FOSS
Research Centre for Sustainable Energy

University of Cyprus
PV Technology

Energy Storage

Technologies & Features

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Outline

1. Introduction to Energy Storage

Energy Storage:

- Storing energy to use it at a different time.
- Multiple forms:
  - Chemical
  - Gravitational potential
  - Electrical potential
  - Latent heat
  - Kinetic
- Converting energy from forms difficult to be stored to more convenient or economical forms.
- Short-term or long-term Energy Storage.

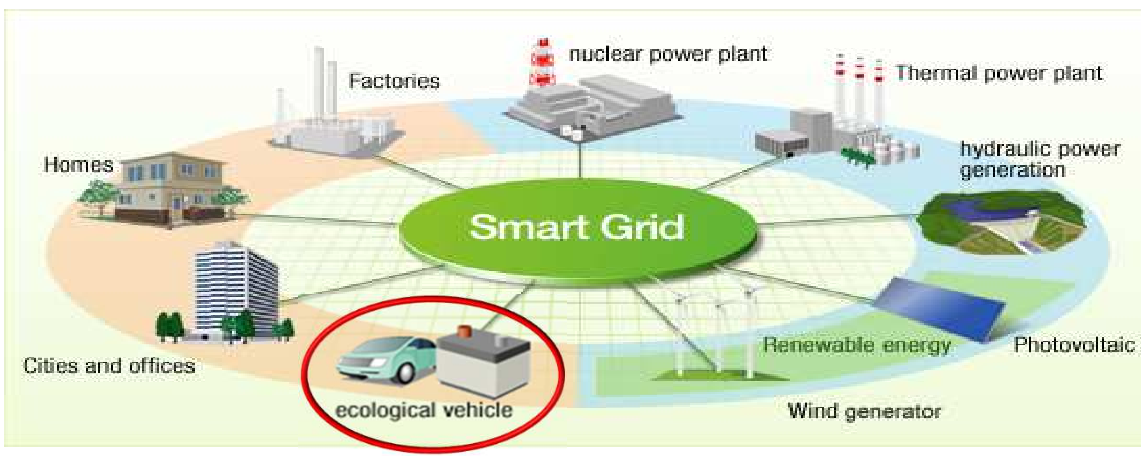
1. Introduction to Energy Storage

Reasons to encourage Energy Storage Systems (ESS):

- Instability problems caused to the network by the increased penetration of RES and in particular of PV systems.
- Due to the varying nature of RES integrated in the distribution network, there is a limit on the further penetration of RES.
- ESS are seen as a promising solution that can actively assist to the creation of an intelligent network and support RES.

1.1 Smart Grids

- Intelligent power network supporting state-of-the-art telecommunication and electronics technologies to meet future energy requirements.
- Ensures stability and security of supply through communication with other parts of the network such as conventional power plants and distributed RES.



1.1 Smart Grids

Main advantages:

- Greater reliability and better service quality.
- Better use of existing infrastructure and alternative forms of energy to minimize the use of conventional generating units in order to meet demand.
- Reducing carbon dioxide (CO_2) emissions.
- Active participation of consumers (Demand Response) in the effort to save energy (e.g. Dynamic Pricing, Time-of-Use Tariffs).

1.2 ESS Applications

- ESS can be used for various applications on the network.
- Main factors for grid integration:
  - Increased penetration of RES

    → excess generation
  - Intermittent generation of RES

    → affects the smooth operation of the network
- ESS systems can be used at the Generation side, the Distribution/Transmission level and at the end-user location to assist to the proper operation of the network.

1.2 ESS Applications

Summary of main services ESS can provide depending on the installation level.

Installation	Category	Application
Generation	Market integration	• Time-shift
Transmission/ Distribution	Power quality Network reliability Network stability Network performance	• Voltage control • Spinning reserve • Power smoothing • Power loss reduction
End-user	Cost reduction Quality and security of supply	• Peak-shaving • Increase revenue

