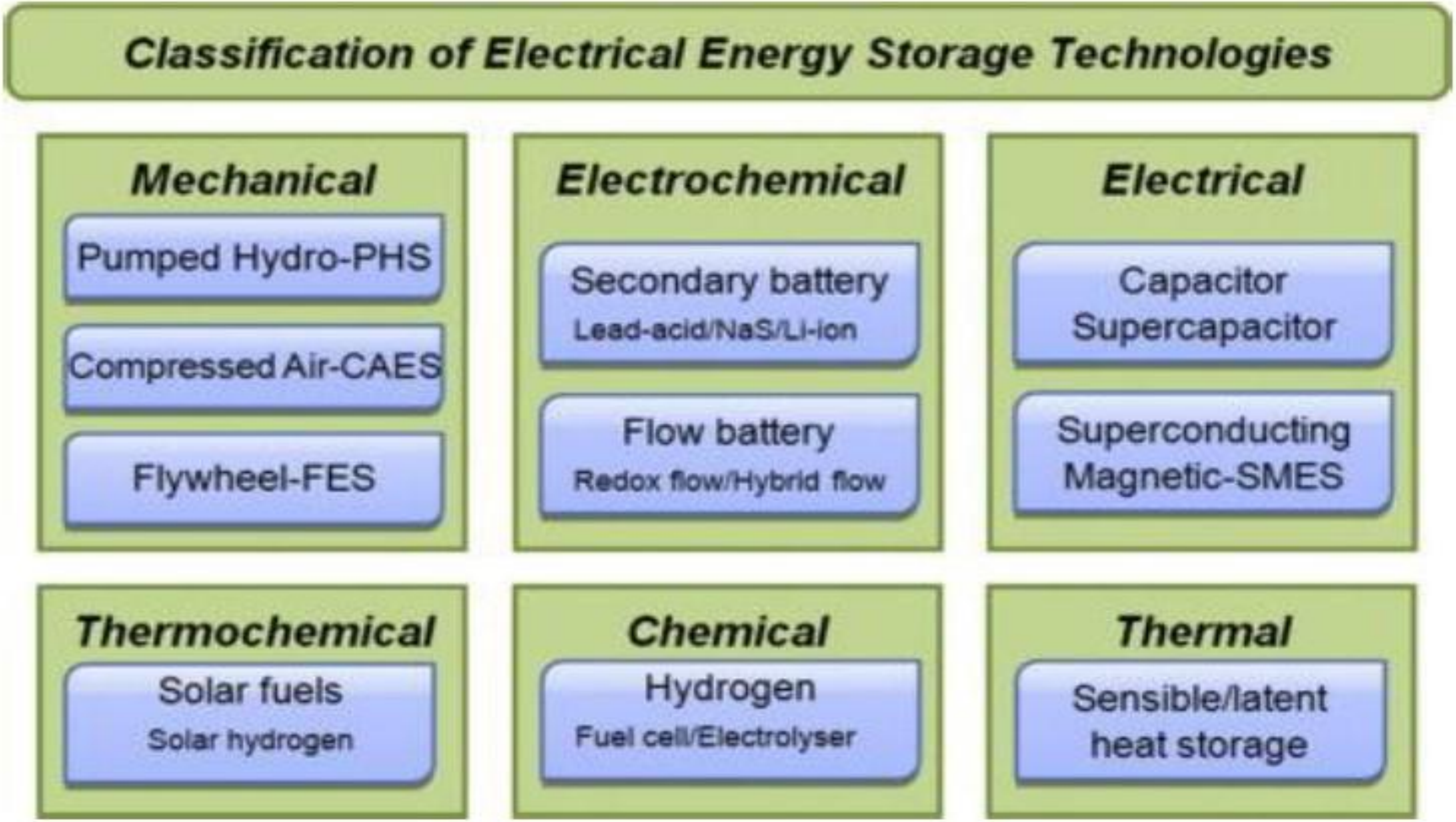
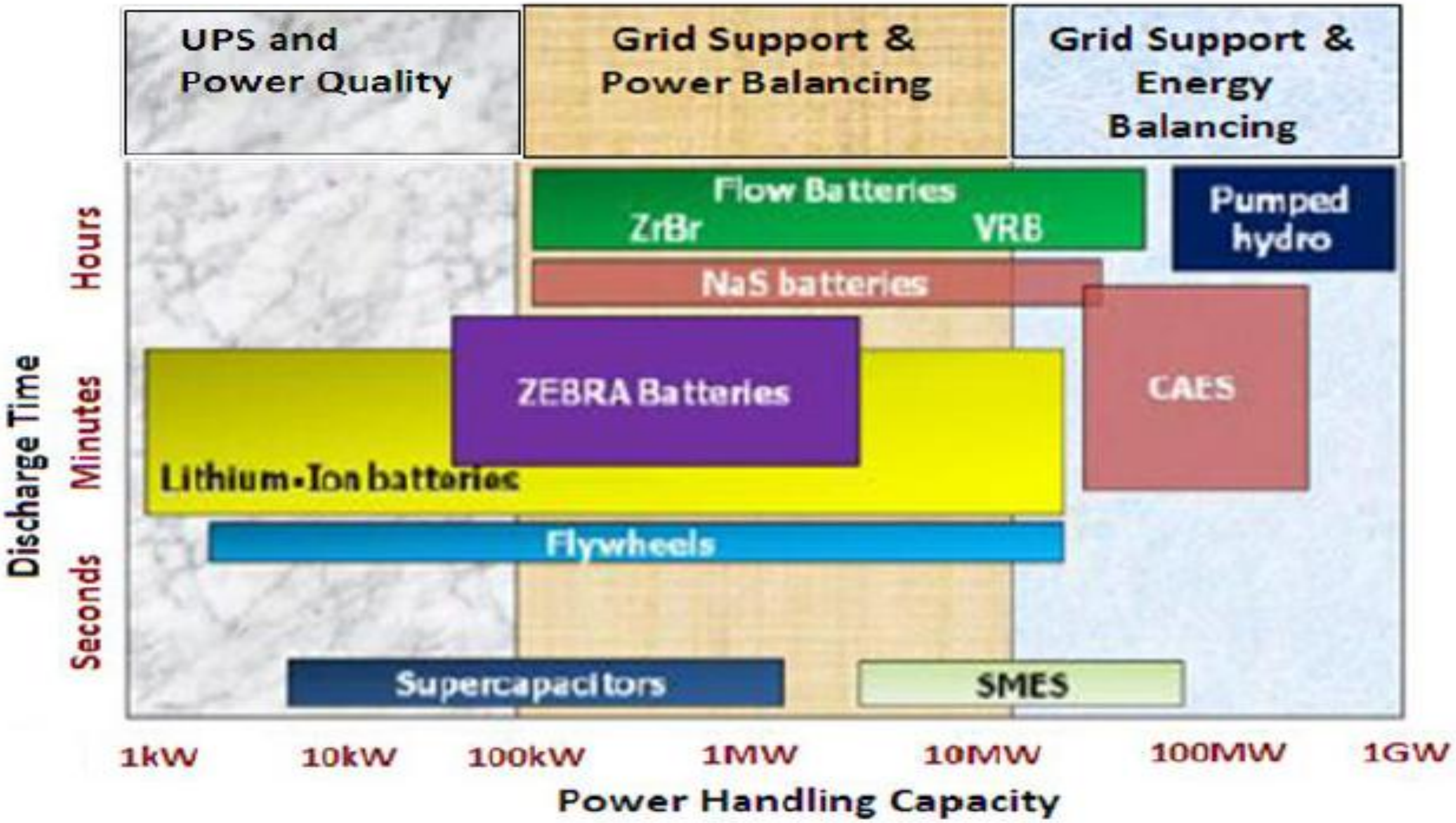
Electric Vehicles

