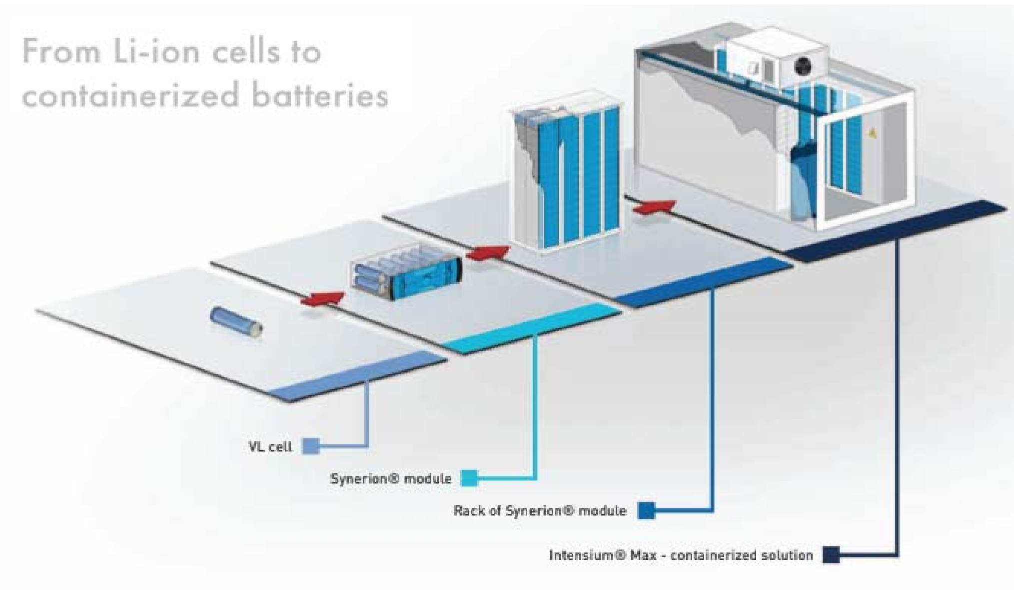
- Limited service life
- Limited discharge current: repeated discharge with high load currents reduces the battery’s cycle life.
- Need for a more complex charge algorithm
- Generates more heat Than NiCd during charge
- High self-discharge

Characteristic	Nickel–Metal Hydride
Nominal voltage per cell	1.2 Vdc
Specific energy (Wh/kg)	60–120 W·h/kg
Energy density (Wh/L)	140–300 W·h/L
Cycle life (to 80% original capacity at 100% DOD)	180–2000 cycles
Calendar life (years)	Typical 5 years
Ambient temperature during charge (°C)	0-50ºC
Ambient temperature during discharge (°C)	0-50ºC
Self-discharge capacity loss per month	0,5 – 3% per month
Memory effect	Yes
Toxic metals	--
Battery management system required	No

2.4 **Lithium ion batteries:** Only sealed

The Lithium ion battery was invented in 1985 by Akira Yoshino, and Sony had the commercial one in 1991

Typical uses: Portable devices, tools, laptops, EV, telecommunications, Storage.



$Li_xC_6 + Li_{(1\_x)}Mn_2O_4 <-> C_6 + Li_xMn_2O_4$

Positive cathode: $Li_xMn_2O_4$

Negative Anode: Li_xC_6

Electrolyte: Organic

Main advantages:

- Very fast recharge
- Low weight
- High energy density.

- Maintenance-free
- Low self-discharge
- Simple charge algorithm

Main disadvantages:

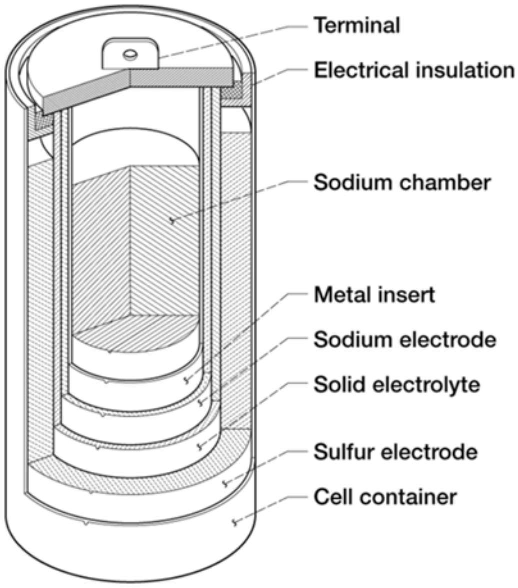
- High price,
- Need of BMS and BTMS,
- Degradation at high temperatures and when stored at high voltage;
- No rapid charge possible at freezing temperatures (<0°C or <32°F)
- Severe transportation regulations required when shipping in larger quantities.

See full details in section 3 of this document.