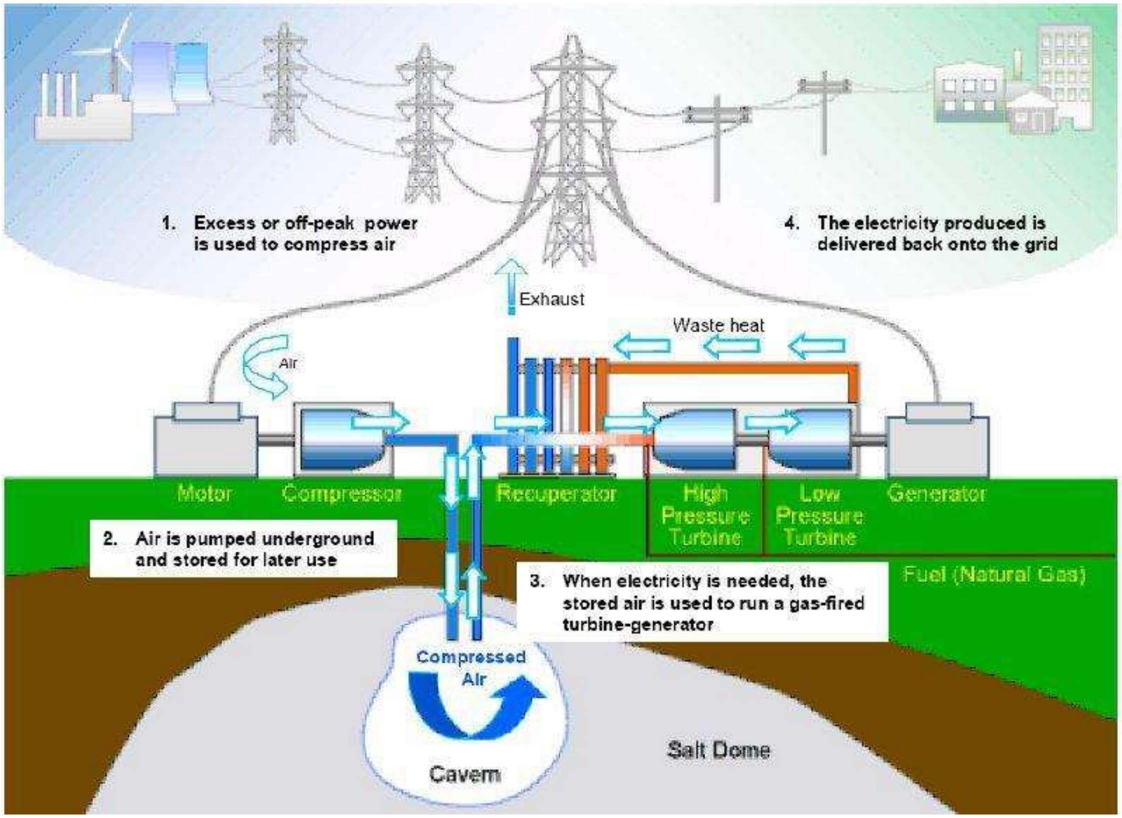
1.3 ESS Technologies

- **Mechanical Storage**
  - Compressed Air Systems
  - Pumped Hydro (Reversible Hydroelectric)
  - Flywheels
- **Electrical Storage**
  - Super Capacitors
  - Super-conducting Magnetic Energy Storage
- **Electrochemical Storage**
  - Accumulators - Batteries
  - Flow Batteries
- **Hydrogen Storage**
  - Fuel Cells

Upward trend in the number of installed systems and overall installed capacity

1.3 ESS Technologies

Compressed Air Energy Storage (CAES)



1.3 ESS Technologies

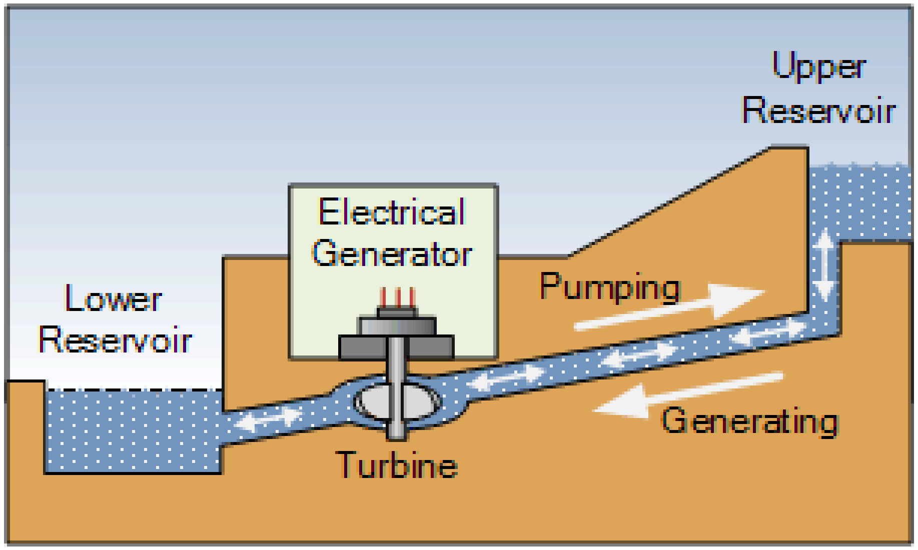
Compressed Air Energy Storage (CAES)