Pratyush Chakraborty

Energy Storage -Introduction

- Energy storage mediates between variable sources and variable loads.
- Without storage, energy generation must equal energy demand. Energy storage works by moving energy through time.


Classification of Electrical Energy Storage Technologies
Mechanical
Pumped Hydro-PHS
Compressed Air-CAES
Flywheel-FES
Electrochemical
Secondary battery
Lead-acid/NaS/Li-ion
Flow battery
Redox flow/Hybrid flow
Electrical
Capacitor
Supercapacitor
Superconducting
Magnetic-SMES
Thermochemical
Solar fuels
Solar hydrogen
Chemical
Hydrogen
Fuel cell/Electrolyser
Thermal
Sensible/latent
heat storage


UPS and Power Quality
Grid Support & Power Balancing
Grid Support & Energy Balancing
Flow Batteries
ZrBr
VRB
Pumped hydro
NaS batteries
ZEBRA Batteries
CAES
Lithium-Ion batteries
Flywheels
Supercapacitors
SMES
Hours
Minutes
Seconds
Discharge Time
1kW
10kW
100kW
1MW
10MW
100MW
1GW
Power Handling Capacity

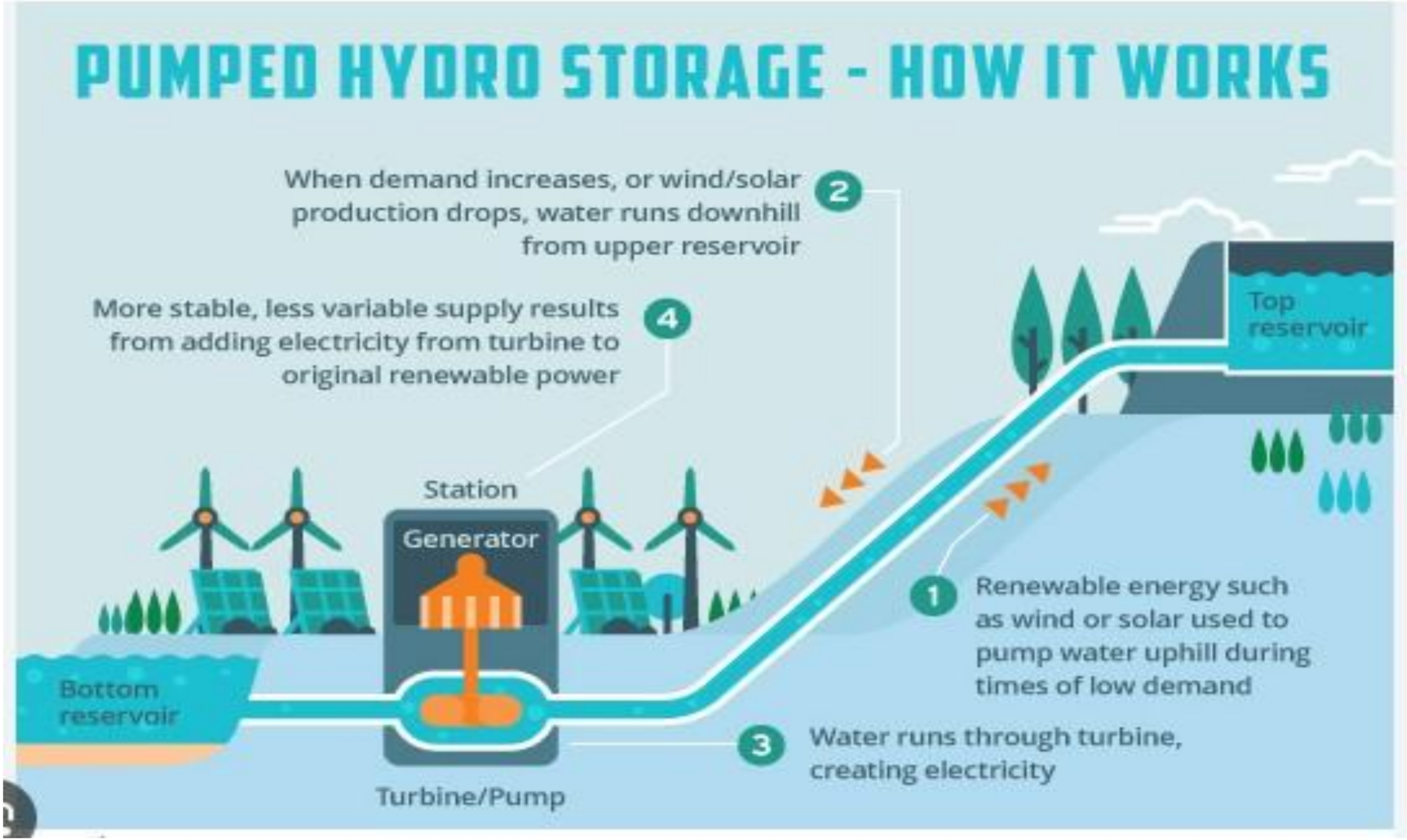
A comparative analysis among various Energy Storage technologies

