The Florida Advanced Technological Education (FLATE) Center wishes to make available, for educational and non-commercial purposes only, materials relevant to the "EST1830 Introduction to Alternative/Renewable Energy" course comprised of images, texts, facilitator's notes, and other demonstration materials.

This instructional resource forms part of FLATE's outreach efforts to facilitate a connection between students and teachers throughout the State of Florida. We trust that these activities and materials will add value to your teaching and/or presentations.

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This material is based upon work supported by the National Science Foundation under Grant No. 0802434 and a Florida Energy Systems Consortium Grant. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or the Florida Energy Systems Consortium.

Introduction to Alternative and Renewable Energy

EST1830

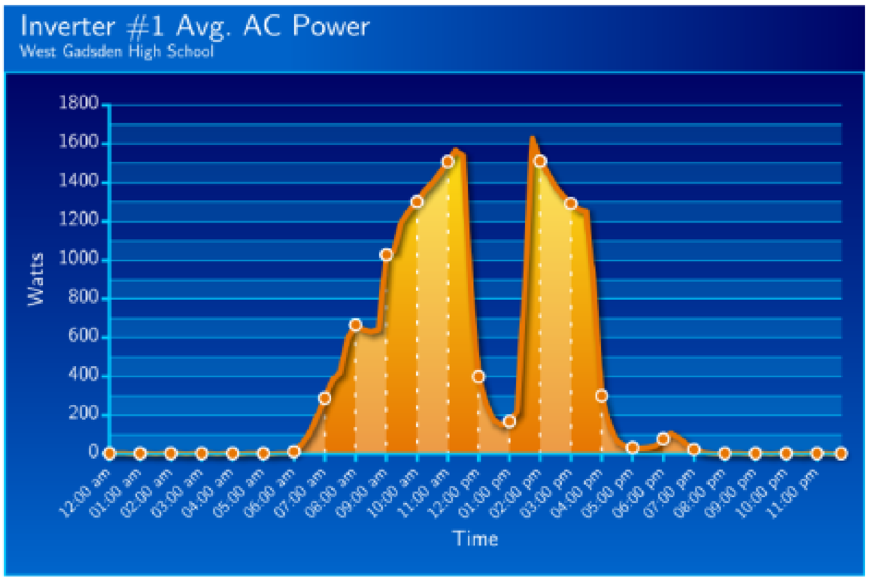
Florida Energy Systems Consortium

FLATE
FLORIDA ADVANCED TECHNOLOGICAL EDUCATION CENTER

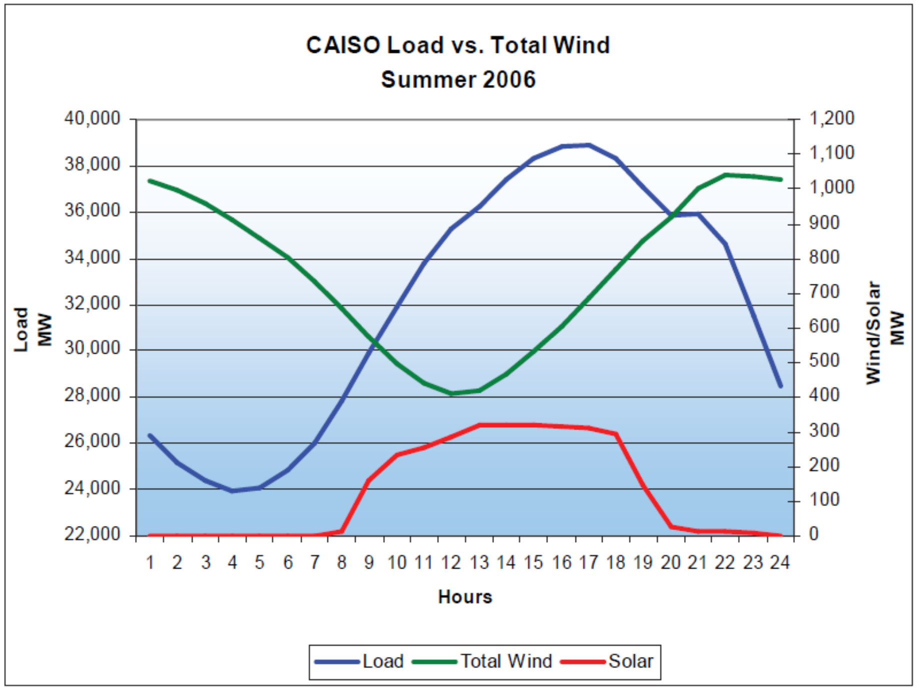
3. Energy Production

3.3 Energy Storage Challenges

Load Imbalance, Renewables



June/July/August

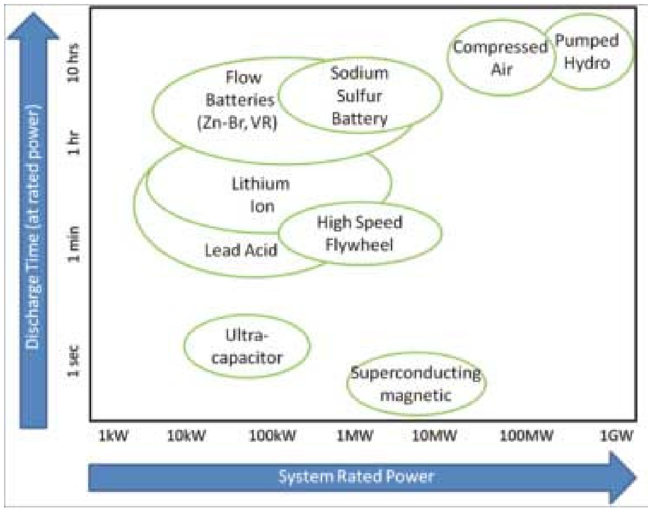


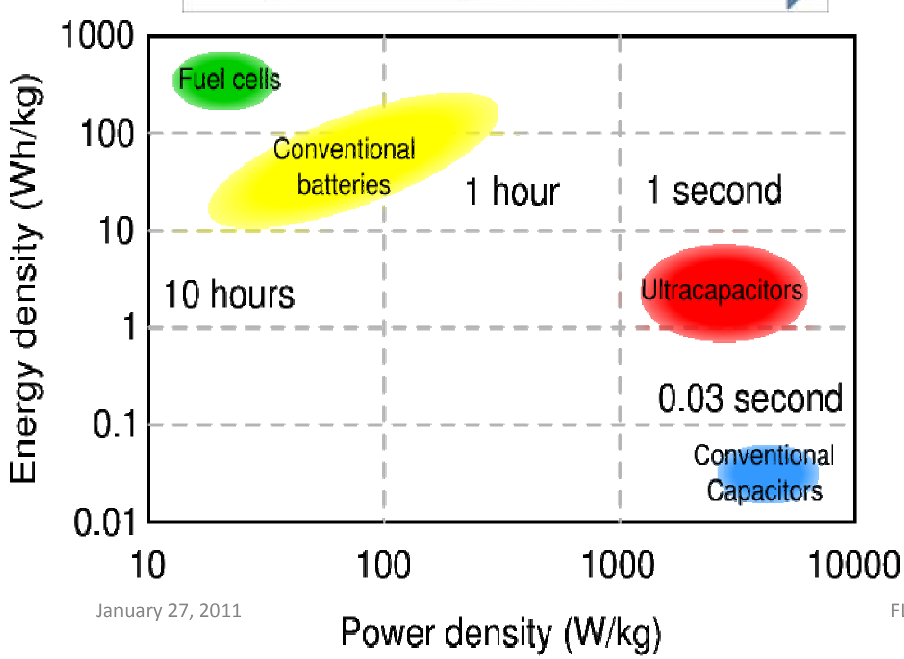
CAISO, Integration of Renewables, November 2007

The sun does not always shine on the solar cell and the wind doesn't always blow on the wind turbine…..