- McIntosh Power Plant (McIntosh, Alabama, USA)
- Cavern volume: 580,00 m3
- Cavern depth (top/bottom): 450m/750m
- Operational pressure: 70 bar
- Cost (1991): 43 million EUR (65 million USD)
- Power: 110 MW
- Duration: 26 hours
- Energy output: 2,860,000 KWh

1.3 ESS Technologies

Pumped Hydro Energy Storage (PHES) or Reversible Hydroelectric

- Energy Storage with the use of reversible hydro used for large-sized (grid scale) energy storage.



1.3 ESS Technologies

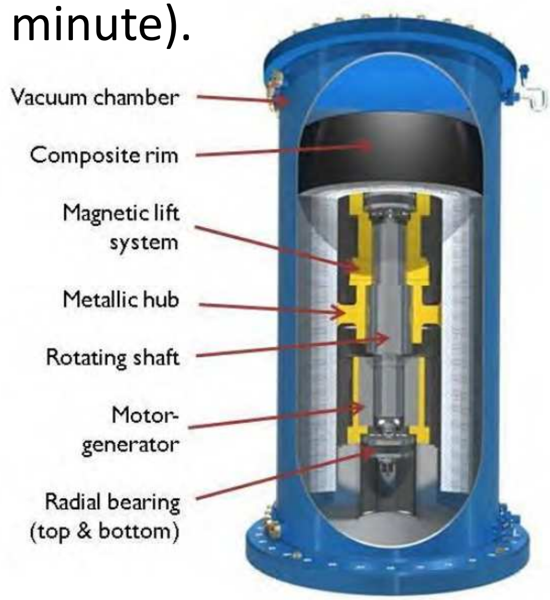
Pumped Hydro Energy Storage (PHES) or Reversible Hydroelectric

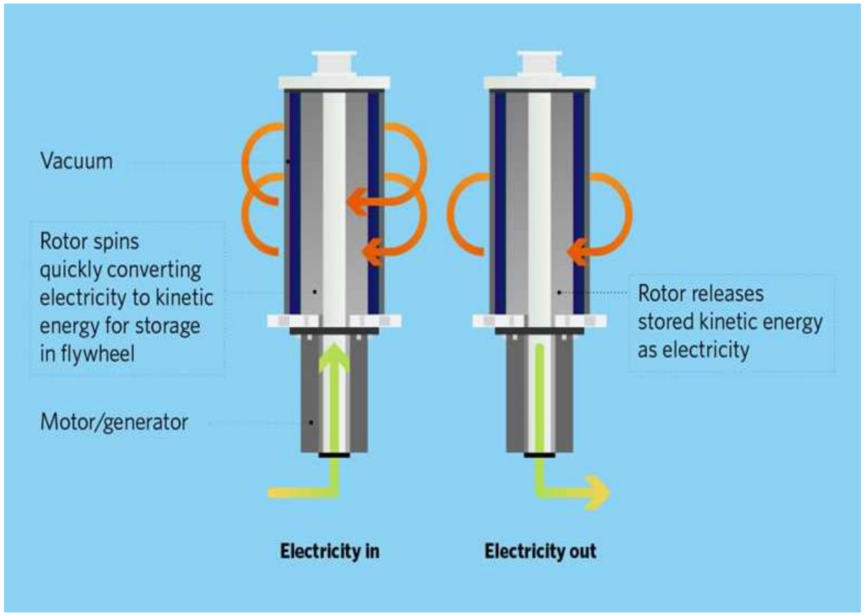
- Cruachan Power Station (Argyll and Bute, Scotland, UK)
- Constructed in 1965 – 440 MW / 7.1 GWh
- Water flow between Cruachan Reservoir and Loch Awe
- Height difference of 396 m (1,299 ft)

1.3 ESS Technologies

Flywheels

- Best suited for peak output powers (100 KW – 2 MW) and for short durations (< 1 minute).





