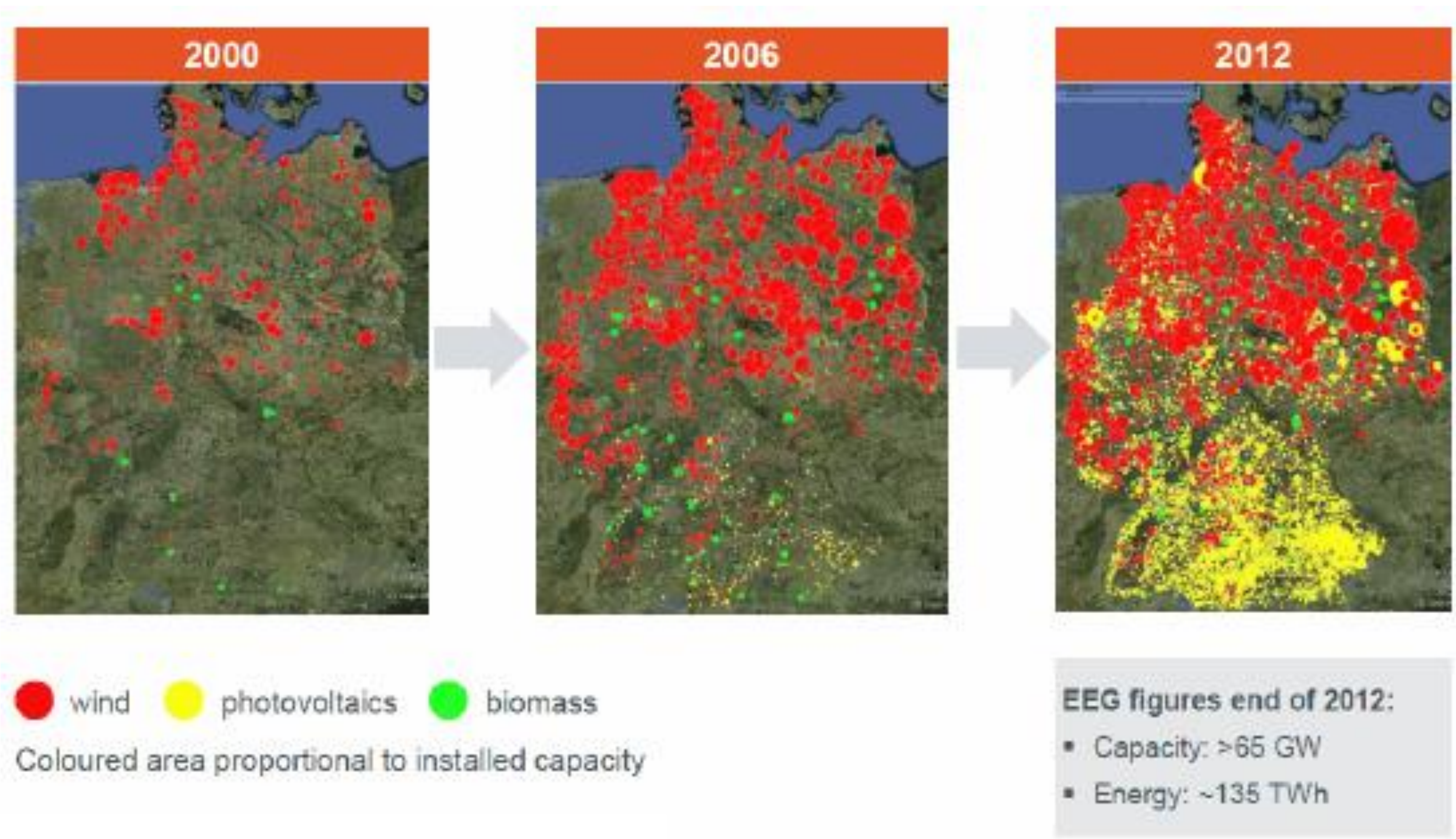
Grid-Scale Energy Storage

October 2016

Energy storage is one of the strategic areas of growth

The changing energy landscape…



Source: 50Hertz, TenneT, Amprion, TransnetBW, Google Earth

Main Drivers for the development of Energy Storage

1 Variable Renewable Generation

- Growing amount of variable energy generation being added to power grids worldwide
- Energy storage has the ability to provide value to the grid operator/utility by improving stability
- Improving the economics of a variable RES generating facility by limiting curtailment or firming output

2 Grid Structures

- Existing power systems have significant differences in both design and operations due to historical patterns
- Increasing distributed generation connected to the low voltage grid
- Rapid changes and different load patterns of demand and supply

3 Market Structures

- Level of Competition
- Fully Regulated vs. Liberalised Market

4 Demographics

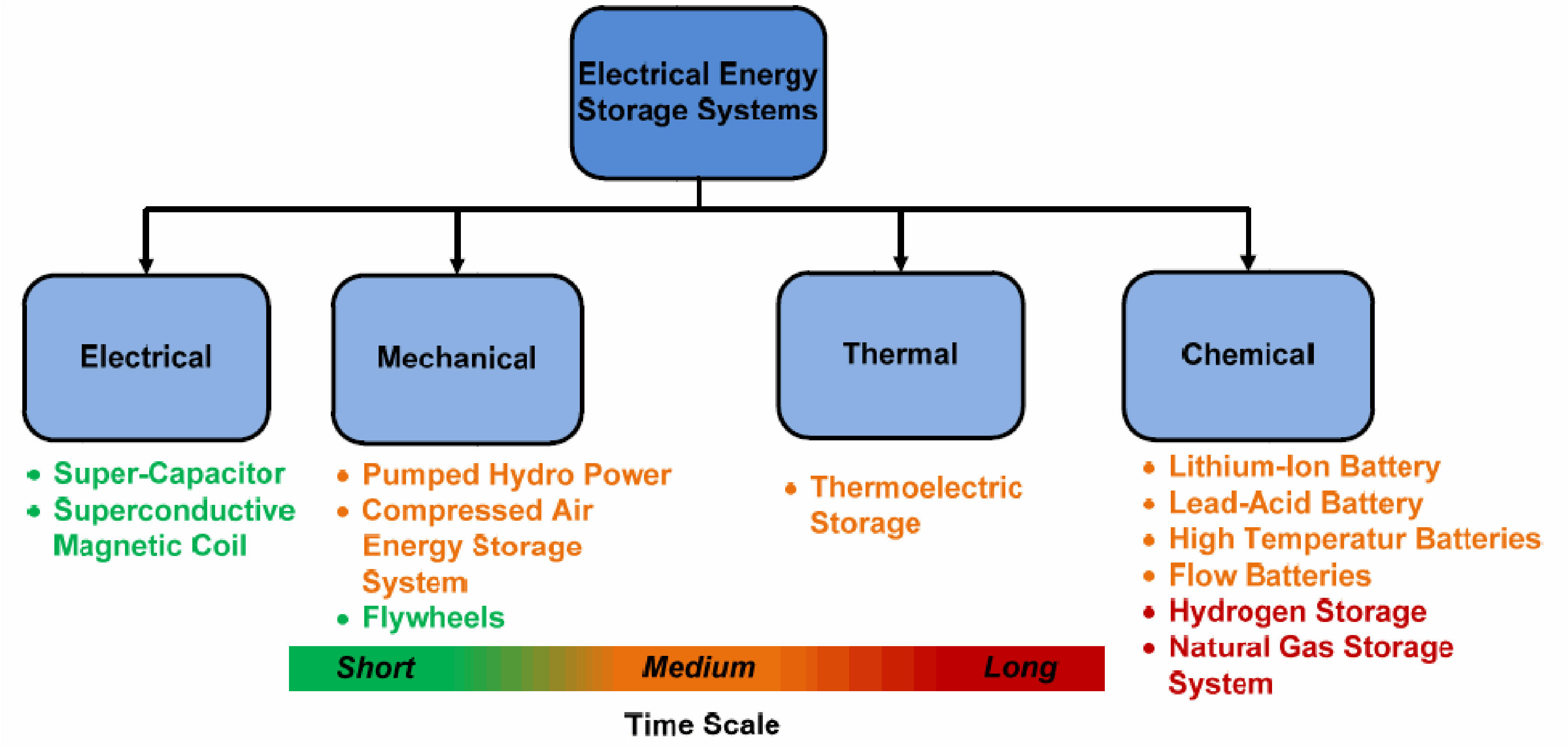
- Increasing population will play a role in determining the future structure of the power grid
- Urban vs. Rural Population