innovate achieve lead

Technology	Typical Capacity	Response time	Discharge time	Efficiency	Life time	Development stage	Application
Pumped hydro energy storage (PHES)	5 MW – 2 GW	1 min (if standing still) 10 sec (if spinning)	4 - 100 h	55-85%	50+ years	Mature	Primary / secondary / tertiary control, energy arbitrage
Compressed air energy systems (CAES)	25 MW – 2.5 GW	10 - 15 min from cold start	2 - 24 h	40-70%	15-40 years	Mature	Tertiary control, energy arbitrage
Batteries	1 kW – 100 MW	Mill seconds to few Seconds	1 min - 10 h	65-85%	2 -10 years (Even up to 20 years)	Premature / mature	Uninterruptible power supply, RES-fluctuation reduction, primary / secondary control
Flywheels	5 kW – 20 MW	Few seconds	4 sec - 15 min	90-95%	~20 years	Mature	Primary control, power quality
Hydrogen Fuel Cell Storage System (HFCSS)	1 kW – 10 GW	Depends on fuel cell	0.01 sec-days	20-40%	5-10 years	Prototype	RES- fluctuation reduction, tertiary reserve
Super magnetic energy storage (SMES)	10 kW – 1 MW	Milli Seconds to few sensonds	5 sec – 5 min	95%	~30 years	Premature	Uninterruptible power supply, power quality
Supercapacitors	< 150 kW	Milli seconds	1 sec – 1 min	85-95%	~10 years	Premature	Uninterruptible power supply, power quality

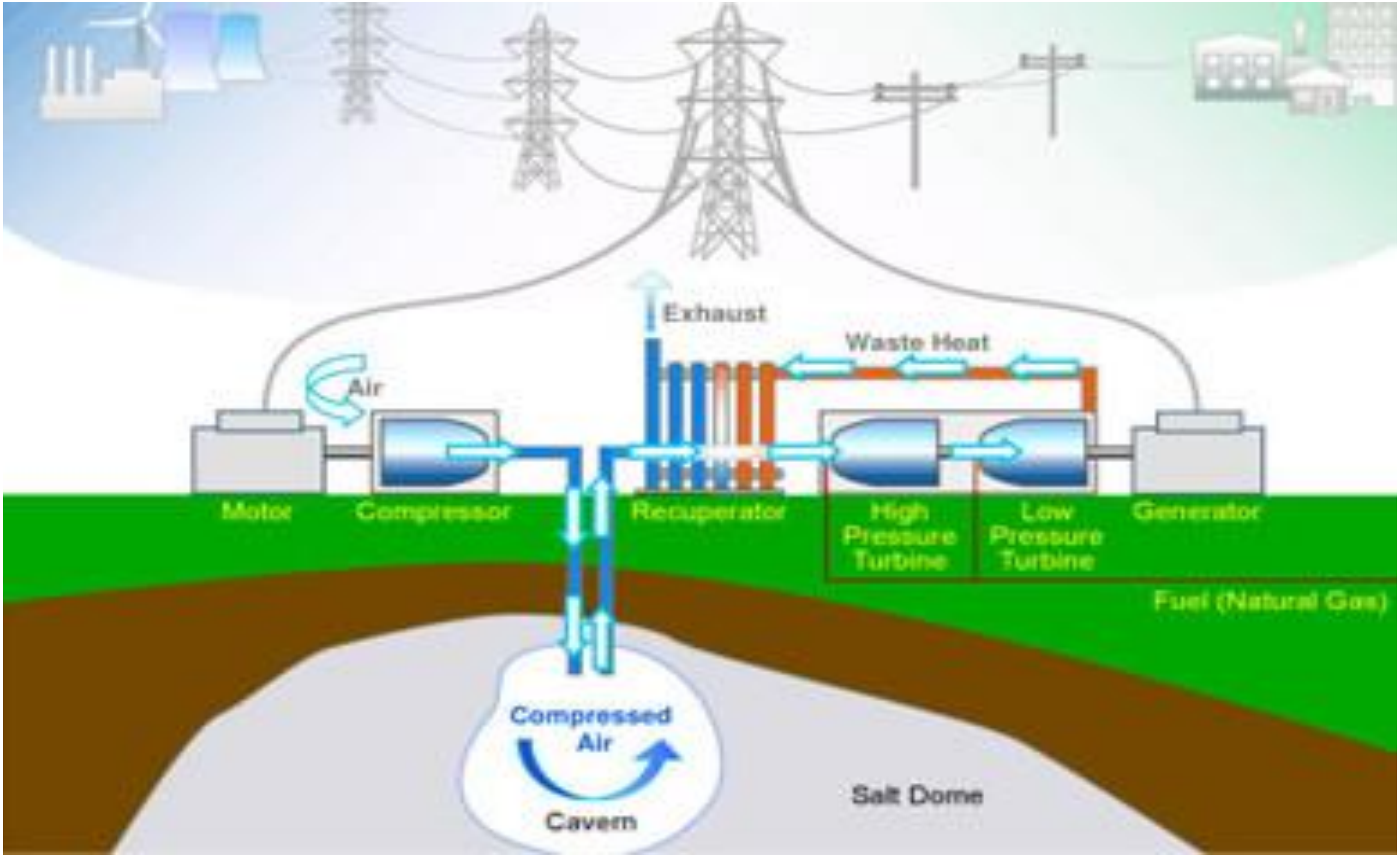
Pumped Hydro

- 99% of world wide installed electrical storage capacity
- Two reservoirs at different elevations
- At off peak hours pump water from lower to upper reservoir
- When needed, water flows back from the upper to lower reservoir powering a turbine


PUMPED HYDRO STORAGE - HOW IT WORKS
2 When demand increases, or wind/solar production drops, water runs downhill from upper reservoir
4 More stable, less variable supply results from adding electricity from turbine to original renewable power
Top reservoir
Station
Generator
1 Renewable energy such as wind or solar used to pump water uphill during times of low demand
Bottom reservoir
3 Water runs through turbine, creating electricity
Turbine/Pump

Compressed Air Energy Storage (CAES)

- Air is used as storage medium.
- CAES systems use off-peak electricity to compress air and store it in a reservoir either in an underground cavern or abandoned mines or above ground pipes or vessels.
- When electricity is needed, the compressed air is heated, expanded and directed through conventional turbine-generator to produce electricity.