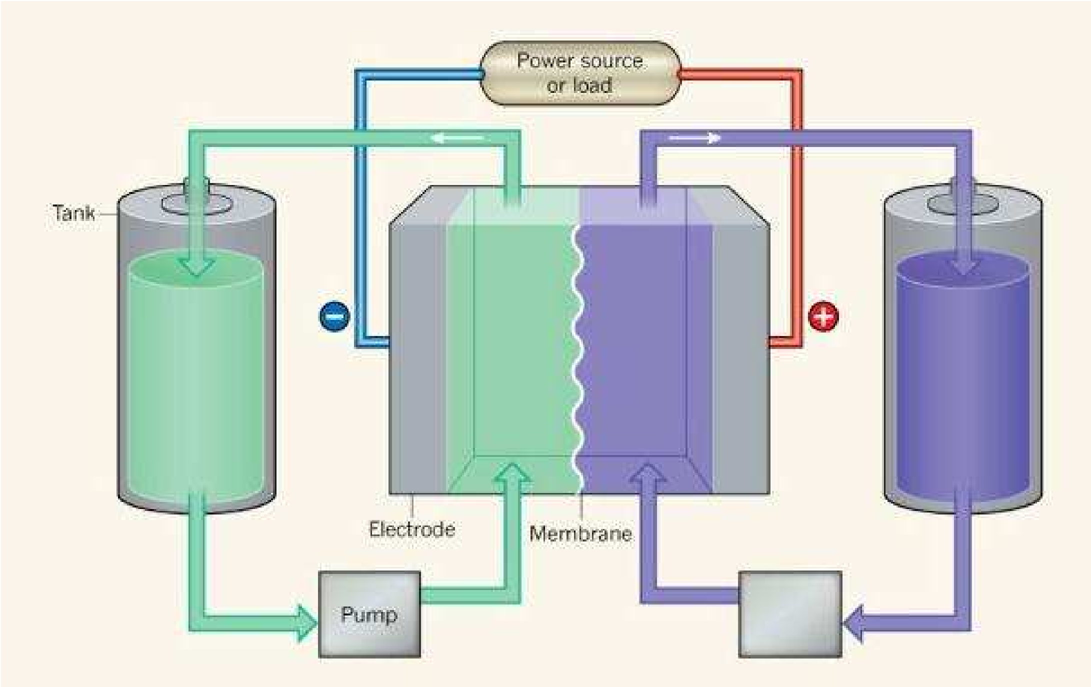
1.3 ESS Technologies

Flywheels

- Stephentown (New York, USA)
- 20 MW / 5 MWh using 200 flywheels
- Opened in 2011, operated by Beacon Power