5 Condition of the Grid

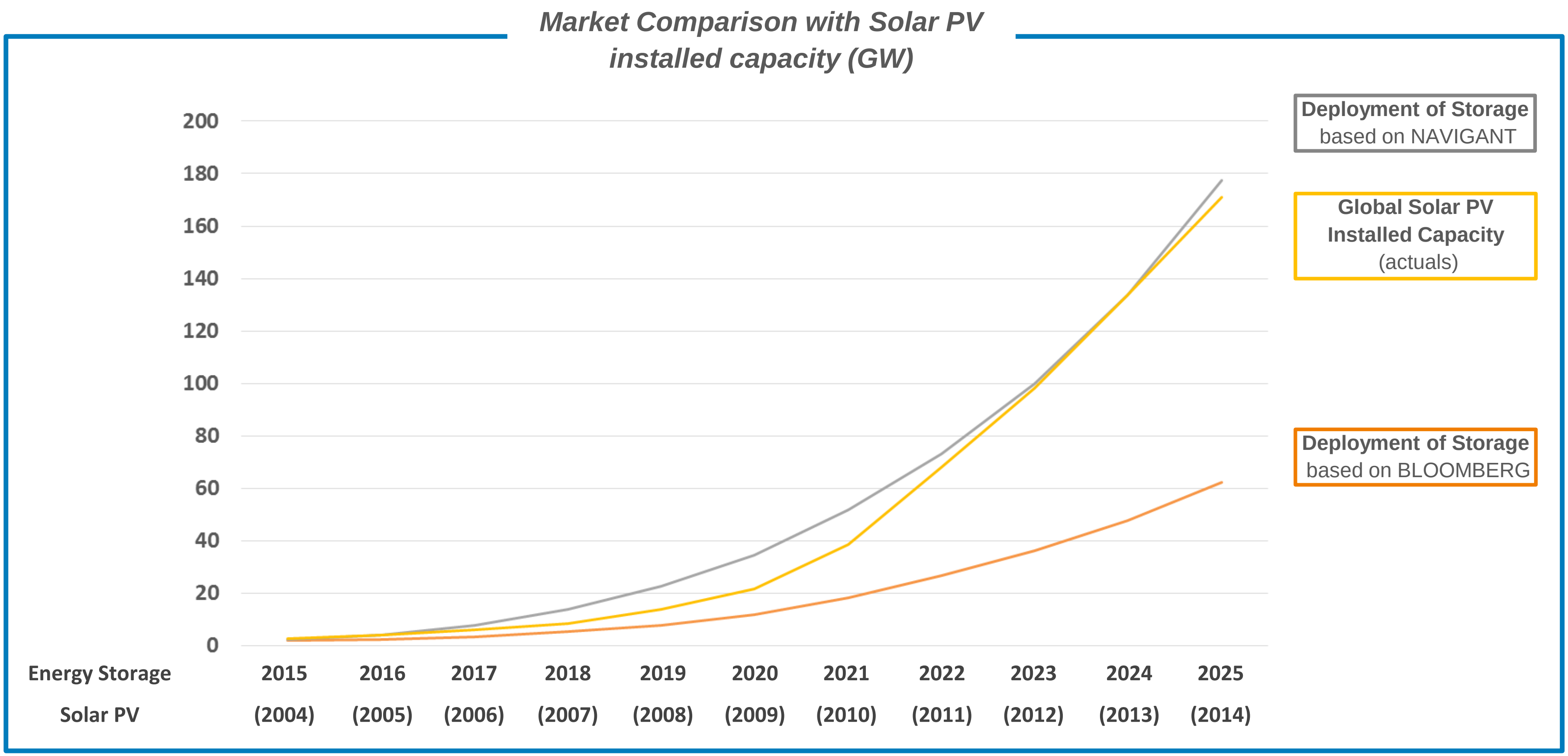
- Overall stability of the electrical grid
- Operators of unstable grids are more likely to deploy utility-scale ESSs to minimize the likelihood of outages
- Distributed ESSs and Microgrids are also expected to become increasingly popular options for unstable grids

Sources: NAVIGANT Report "Country Forecasts for Grid-Tied Energy Storage", 4Q 2015