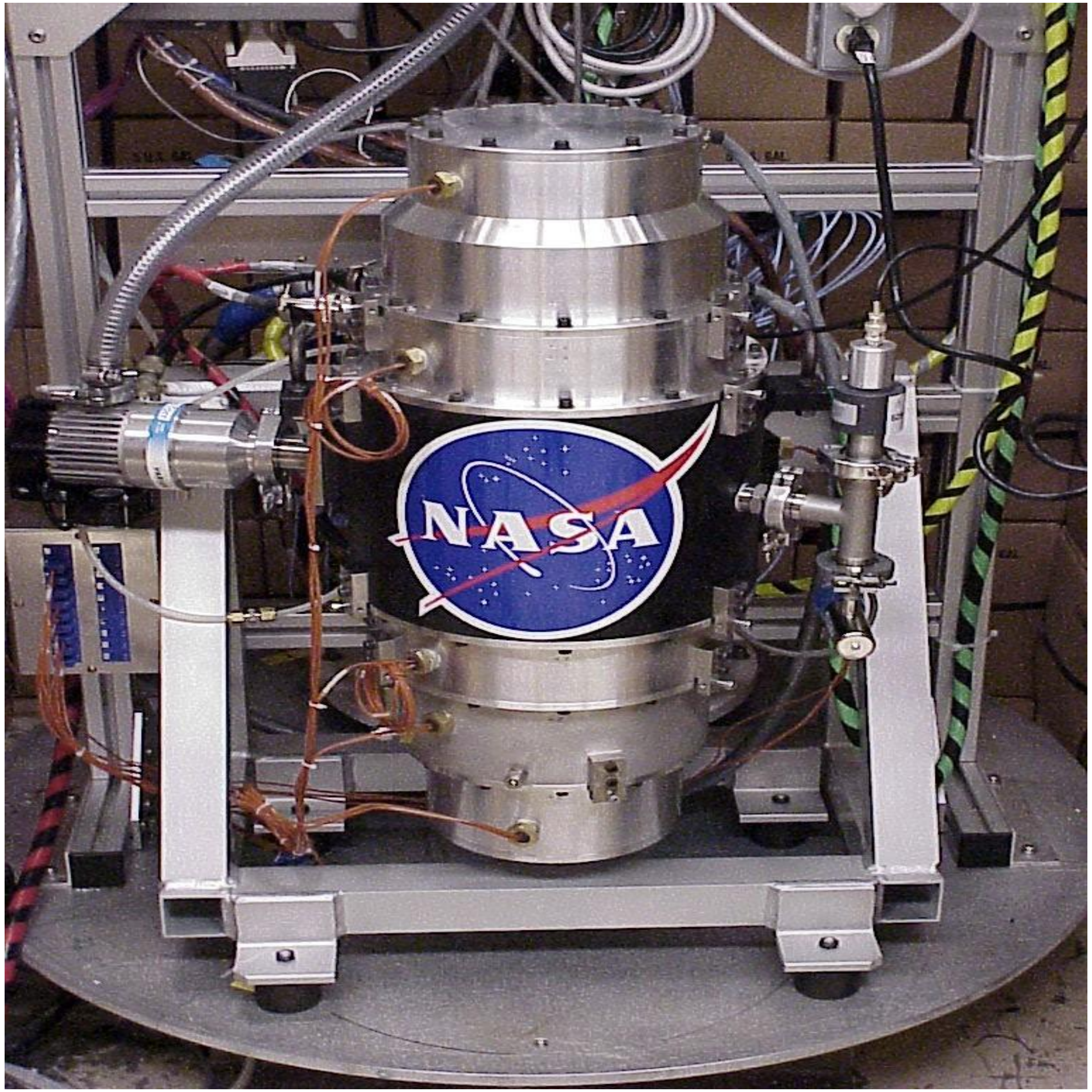

Exhaust
Waste Heat
Air
Motor
Compressor
Recuperator
High Pressure Turbine
Low Pressure Turbine
Generator
Fuel (Natural Gas)
Compressed Air
Cavern
Salt Dome

- Compression of air creates heat; the air is warmer after compression.
- Expansion removes heat. If no extra heat is added, the air will be much colder after expansion.
- If the heat generated during compression can be stored and used during expansion, then the efficiency of the storage improves considerably

Salt caverns are underground cavities created in salt deposits through solution mining, a process of dissolving the salt with water. They are used to store large quantities of energy resources like crude oil, natural gas, and hydrogen because of their natural sealing properties and low absorption of hydrocarbons, which create an impermeable barrier. These facilities are cost-effective and efficient alternatives to surface storage for strategic petroleum reserves and other energy applications.

Flywheel Energy Storage

- Stores energy in the form of angular momentum of a spinning mass
- Work done to spin mass is stored in the form of kinetic energy
- A flywheel system transfers kinetic energy into ac power through the use of controls and power conversion systems
- High power density, low energy capacity


NASA

Electrochemical Energy Storage

- Electrical energy is stored in chemical energy
- Both techniques share the same carrier, electron. Losses are limited.
- A battery consists of two electrodes, a positive and a negative placed in an electrolyte
- Secondary batteries are rechargeable, primary batteries are not
- The electrodes exchange ions with the electrolyte and electrons with external circuit.
- Common Batteries- Lead acid, Sodium Sulfar, Lithium Ion, Nickel Cadmium, Nickel metal hydrides