1.3 ESS Technologies

Flow Batteries



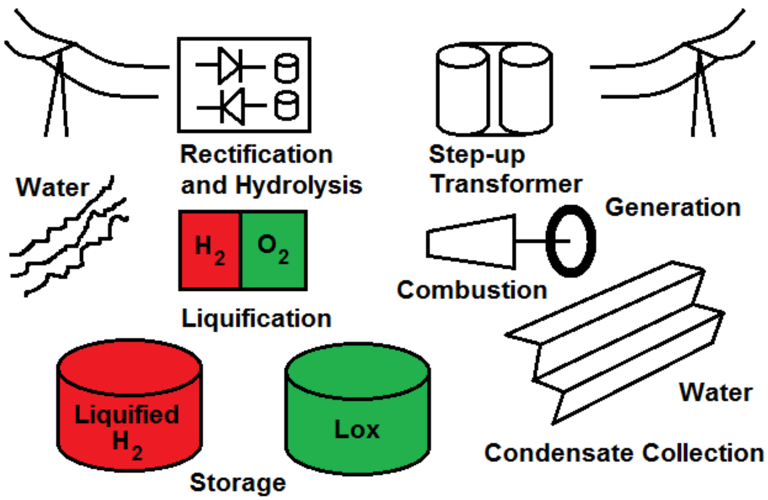
1.3 ESS Technologies

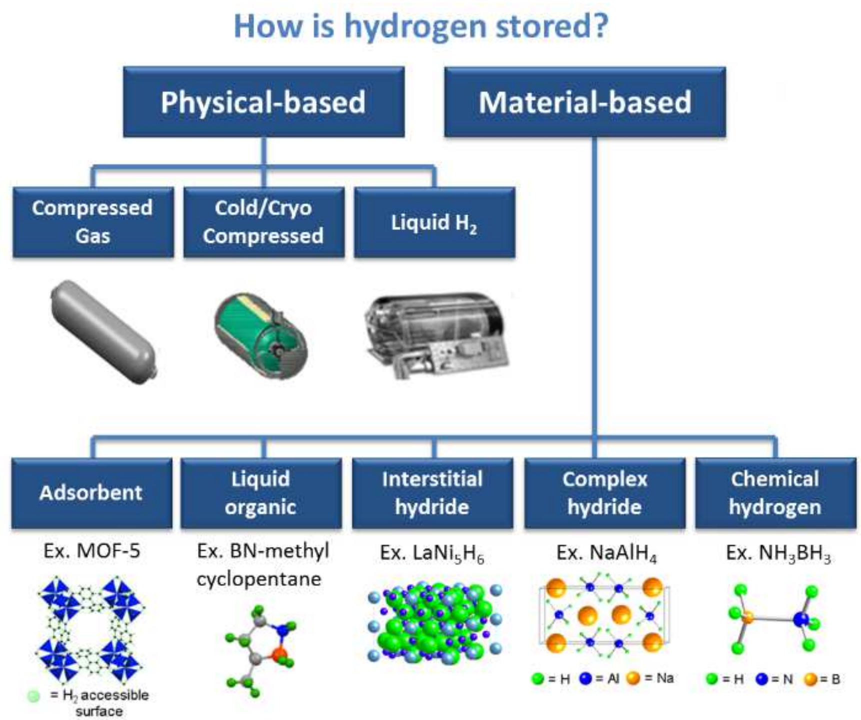
Flow Batteries

- 3 MW / 12 MWh Vanadium Redox Flow Battery in Hubei, China
- 250 KW / 1 MWh flow battery module (phase A) successfully commissioned in November 2018