Storage classification by Form

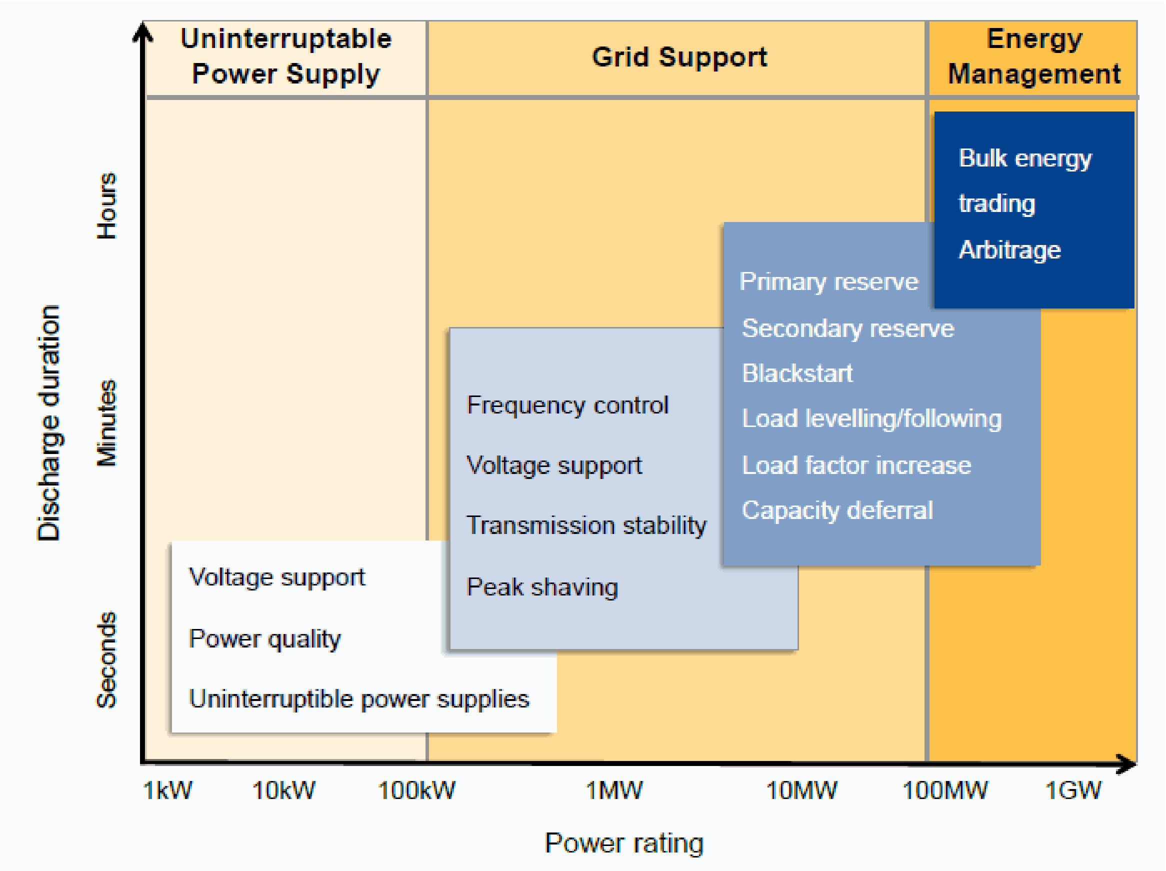


Projected installed capacity worldwide

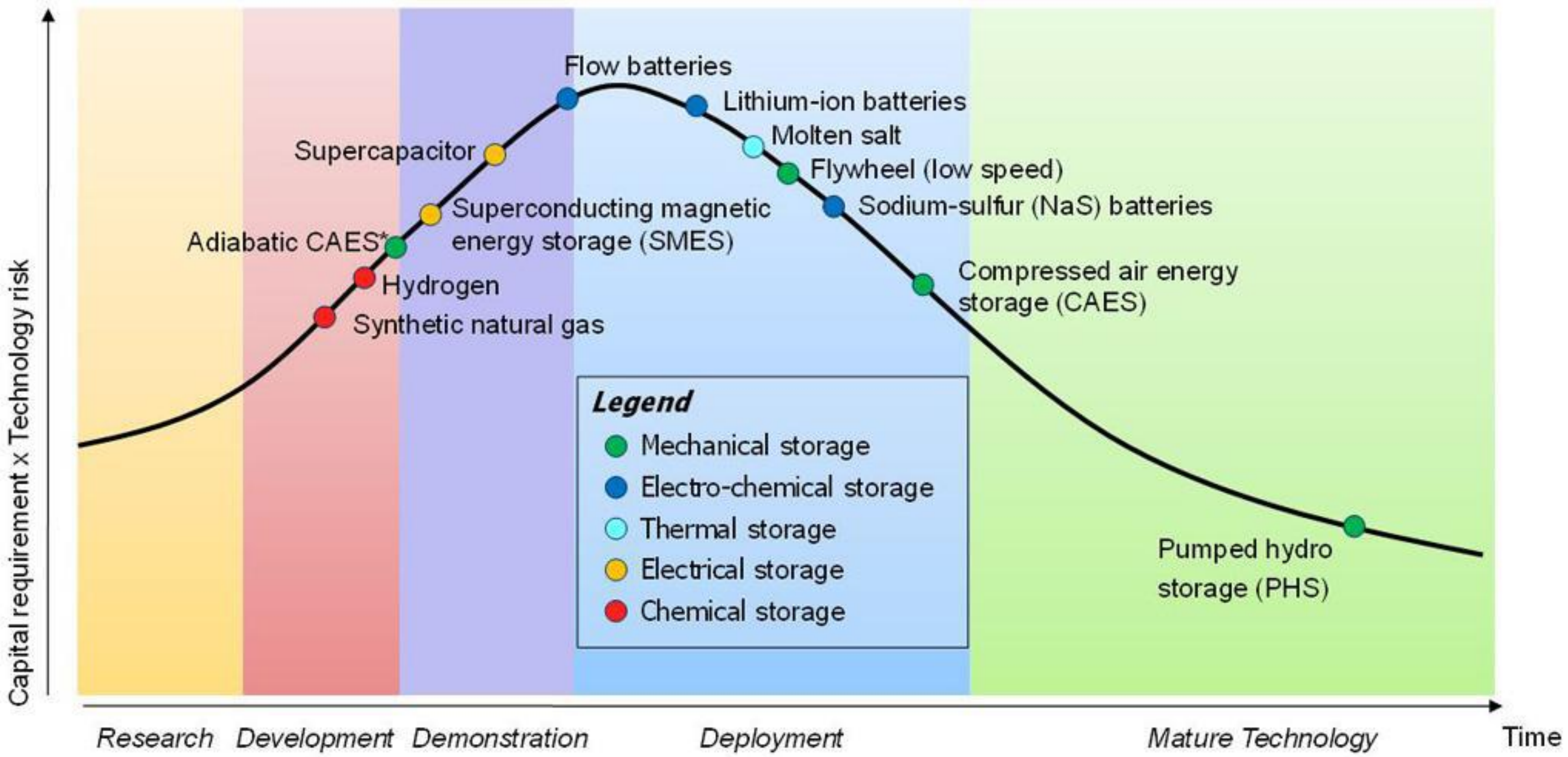


Sources: NAVIGANT Report "Country Forecasts for Grid-Tied Energy Storage", 4Q 2015
BLOOMBERG Report "New Energy Outlook 2016", June 2016
ENERDATA (Solar PV installed Capacity 2000-2014)