Battery Cell

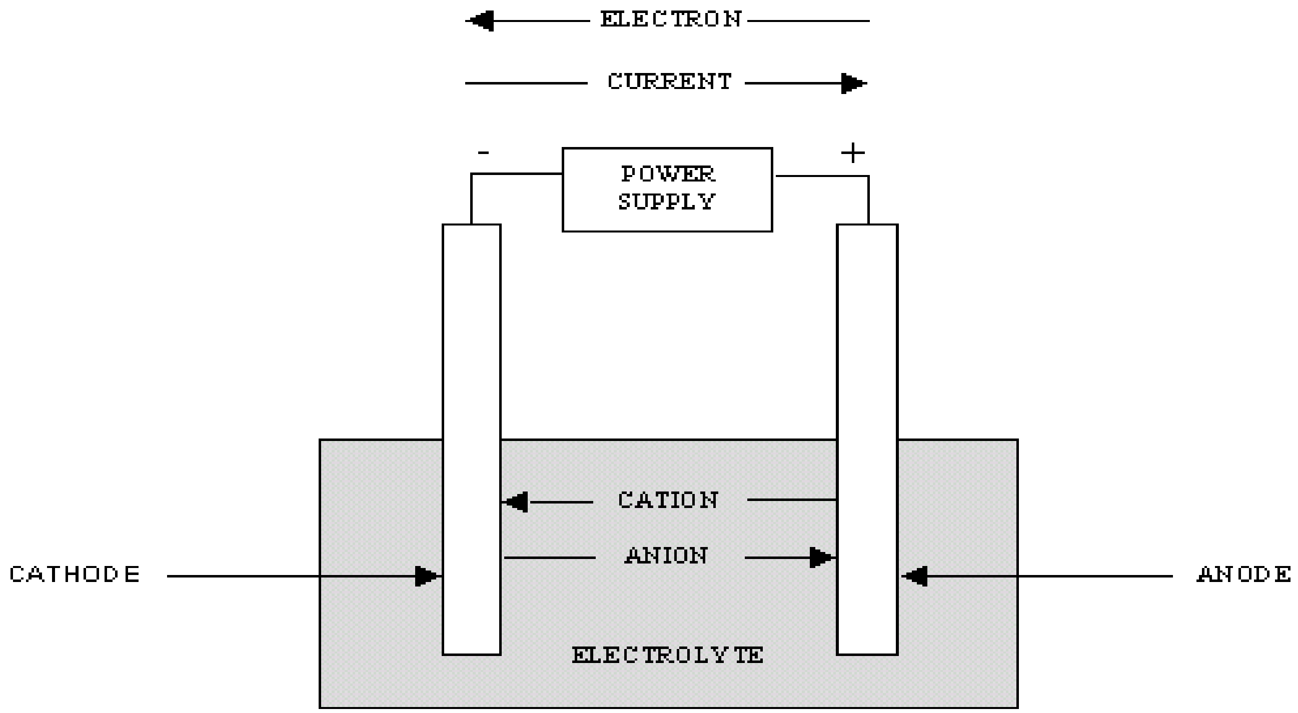
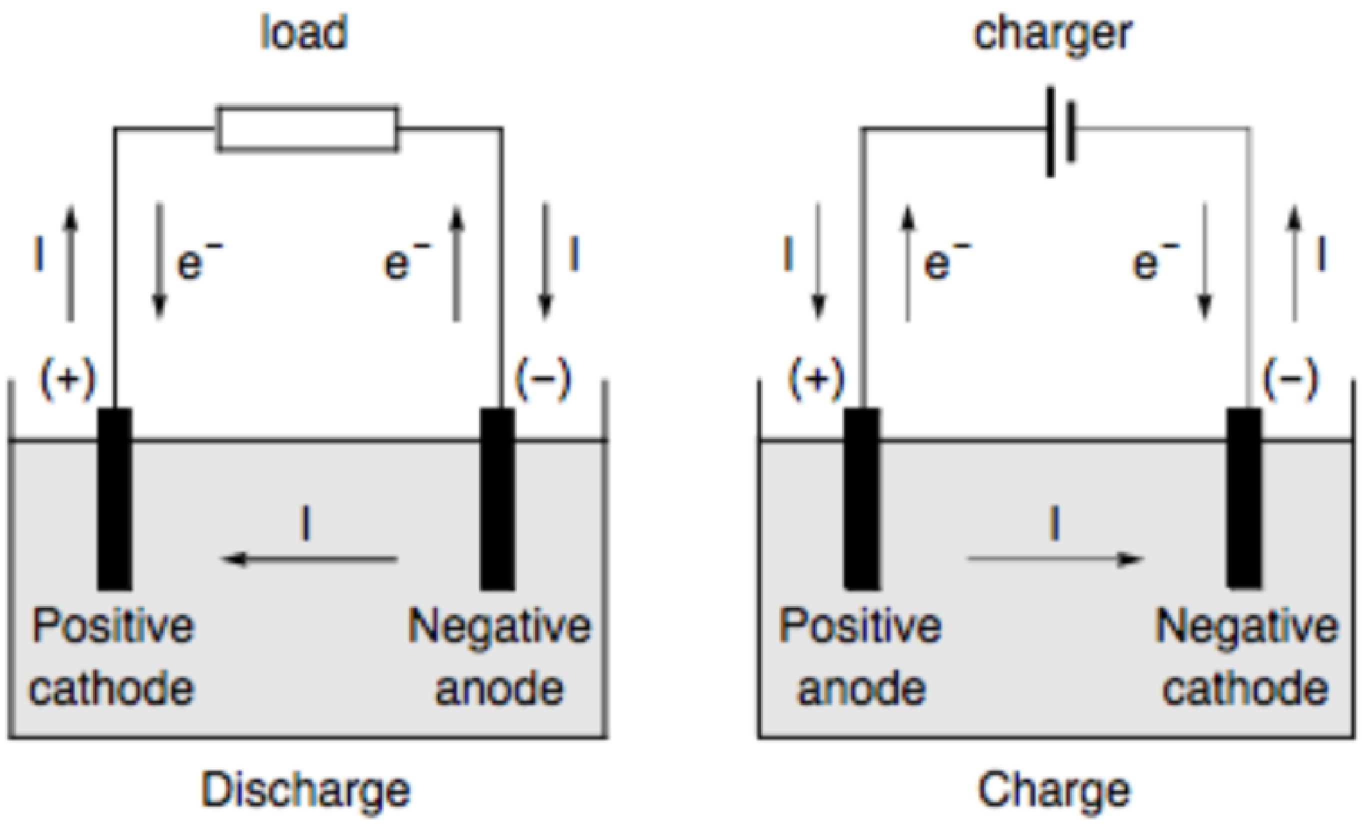