Grid Scale Energy Storage Technologies

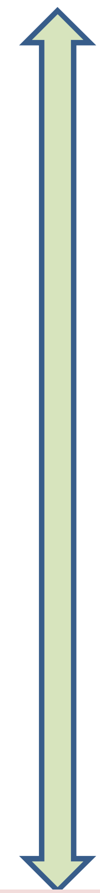
http://www.greentechmedia.com/





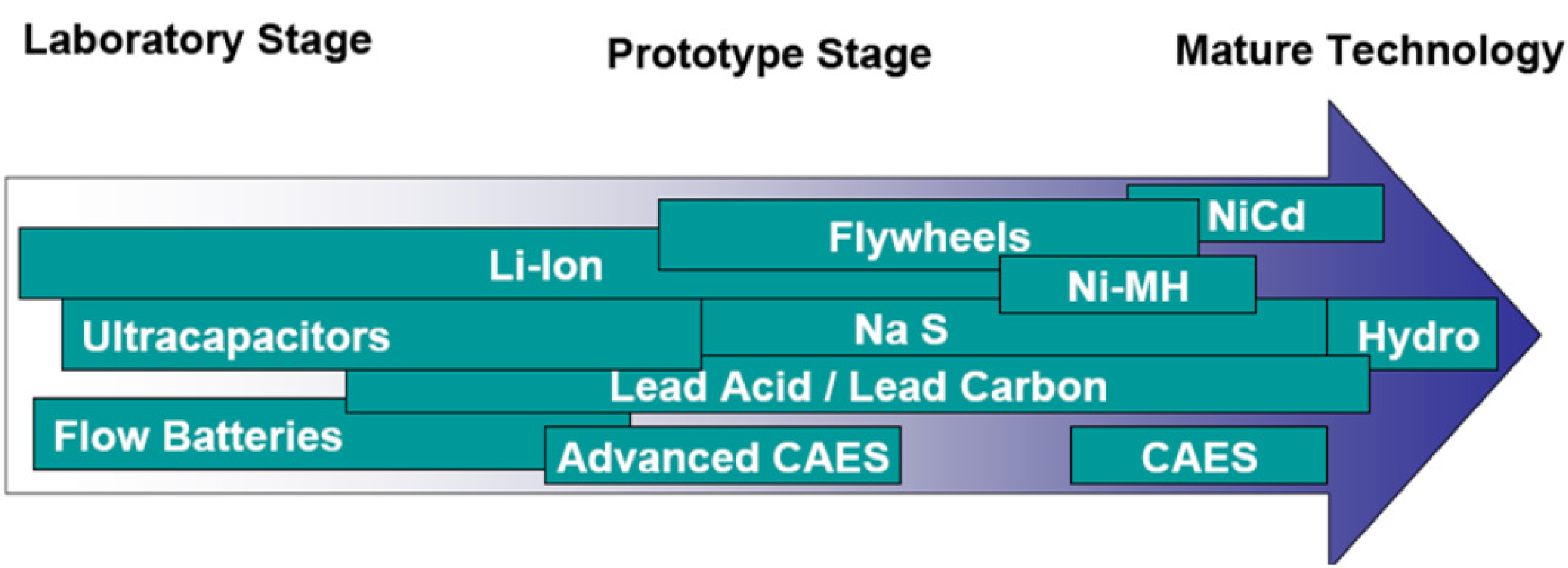
- Ultracapacitors
- Flywheel
- SMES- Superconducting Magnetic Energy
- Battery
  - Lead Acid
  - Sodium Alumina
  - NiMH; NiCad; Lithium Ion
  - Flow Batteries
    - Vanadium Redox
    - Zinc Bromine
  - Metal Air
- Compressed Air Energy Storage (CAES)
- Pumped Hydro