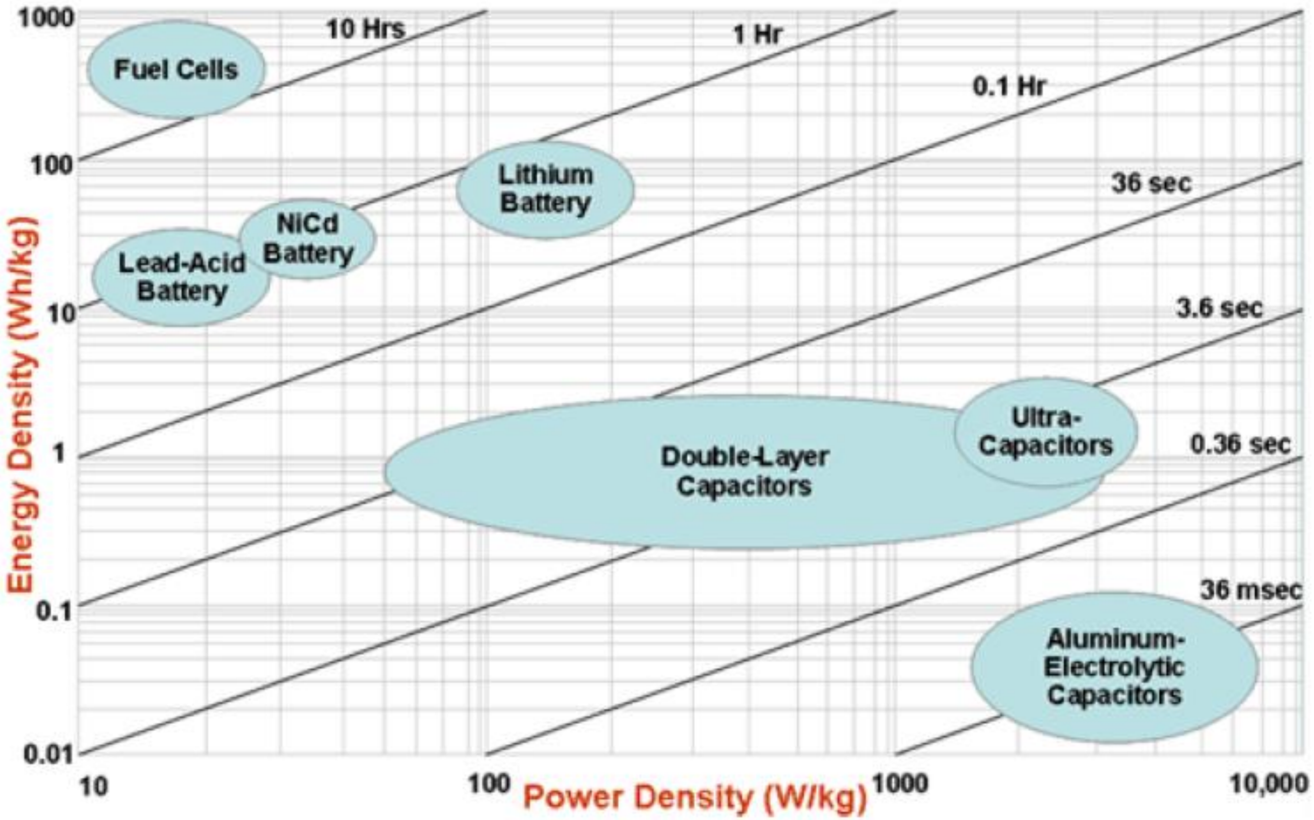
Various needs of electricity storage



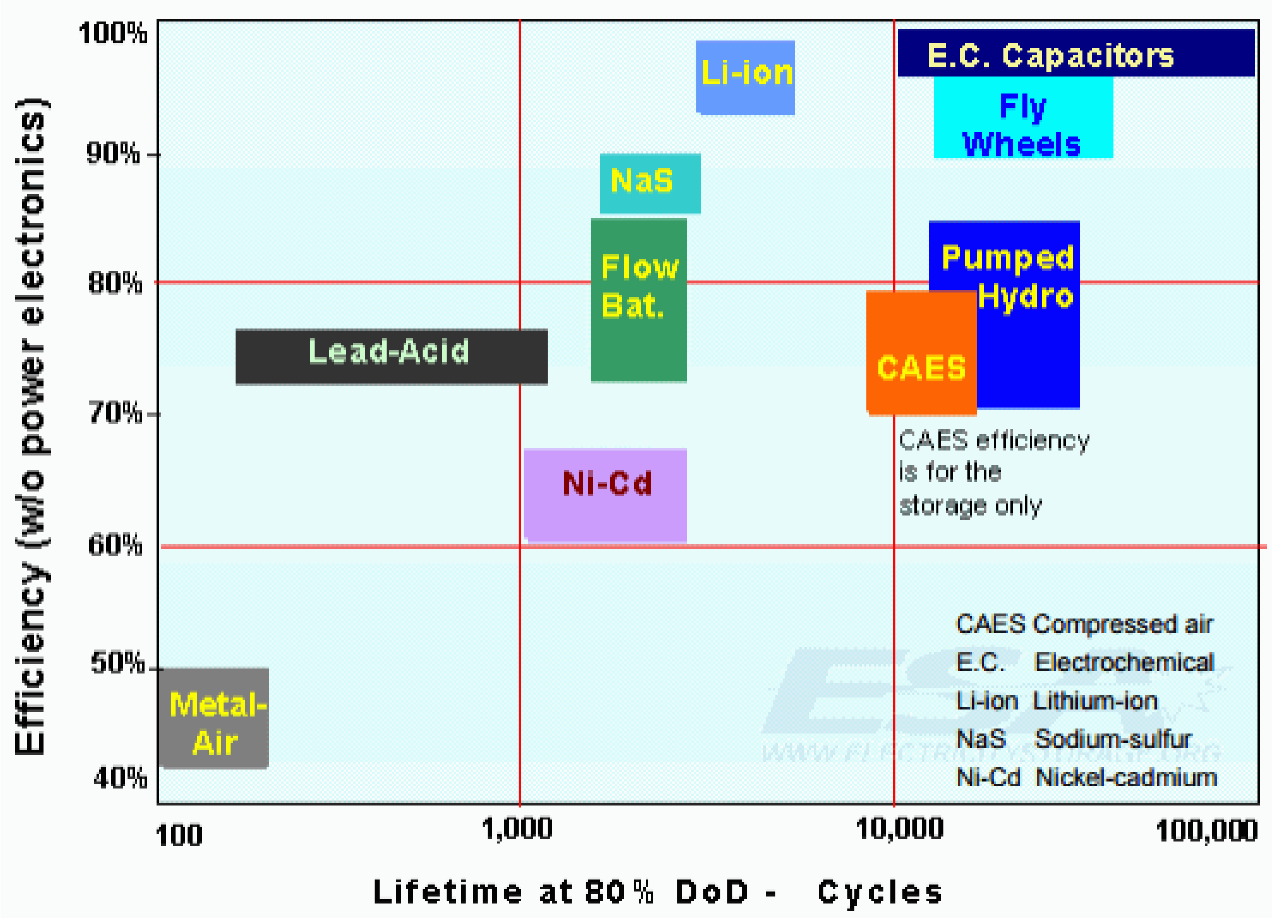
Maturity of energy storage technologies



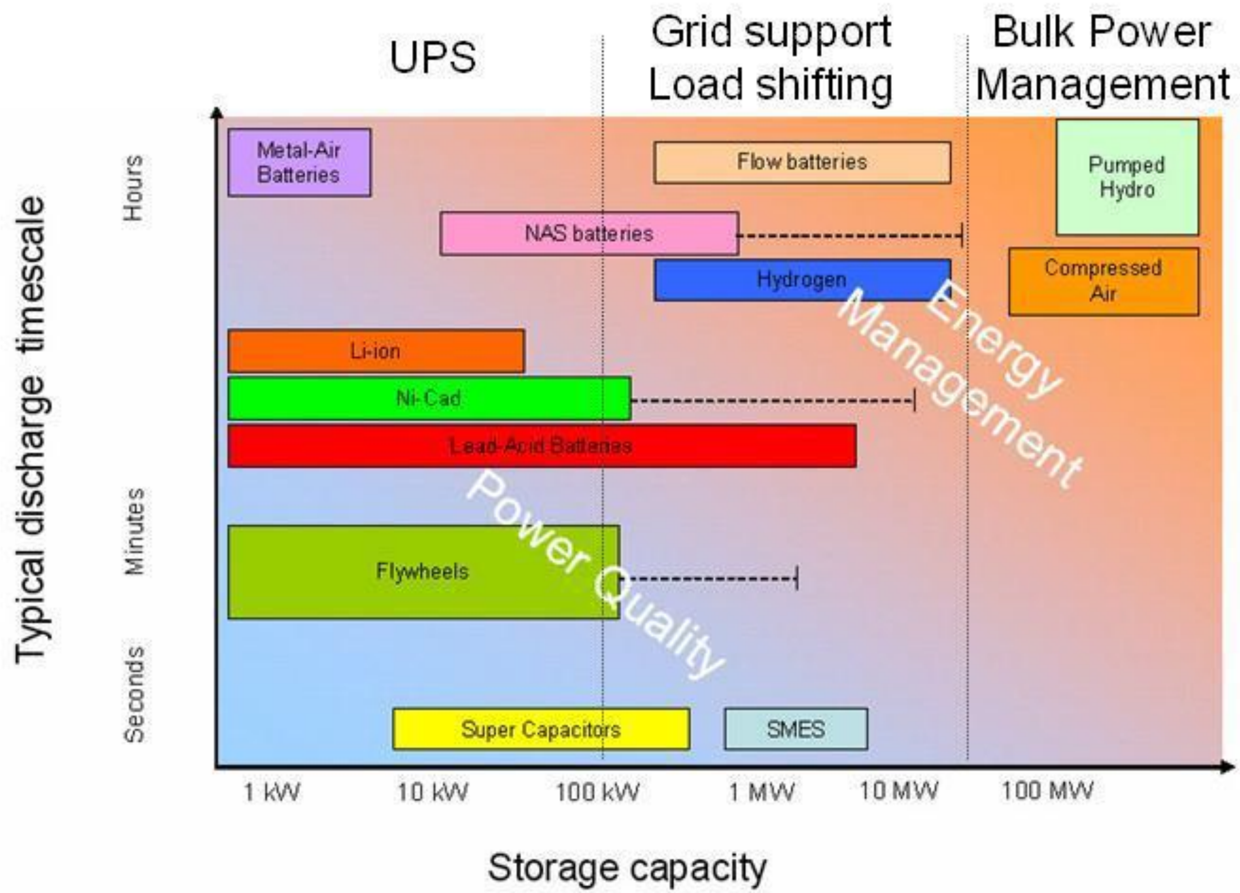
Classification: Energy (Wh/kg) vs. Power (W/kg)