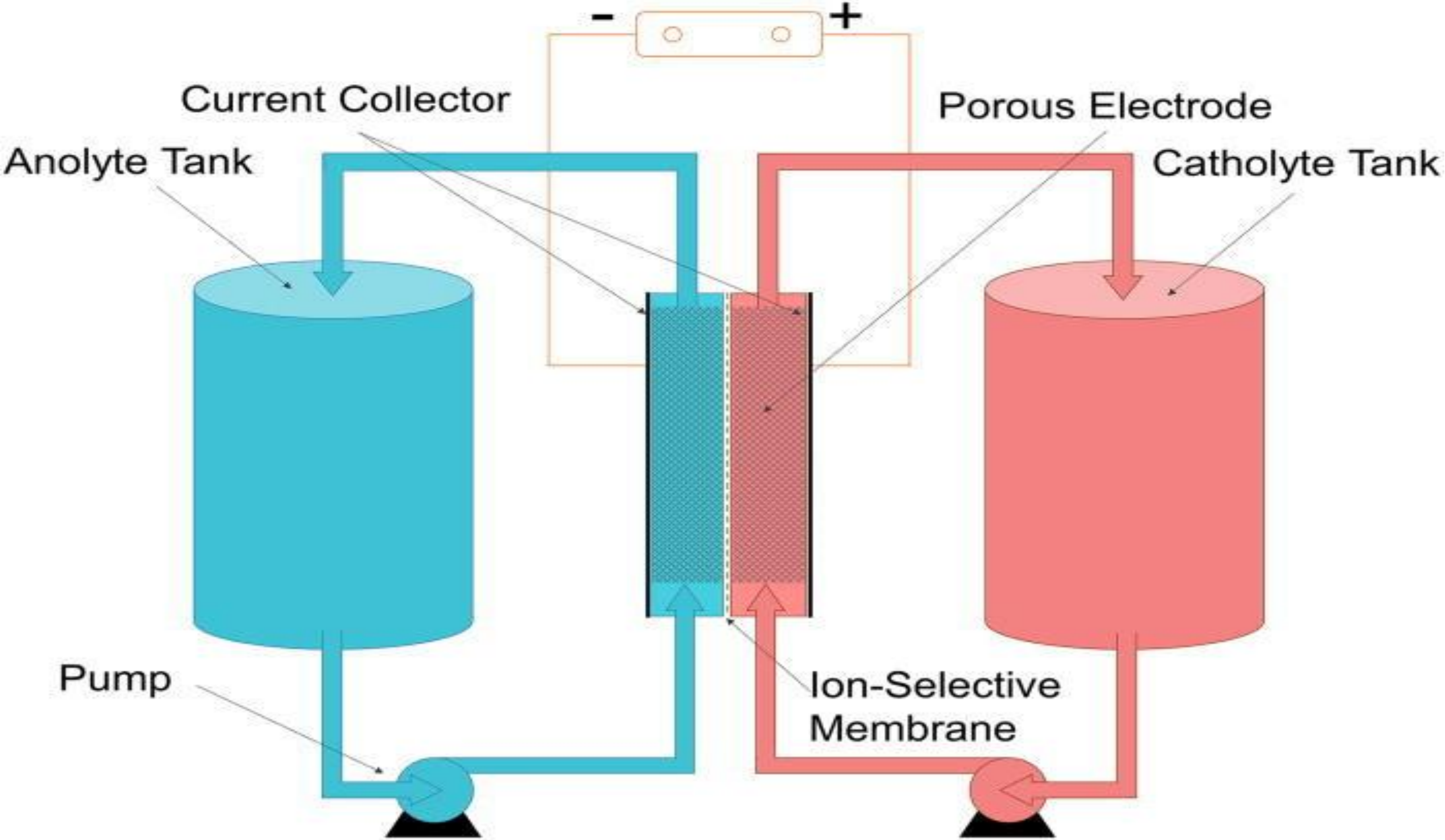
Figure 3: Recharging a Cell

Battery Cell



Flow Battery

- A **flow battery**, or **redox flow battery** (after reduction–oxidation), is a type of electrochemical cell where chemical energy is provided by two chemical components dissolved in liquids that are pumped through the system on separate sides of a membrane.
- Ion transfer inside the cell (accompanied by flow of electric current through an external circuit) occurs through the membrane while both liquids circulate in their own respective space.