2.5 Sodium–Sulfur (Na–S) **Zebra battery.** Only sealed

The Sodium–Sulfur battery was invented in 1960 by Ford for EV uses.

Typical uses: Grid and standalone systems, space, transport, heavy machinery, EV.



$2Na + 3S <-> Na_2S_3$

Positive cathode: S

Negative Anode: Na

Electrolyte: Solid

Utilises molten sodium tetra chloroaluminate ($NaAlCl_4$), which has a melting point of approximately 160°C, as the electrolyte. The negative electrode is molten sodium. The positive electrode is nickel in the discharged state and nickel chloride in the charged state.

Main advantages:

- High energy density
- High efficiency of charge and discharge
- long cycle life
- Built from inexpensive materials

Main disadvantages:

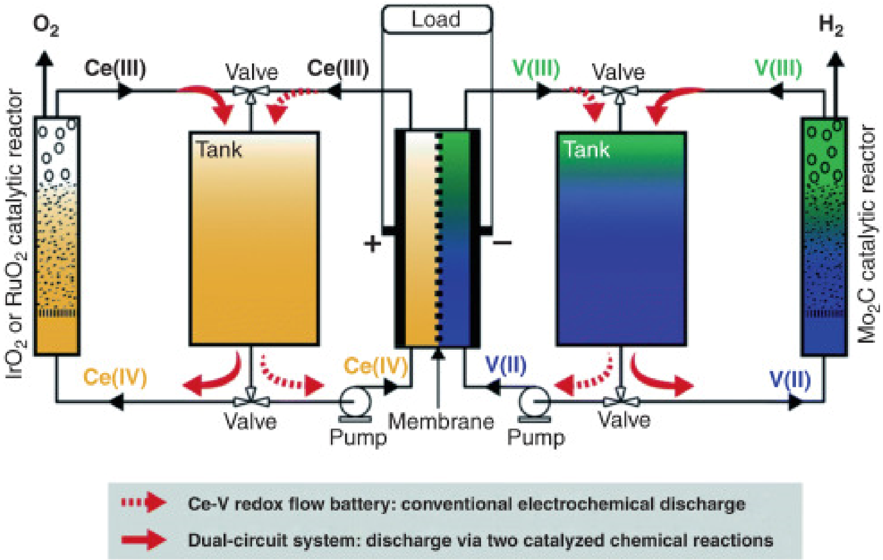
- High operating temperatures (from 300ºC to 350 ºC)
- Highly corrosive components
- Stringent operation and maintenance requirements
- When the Zebra battery is not in use, it needs 12 hours for the reheating process, plus 6- 8 hours for charging.

Characteristic	Sodium–Sulfur Zebra battery.
Nominal voltage per cell	2V
Specific energy (Wh/kg)	200-250 Wh/kg
Energy density (Wh kg^{-1})	760 Wh kg^{-1}
Cycle life (to 80% original capacity at 100% DOD)	4500 cycles
Calendar life (years)	15-20 years
Ambient temperature during charge (°C)	290-360 ºC
Ambient temperature during discharge (°C)	290-360ºC
Self-discharge capacity loss per month	--
Memory effect	No
Toxic metals	--
Battery management system required	No

2.6 Redox Flow Battery (RFB)

Modern redox flow batteries (RFBs) were invented in 1976 by Lawrence Thaller at the National Aeronautics and Space Administration (NASA) (Thaller, 1976)

Typical uses: Big storage for electrical networks (under development), load balancing, peak shaving, UPS, stand-alone power system.



The formula (anode & cathode) depends on the components - The system described is a cerium–vanadium (Ce–V) flow battery:

V^{3+} (aq) + e- → V^{2+} (aq)

Ce^{3+} → Ce^{4+} + e-

There are three types available:

- Vanadium redox battery (VRB)
- Polysulfide–bromine battery (PSB)
- Zinc–bromine (Zn–Br) battery

Main advantages:

- Long service life (20 years)
- No degradation of electrodes and electrolytes (unlimited number of charge and discharge cycles)
- High safety: free of combustible materials
- Availability of operation under normal temperatures

Main disadvantages:

- Low energy density
- Require pumps, sensors, flow and power management, and secondary containment vessels.
- Stringent operation and maintenance requirements

Characteristic	Redox Flow Battery
Nominal voltage per cell	1.15–1.55 V
Specific energy (Wh/kg)	10–20 Wh/kg
Energy density (Wh/L)	15–25 Wh/L
Cycle life (to 80% original capacity at 100% DOD)	>12,000-20,000 cycles
Calendar life (years)	20-30 years
Ambient temperature during charge (°C)	15-55ºC
Ambient temperature during discharge (°C)	15-55ºC
Self-discharge capacity loss per month	10%
Memory effect	No
Toxic metals	Yes. P.e Vanadium
Battery management system required	Available

Coming soon… *Chapter 3 - Lithium ion battery types*