1.3 ESS Technologies

Hydrogen Storage





Source: energy.gov/eere/fuelcells/hydrogen-storage

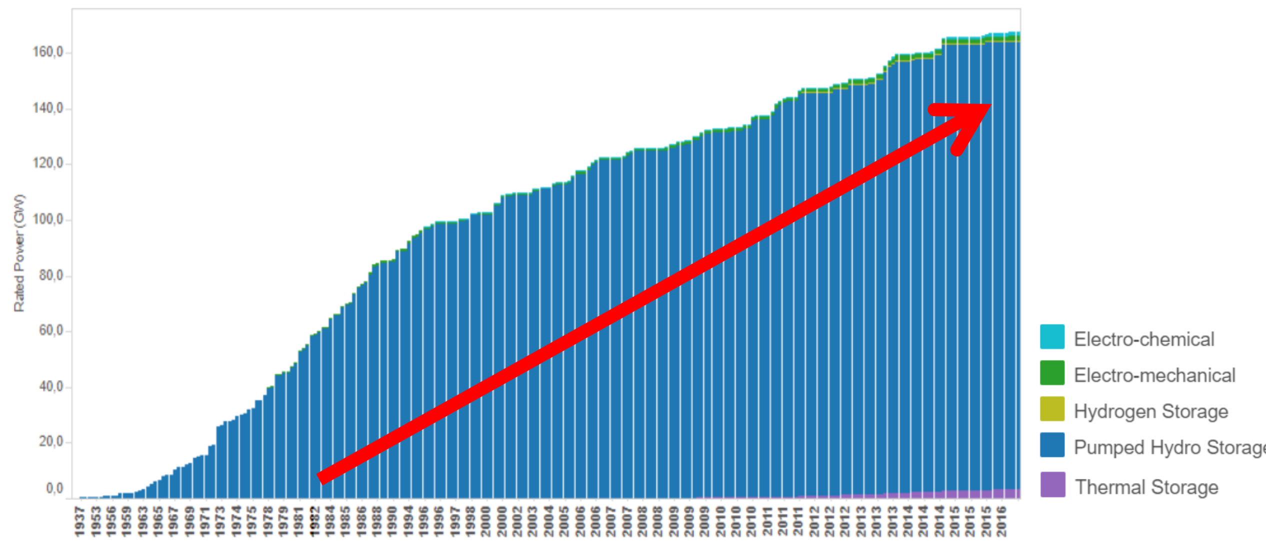
1.3 ESS Technologies

Hydrogen Storage

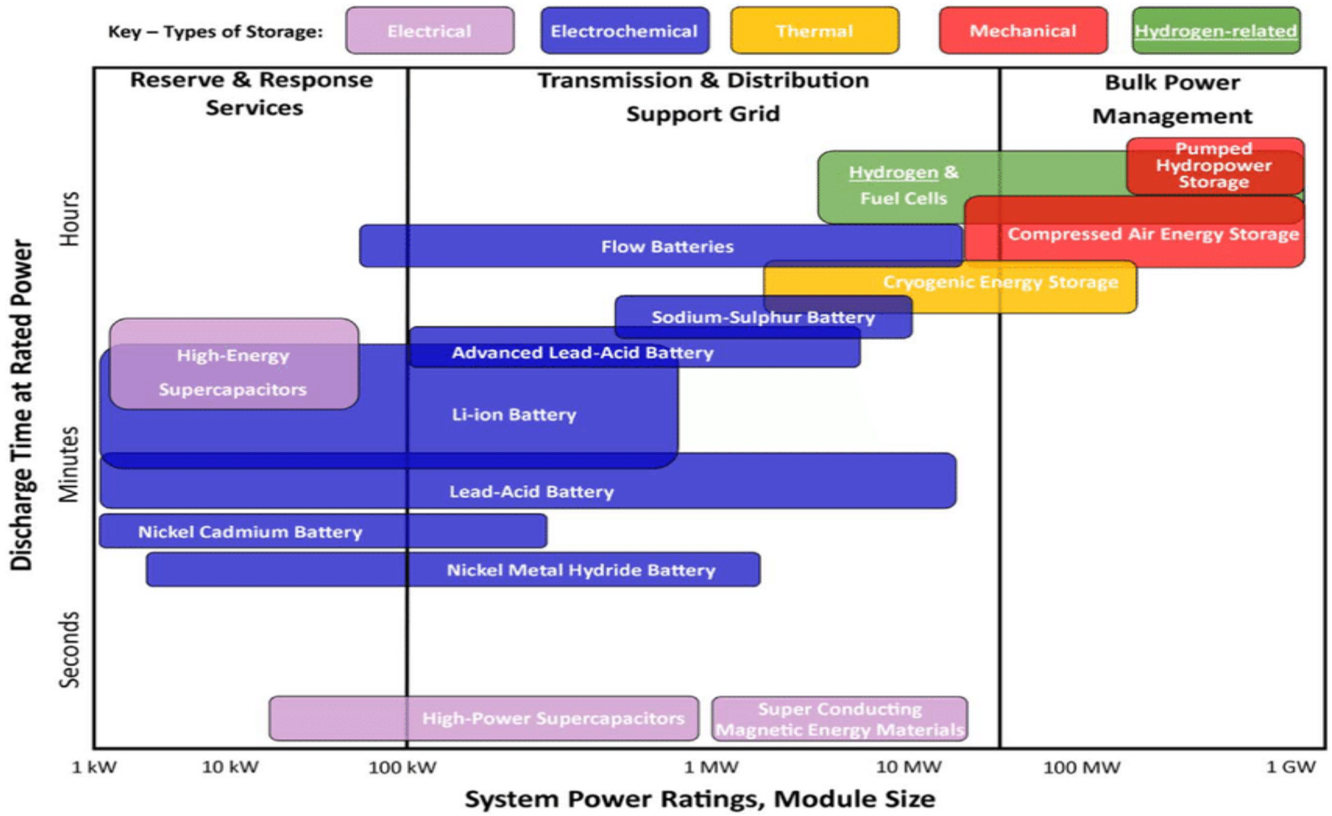
- Toyota Mirai (Japanese for "future")
- Mid-size hydrogen fuel cell car manufactured by Toyota
- Unveiled in 2014, global sales totalled 5,300 vehicles
- Top selling market (December 2017): USA 2,900
- AC synchronous electric motor drives the front wheels producing 151 horsepower and 247 lb-ft of torque
- Motor fed by a 1.7 KWh nickel-metal hydride battery continuously topped up by the solid polymer electrolyte fuel-cell stack

1.3 ESS Technologies

- Total ESS installed capacity: **167 GW** by the end of 2016.
- 161 GW (about 96%) account for PHES, considered as the most technically mature energy storage technology.