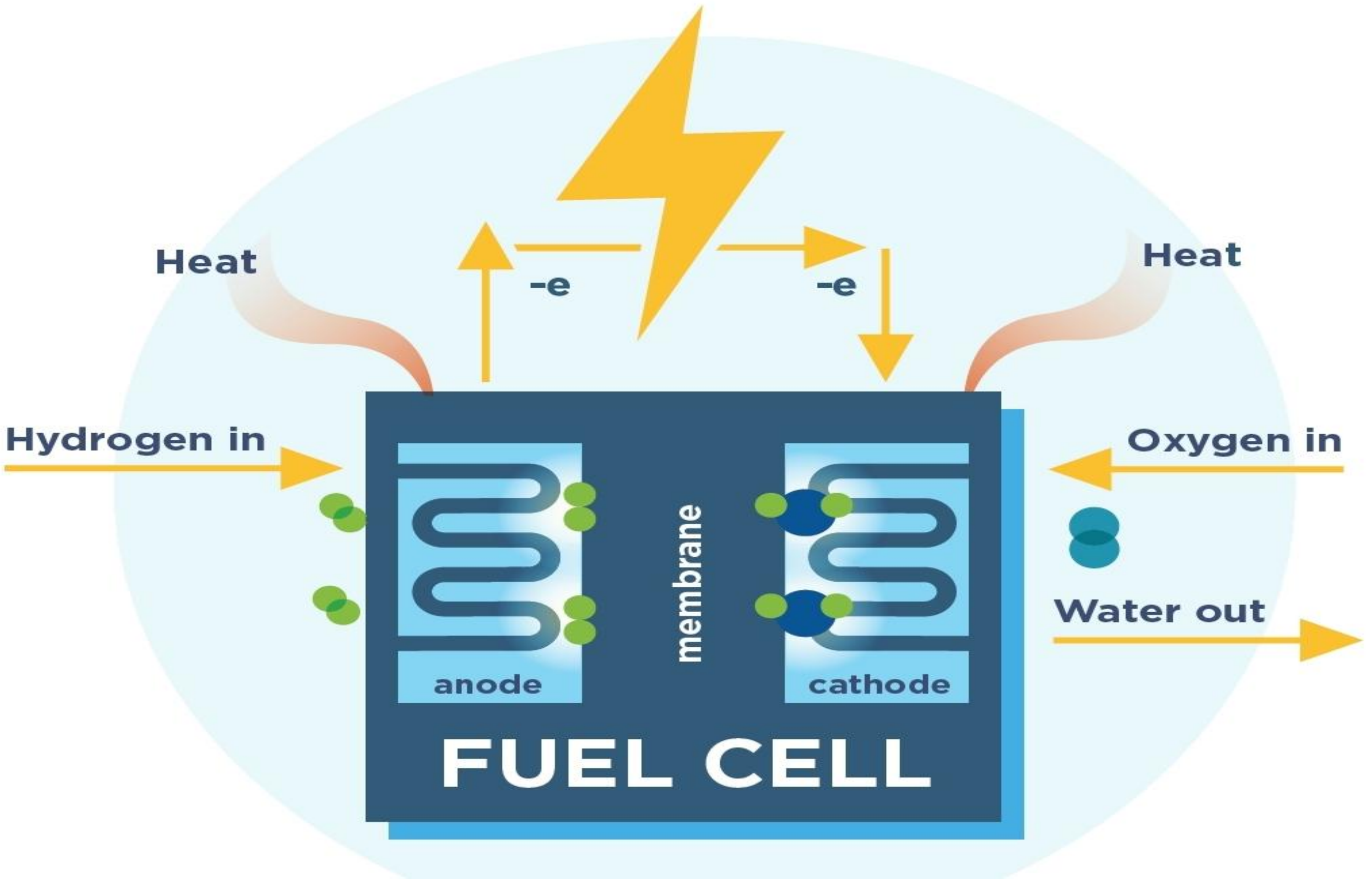


-
+
Current Collector
Porous Electrode
Anolyte Tank
Catholyte Tank
Pump
Ion-Selective
Membrane

- The fundamental difference between conventional and flow batteries is that energy is stored in the electrode material in conventional batteries, while in flow batteries it is stored in the electrolyte.
- The power and energy ratings are independent in flow battery; the storage capacity being determined by the quantity of electrolyte used and the power rating determined by the active area of the cell stack.

Chemical Energy Storage

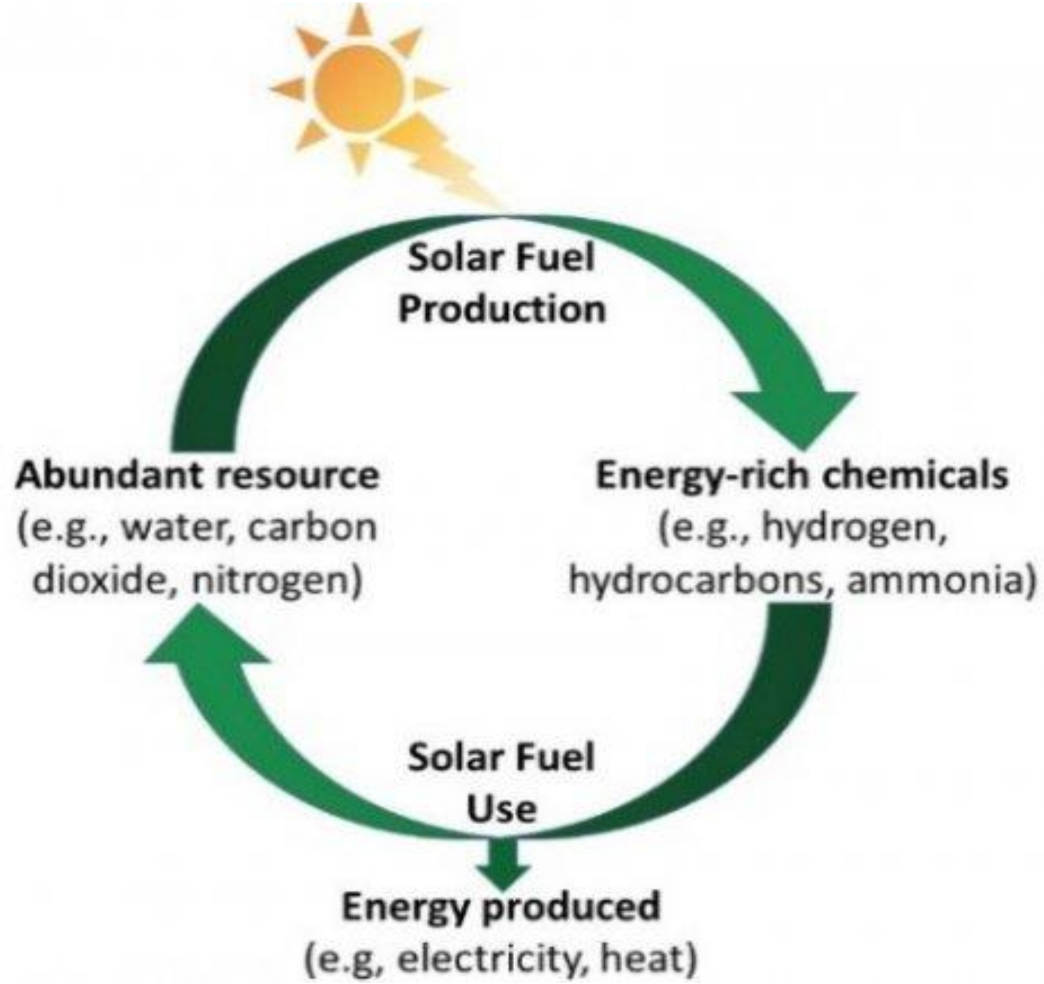
- Power to Gas (P2G) Technology
- Use excess electricity to produce hydrogen via water electrolysis
- Hydrogen is produced and can be stored upto TWH range and for greater periods of time
- Gaseous storage under high pressure in gas bottles or tanks
- Fuel cell is needed to generate water from hydrogen and oxygen
- Reverse of electrolysis –an electrochemical reaction takes place
- Heat produced can be used to generate electricity


Heat
-e
-e
Heat
Hydrogen in
Oxygen in
membrane
Water out
anode
cathode
FUEL CELL

Fuel Cells

- Fuel cells work like batteries, but they do not run down or need recharging. They produce electricity and heat as long as fuel is supplied.
- A fuel cell consists of two electrodes—a negative electrode (or anode) and a positive electrode (or cathode)—sandwiched around an electrolyte.
- A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode.
- In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat.