Short Term Delivery



Long Term Delivery

Maturity of Technology

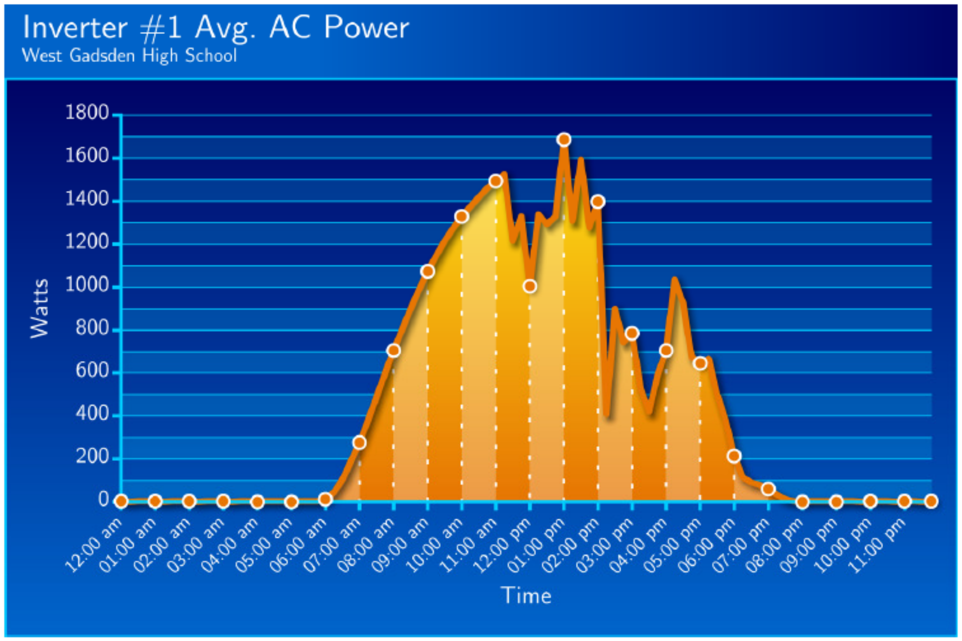


Grid-Scale Energy Storage, Mark Johnson, David Danielson, Imre Gyuk, 3/1/2010, ARPA-E Pre-Summit Workshop

Load Imbalance

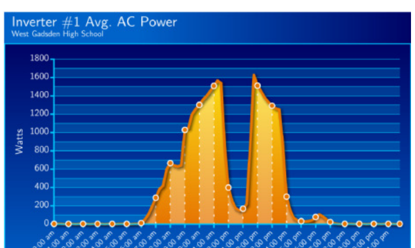
Real time data Examples from West Gadsden High School PV Array