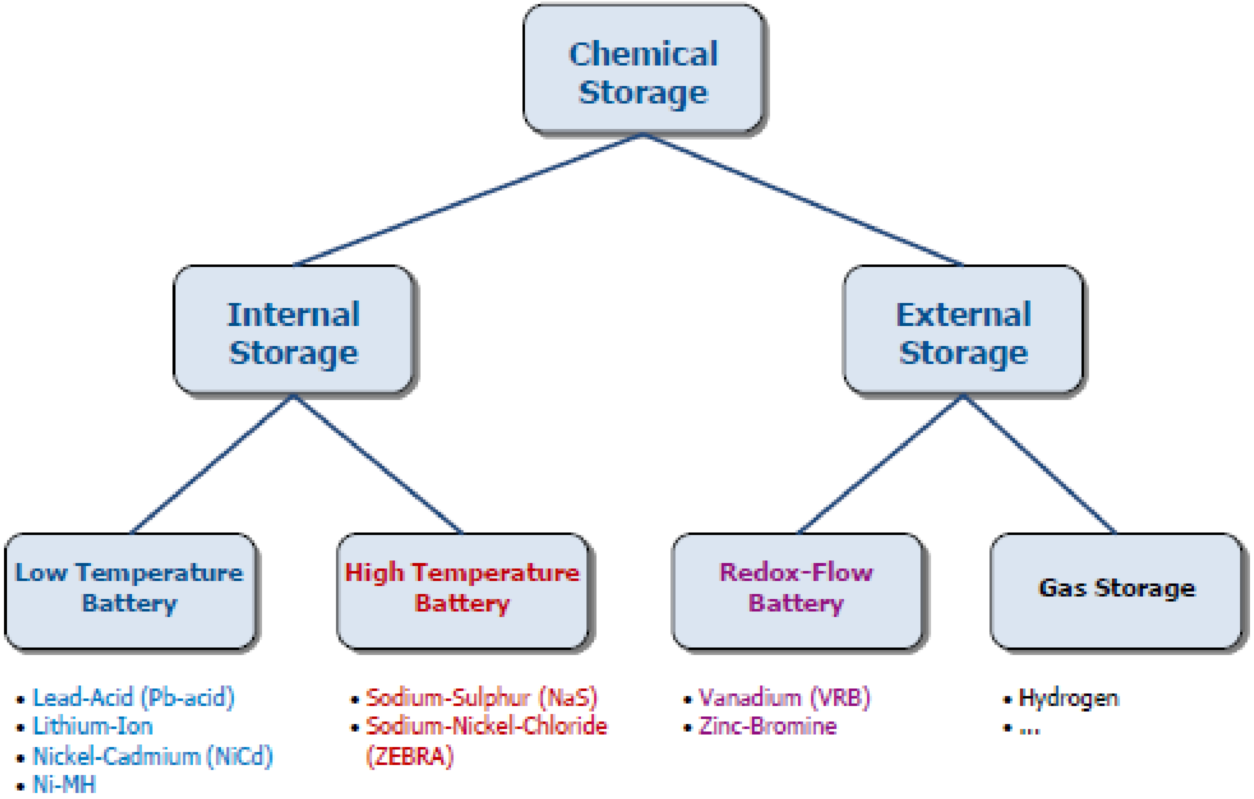
Classification: Efficiency/Lifetime



Classification: Discharge timescale vs. Storage Capacity



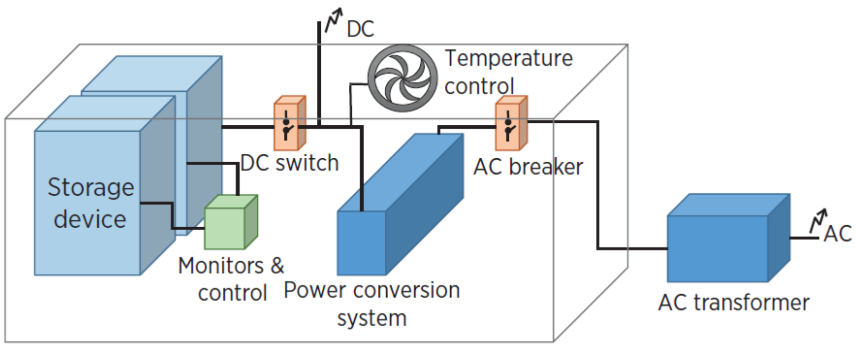
Chemical Storage



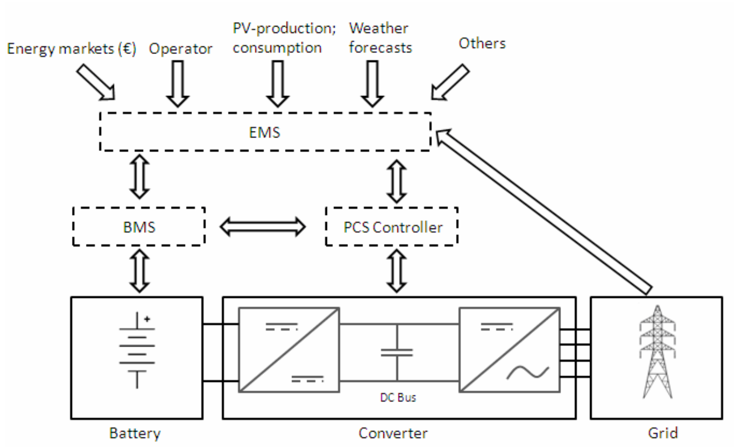
A battery storage system: Physical components

- **Battery system or Energy Storage System (ESS)**
  - Battery Packs [MWh] (and [MW])
  - Battery Management System (BMS)
- **Power Conversion System (PCS)**
  - Converter [MW]
  - PCS Controller
- **Step-up Transformer [MW]**
- **DC Isolation Switch**
- **AC Switchgear**
- **HVAC**
- **Fire Detection and Suppression System**
- **Energy Management System (EMS)**

Physical components

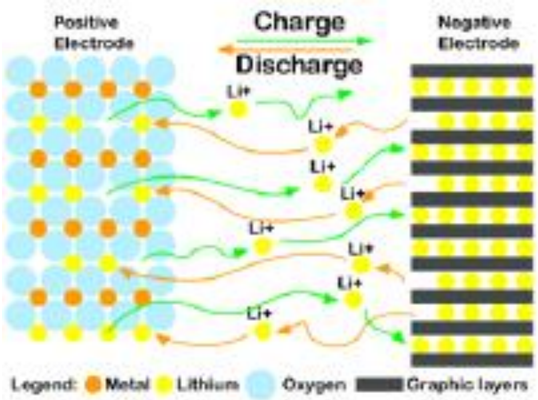


Functional components



Chemical Storage: Lithium-ion

- Rechargeable battery
- Exchange of Li+ ions between the positive and the negative electrode (rocking-chair)



Main Advantages

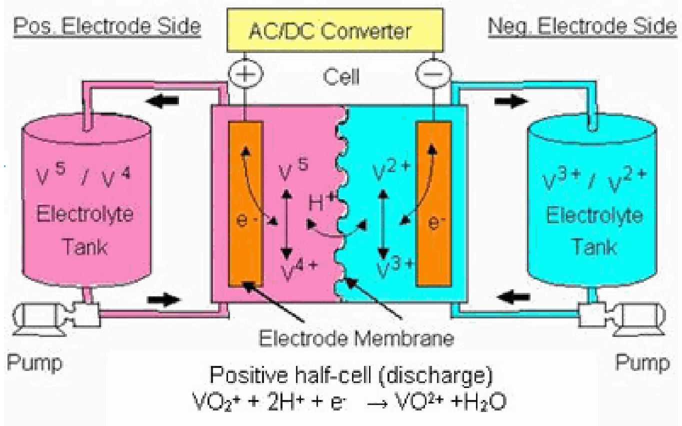
- High round-trip efficiency : 85-90%
- High energy density: 200 – 350 Wh/l, reduction of used space
- Low self-discharge: ~5 % per month
- Low maintenance
- Long cycle and calendar life: 1000-5000 full cycles
- Lots of research on this technology, price continuously decreasing

Main Disadvantages

- No inherent safety: thermal limitations, overcharge can lead to combustion of cells
- Sophisticated battery management system required (single cell monitoring)
- High cost: especially compared to lead-acid batteries, 450-1250 €/kWh

Chemical Storage: Redox-Flow

- Modern flow batteries are generally 2 electrolyte systems called catholyte and anolyte
- Act as liquid energy carriers
- The catholyte and anolyte are pumped simultaneously through the two half-cells of the reaction cell separated by a membrane. The reaction is reversible allowing charge and discharge.



Source: Sumitomo Electric Industries, Ltd. (SEI) - Copyright 2001

Main Advantages

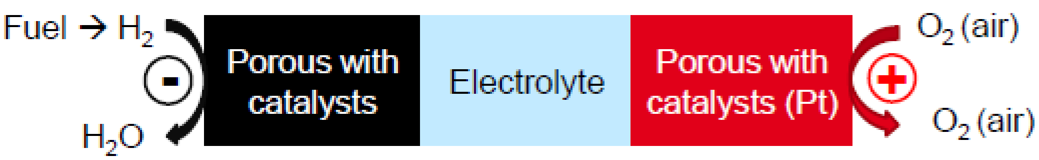
- Energy and power scalable independently
- Almost infinite capacity, which is only limited by the space of tanks
- High cycle and calendar life expectancy for VRB: > 10000, 10-15 years
- Low self-discharge 0,1-0,4% per day (for VRB)
  (but consumption of the circulation system)

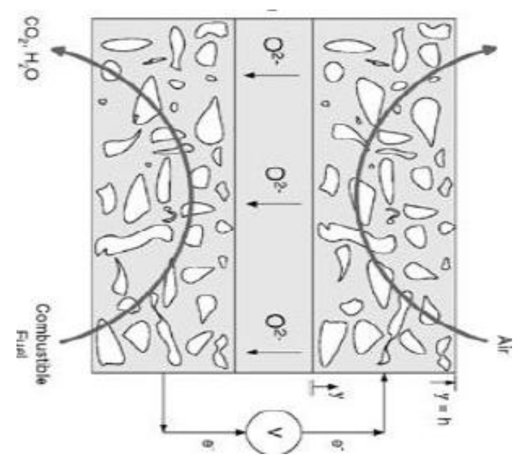
Main Disadvantages

- Leakage caused by acidic fluids, large amounts of acid
- Requires pumps, valves, sensors, reservoirs, … prone to errors and costly maintenance
- Energy density generally low: 15-35 Wh/l (VRB), 50-90 Wh/l (Zn-Br)
- Low efficiency: 65-75% for VRB, 70-80% for Zn-Br
- Expensive system
- Not really mature, in an early stage of field deployment and demonstration trials