Solar Fuel – Thermo chemical

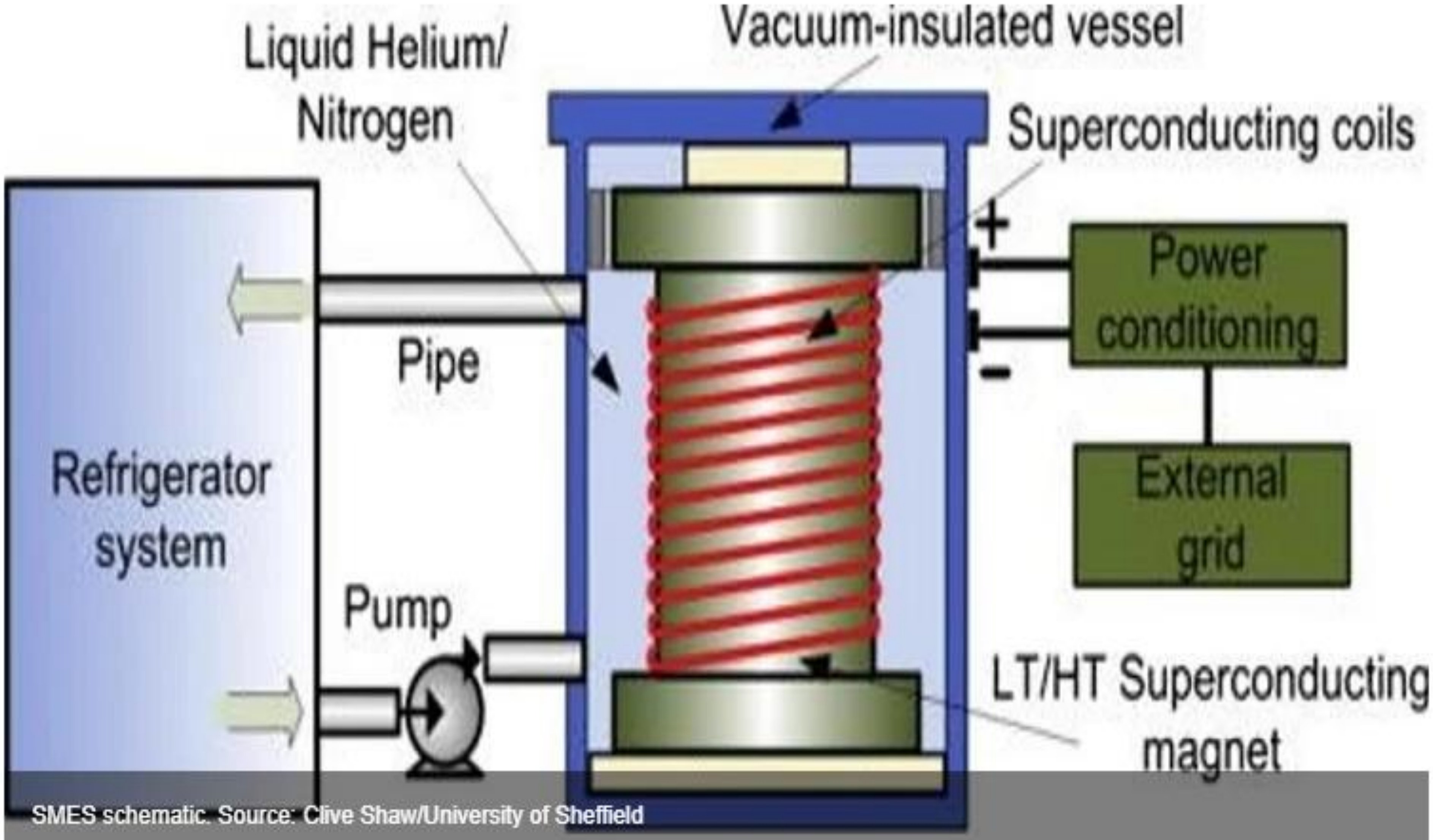


- **Solar fuels** are fuels made from common substances like water and carbon dioxide using the energy of sunlight.
- There is vast energy in sunlight striking the earth, but it is time-varying and dispersed, making it challenging to harness sunlight for practical use.
- Solar fuels could be an abundant supply of sustainable, storable, and portable energy.

Superconducting Magnetic Energy Storage Systems (SMES)

- Superconducting magnetic energy storage (SMES) systems store energy in a magnetic field. This magnetic field is generated by a DC current traveling through a superconducting coil.
- In a normal wire, as electric current passes through the wire, some energy is lost as heat due to electric resistance. However, in a SMES system, the wire is made from a superconducting material that has been cryogenically cooled below its critical temperature.
- As a result, electric current can pass through the wire with almost no resistance, allowing energy to be stored in a SMES system for a longer period of time.

- Common superconducting materials include mercury, vanadium, and niobium-titanium.
- SMES systems are an extremely efficient storage technology, but they have very low energy densities and are still far from being economically viable



SMES schematic. Source: Clive Shaw/University of Sheffield

Super Capacitors

- A **supercapacitor** (**SC**), also called an **ultracapacitor**, is a high-capacity capacitor, with a capacitance value much higher than solid-state capacitors. It bridges the gap between electrolytic capacitors and rechargeable batteries. It typically stores 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, can accept and deliver charge much faster than batteries, and tolerates many more charge and discharge cycles than rechargeable batteries.
- Supercapacitors are used in applications requiring many rapid charge/discharge cycles, rather than long-term compact energy storage

Types

- Double-layer Capacitors
- Pseudo Capacitors
- Hybrid Capacitors

Thermal Energy Storage System

- Excess electricity is used to heat up water.

Districht heating accumulation tower of Theiss, near Krems an der Donau, Lower Austria with 50000 cubic meters volume

- The sensible heat of molten salt is also used for storing solar energy at a high temperature. It’s termed molten-salt technology or molten salt energy storage (MSES).
- Molten salts can be employed as a thermal energy storage method to retain thermal energy. Presently, this is a commercially used technology to store the heat collected by concentrated solar power (e.g., from a solar tower or solar trough).
- The heat can later be converted into superheated steam to power conventional steam turbines and generate electricity at a later time.