6/15/2010

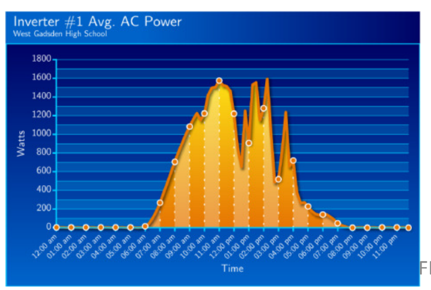


http://data.energywhiz.com/9-12/performanceinfo.php?systemID=wgq

6/14/2010



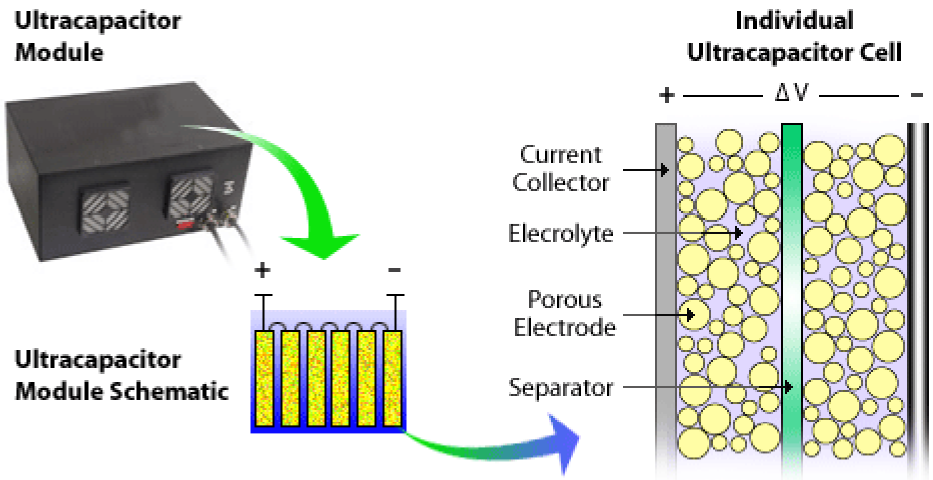
6/13/2010



Timing is important

- Seconds
  - Frequency (Hz=cycle/second)
  - AC: 60Hz (US); 50Hz (Europe)
- 1 second to 1 minute
  - Voltage regulation
- 1 to 10 minutes
  - Electrical Power (ramp-up)
  - Watts, kW, MW
- 10 minutes to hours
  - Electrical Energy
  - kW-h
  - Refers to the flow of power along a conductor to create energy.
  - Electrical energy is a secondary source of energy, which means that we obtain electrical energy through the conversion of other forms of energy.

Ultracapacitors

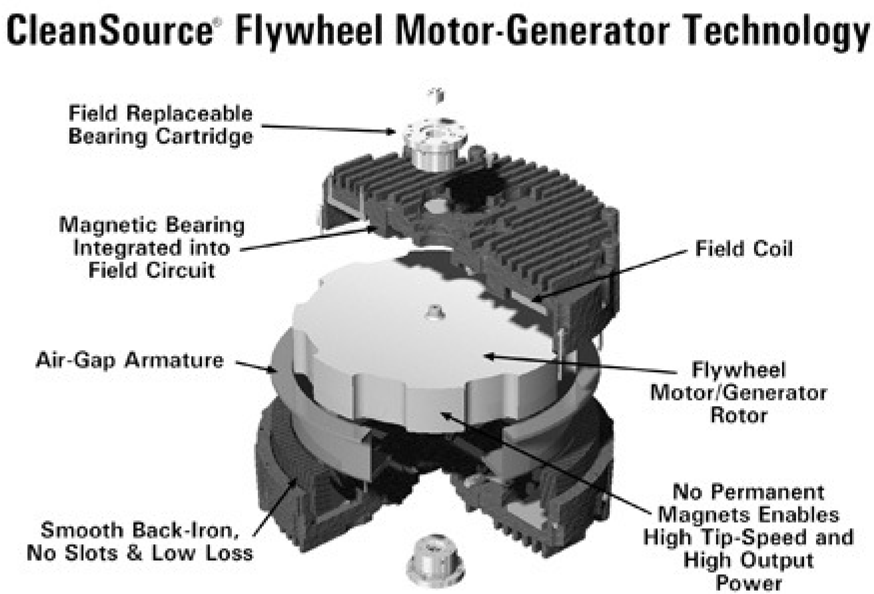


- High power, but lower energy density than batteries
- Cycled 100,000+ times: ideal for applications with frequent charge/discharge requirements.

Types of Solid State Ultracapacitors:
-Electrical Energy Storage Units
-Organic Solid State Ultracapacitors

Like batteries, ultracapacitors are energy storage devices. They use electrolytes and configure various-sized cells into modules to meet the power, energy, and voltage requirements for a wide range of applications. But batteries store charges chemically, whereas ultracapacitors store them **electrostatically**. Currently, ultracapacitors are more expensive (per energy unit) than batteries.