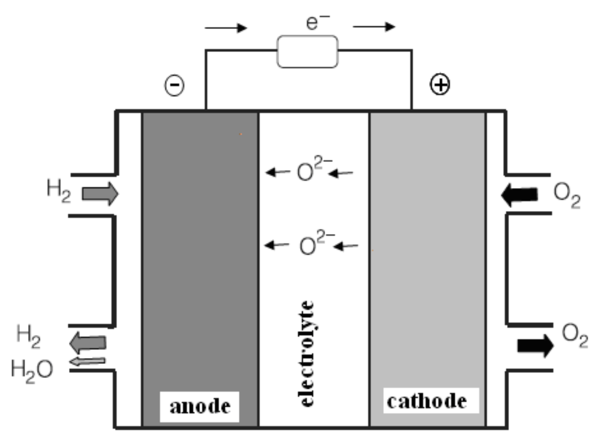
Fuel Cells

- Two porous structures to the negative and positive electrode
- Electrolyte to exchange O2- ions between the electrodes



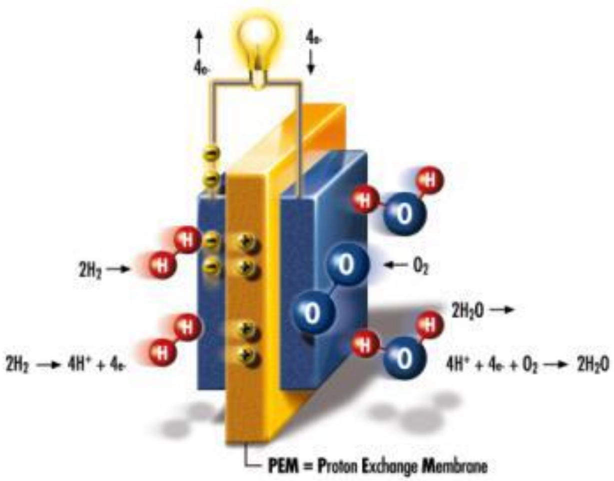


- Particularity: Open system



Fuel Cells (Gas Storage)

- A hydrogen energy storage system generally consists of hydrogen production (electrolysis of water), hydrogen transmission and storage, and hydrogen conversion to electricity
- Fuel cells convert hydrogen and oxygen into electricity through an electrochemical process, resulting in water and heat as potentially useful byproducts



$$2\,H_2 + O_2 \rightarrow 2\,H_2O$$

Main Advantages

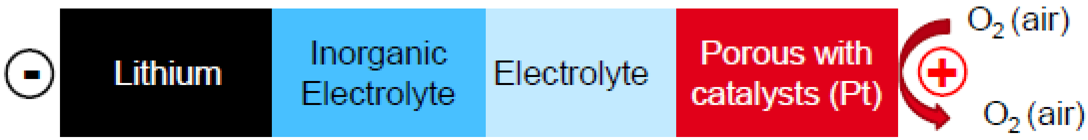
- Environmentally friendly: no emission of greenhouse gases (GHG)
- Fuel with very high specific energy : 33,3 kWh/kg
- Very large amounts of energy can be stored, injection in the natural gas grid
- Multiple valorization of hydrogen: hydrogen can also be used in other energy sectors

Main Disadvantages

- High cost for electric applications, high costs for electrolyzers
- Low round-trip efficiency: 30-40%; but less relevant for long-term storage. The efficiency can be increased if the heat of the fuel cell can be valorised
- Technology is not mature yet for large-scale grid applications
- Storage density is about one-third lower than for methane
- Operating costs strongly depend on price of the purchasing power due to low efficiency

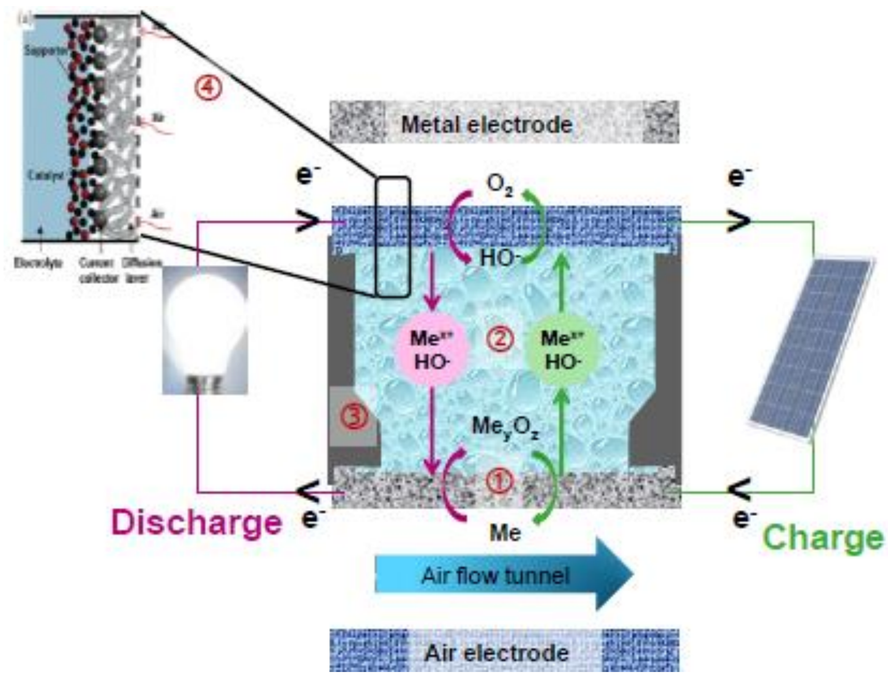
Hybrid technology: Metal air (ex: Lithium air)

Hybrid between **Metal-ion battery** and **Fuel Cell**



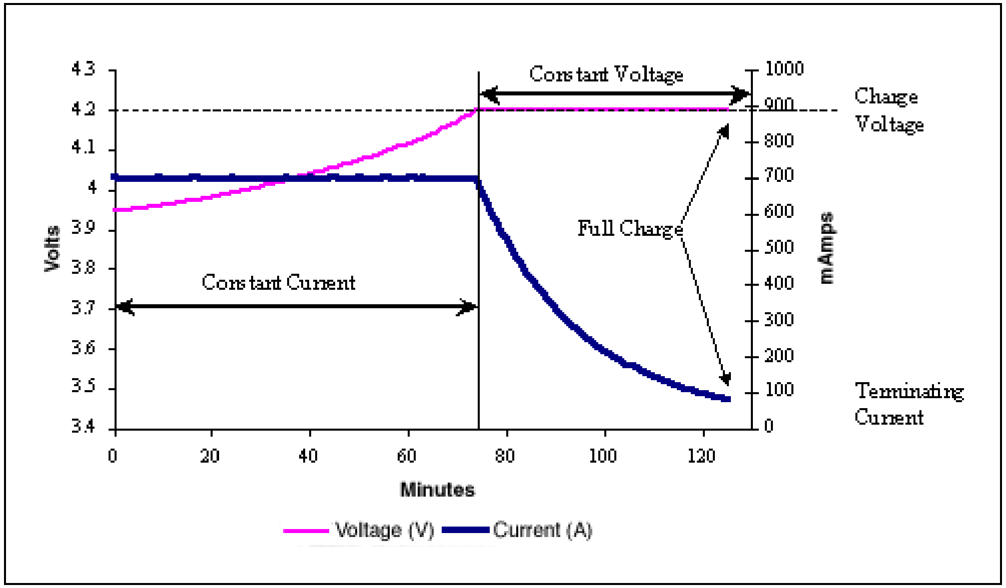
- Particularity:
  Semi-Open system

- Personal interpretation for Li-air:
  - Combination of two unsolved drawbacks
  - Lithium unstable in air//Catalysts pollution