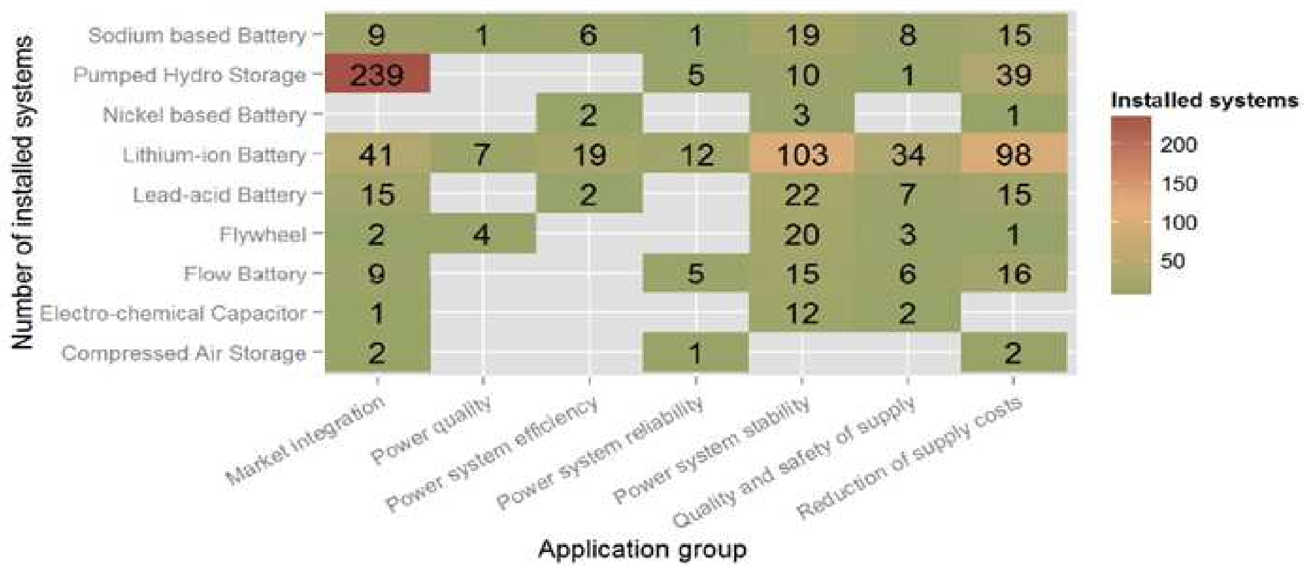


1.3 ESS Technologies



1.3 ESS Technologies

The following diagram shows the total number of installed ESS world-wide by the end of 2016, broken down according to the installation level.



1.4 Battery ESS Technologies

- In order to support the development of RES, a storage technology which can offer the appropriate services to the network while having the capability of high capacity and fast response must be selected.
- The most compatible technology for RES applications and more specifically for PV systems are **Battery Energy Storage Systems (BESS**) since many types, such as Lead-based, Nickel-based and Lithium-based batteries have the appropriate features.

1.4 Battery ESS Technologies - Comparison

- Summary of the main features of the most common BESS types.
- Lead-based & Nickel-based types: widespread in the field of PVs (stand-alone systems).

	Lead-based	Nickel-based	Lithium-based
Energy Density (Wh/kg)	LOW	MEDIUM	HIGH
Power Density (W/kg)	MEDIUM	HIGH	HIGH
Cost (€/kWh)	LOW	MEDIUM	HIGH
Operating Temp. Range (°C)	MEDIUM	MEDIUM	LOW
Efficiency (%)	MEDIUM	MEDIUM	HIGH
Cycle Life (No. of cycles)	LOW	MEDIUM	HIGH
Calendar Life (Years)	MEDIUM	MEDIUM	HIGH
Depth of Discharge (%)	LOW	MEDIUM	HIGH
Low Self Discharge (%/day)	MEDIUM	HIGH	HIGH

1.4 Battery ESS Technologies - Comparison

- In recent years, Lithium-ion batteries have been integrated to RES systems since they can offer high energy density, lower self-discharge rate, ability for regular deep cycles, long lifetime and require low maintenance, properties that are suitable for lifelong PV applications.

- A major disadvantage of this technology is the comparatively high cost compared to other energy storage technologies. This is expected to decline over the next few years, down by as much as 50%.

1.4 Battery ESS Technologies - Comparison