A battery storage system: Charge Profile

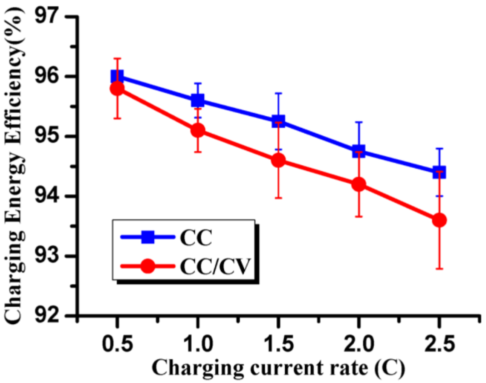
- **Constant Current (CC) or Constant Power (CP)**
  - To transfer the bulk of the energy
  - Until the charge voltage is reached
- **Power Conversion System (PCS)**
  - To fully charge the battery
  - Until the current becomes very small



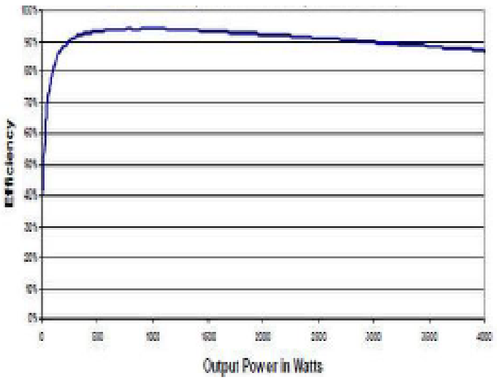
A battery storage system: Efficiency / Energy

- **Efficiency**
  - $Roundtrip\ efficiency = \frac{\sum Energy\ out}{\sum Energy\ in}$
  - Main Parameters:
    - i. Power rate
    - ii. Internal resistance: battery type, temperature, SoC, SoH, charging/discharging, …

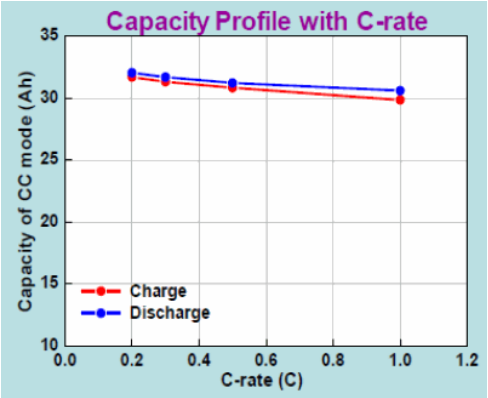
Battery

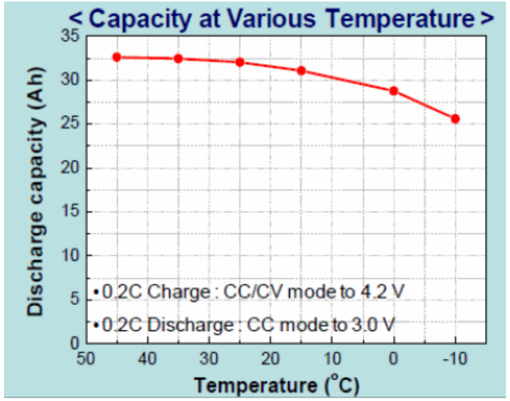


Inverter



- **Energy**
  - Main Parameters:
    - i. Power rate
    - ii. Temperature





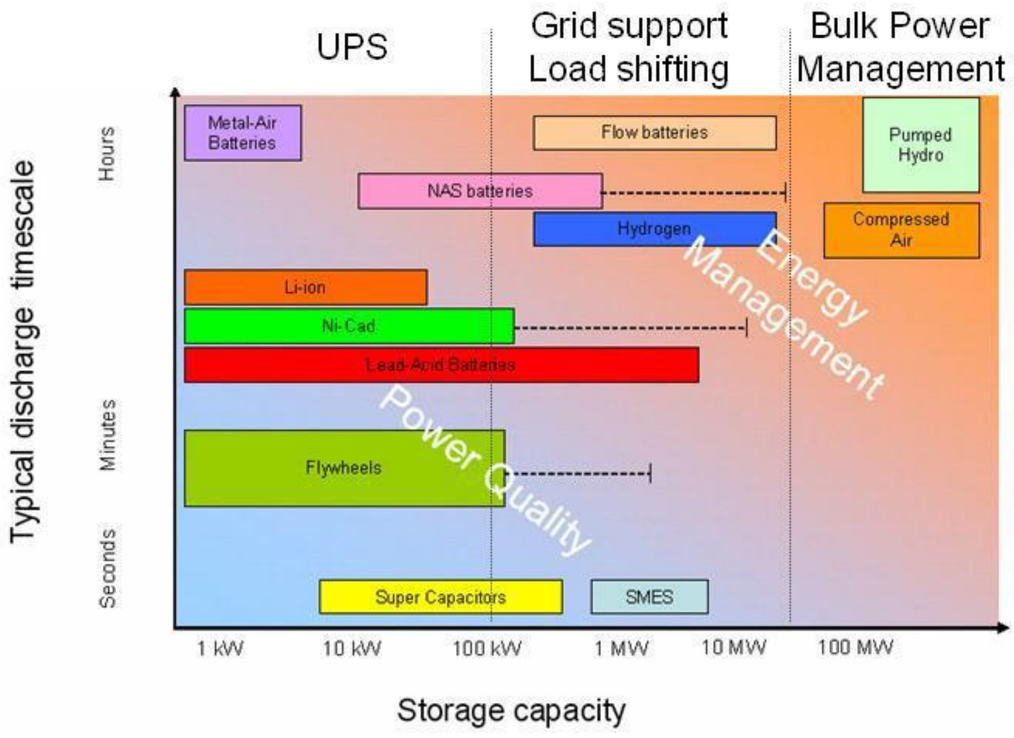
Source: S&C Electric

Conclusions

- Different ways to classify the technologies
- Different technologies for different applications

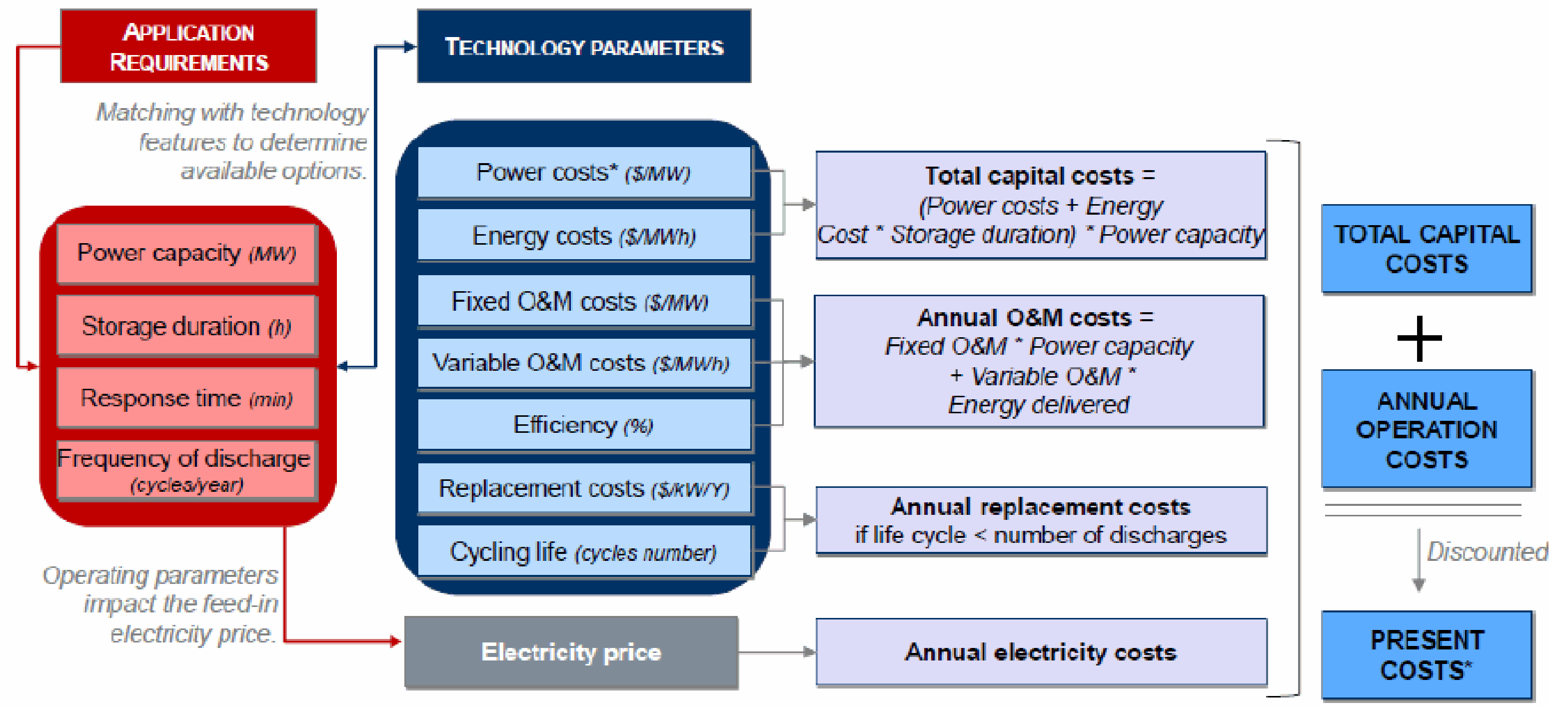
Factors taken into account:

- Size, weight
- Capital costs
- Cost per cycle
- Maintenance
- Safety
- Environmental issues
- Energy/Power ratio



Storage Costs Parameters

- **The economics of electrical storage are affected both by technological features and applications, making them difficult to assess**



Note: * Power costs include storage device costs, balance of plant costs and power conversion costs.
** O&M: operation & maintenance except electricity price. Include gas price for compressed air energy storage.

Source: SBC Energy Institute

Various business models on the radar screen

Integrate renewables

- **Balance output** from renewable sources (at generation site)
- **Optimise** production profile

Trading activities

- **Price arbitrage** between peak and off-peak

Support to grid

- **Balancing services**
  - Frequency response
  - Reserve services

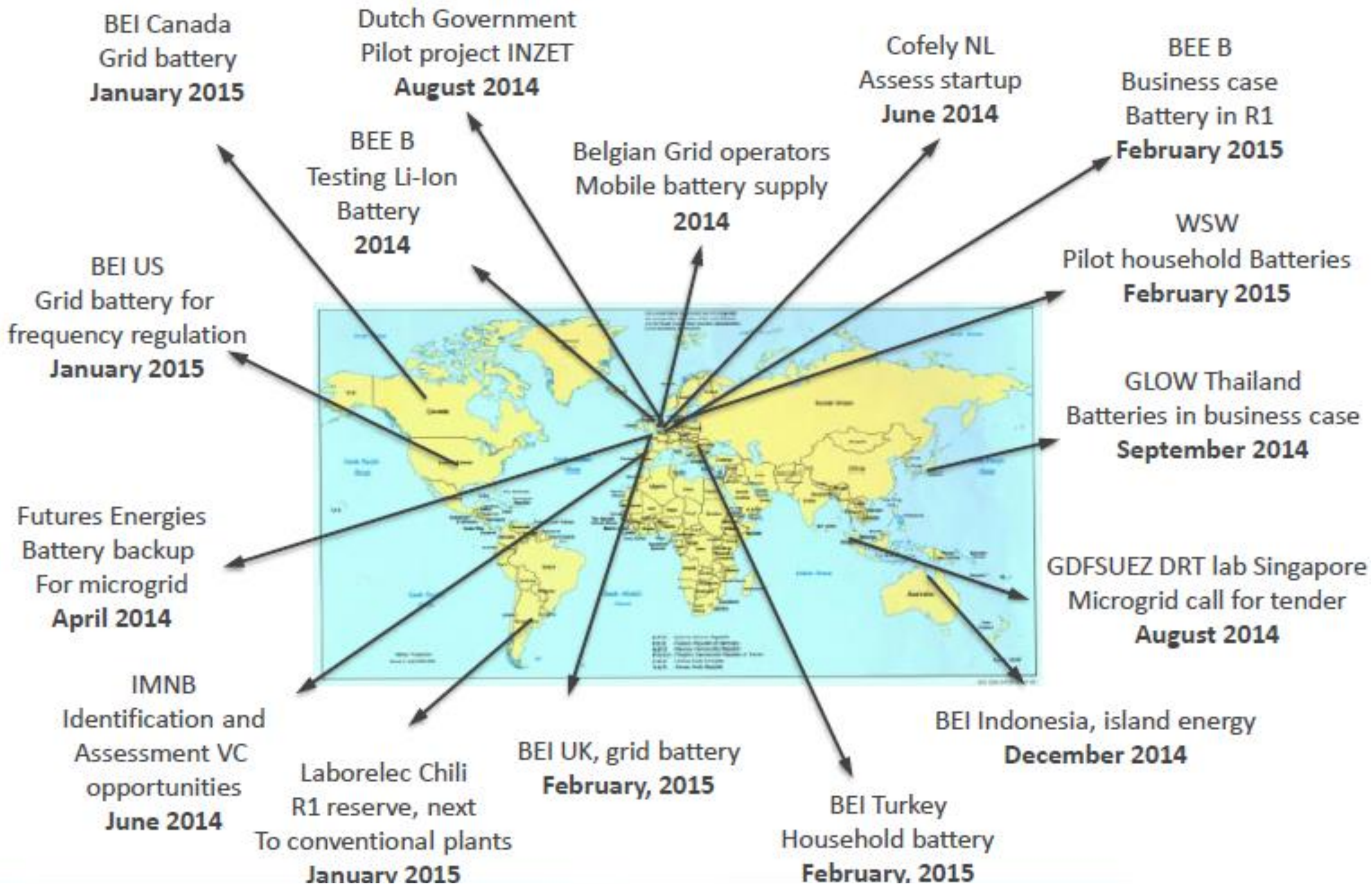
Support to DNOs

- Balance supply and demand
- Peak shaving
- Congestion relief

Support to industrials

- **Industrial applications**
  - End-user peak shaving
  - Energy cost management
  - Continuity of supply

A rapidly increasing interest within ENGIE



ENGIE has significant experience with storage worldwide

Pump Storage

- UK: Dinorwig (1,728 MW) and Ffestiniog (360 MW)
- BELGIUM: Coo-Trois-Points (1,080 MW)
- USA: Northfield Mountain (1,080 MW)

Batteries and flywheels

SCLE SFE

- **Smart ZAE project** to optimize the distribution grid at an economic activity zone in Toulouse (France)
  - It includes a **lithium-ion battery (100kW/100 kWh)** and **10 flywheels (10kW/10kWh each)**
- **ALATA project** to support a 4.4 MW solar installation with a **2.4 MW/ 4.4 MWh battery** in Corsica (France)

LABORELEC

- **Battery Lab** to support ENGIE teams in the choice of the best battery technology

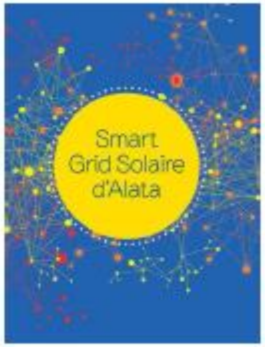
Software

- Acquisition of a participation in Kiwi (UK) and AMS (US)
- Development of in-house EMS (by Laborelec)

Examples of ENGIE batteries currently in operation

SCLE SFE

- **Smart ZAE project** in Toulouse (France) with lithium-ion battery (100kW/100 kWh) and 10 flywheels (10kW/10kWh each)

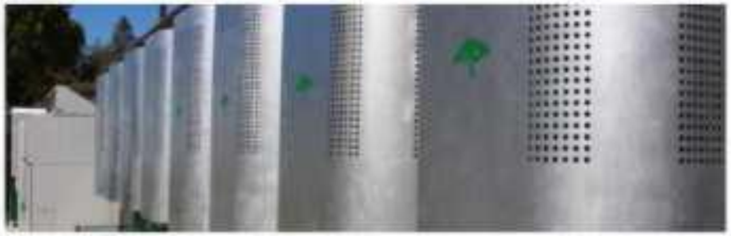


- **ALATA project** to support a 4.4 MW solar installation with a 2.4 MW/ 4.4 MWh battery in Corsica (France)

Recent acquisition of GCN in USA

greencharge networks

Case Study: Pacific Gas and Electric



GREEN CHARGE SOLUTION

Create Virtual Power Plant (VPP), co-located with PV installations to bid into CAISO wholesale day ahead and real time market

Systems

18

VPP Size

1,080kWh

VPP Aggregation and Control

Green Charge aggregation into single resource for CAISO bidding

GCN GridSynergy™ Master Command and Control

Modules utilized:

- Virtual Aggregation
- Wholesale DR
- Renewable & Load Shifting
- Optimizer

Grid-Scale Storage projects under development at ENGIE