Flywheel

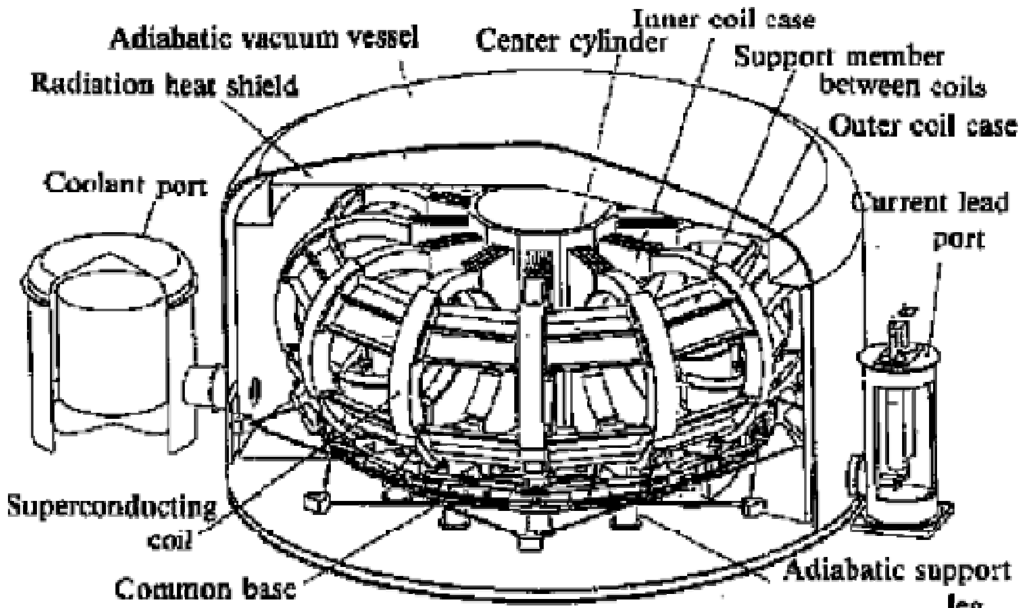


- Flywheels store energy mechanically (kinetic)
- High cycle life (100,000+ cycles) ideal for frequent charge/discharge of power.
- Power and energy scale independently, but there are practical limit to energy density:
    - Higher Moment of Inertia Materials
    - Low Cost Structures
- Commercial plants are on-line providing frequency regulation: 3MW in Massachusetts, 20MW planned in New York and Illinois

UPS- Uninterrupted Power Supply

http://www.youtube.com/watch?v=JckymSbfVYk&feature=related

SMES

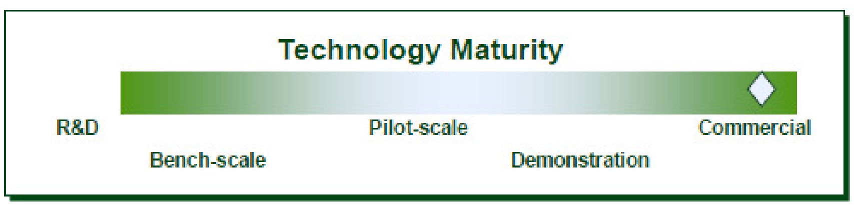


Conceptual Design

- SMES store electricity in magnetic field of a superconducting coil cryogenically cooled below its critical temperature.
- Efficient energy storage
- Power available instantaneously
- Several large (3MW) demonstration units are installed in the US (Wisconsin, Texas), as are numerous “micro-SMES” units
- New Technology For Longer Duration:
  - Reduce Cost of Superconducting Material Structures
  - High Critical Temperature Superconductors

Battery Storage

Lead Acid Battery



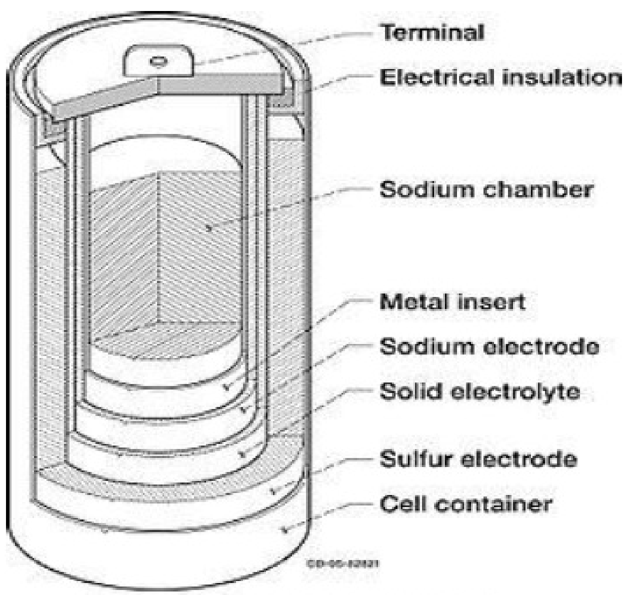
Description

- Oldest and most developed battery technology
- Energy management applications have been installed (California, Hawaii, Puerto Rico, and Germany) with power from 3 to 10 MW
- Highly-sensitive to operating temperature and charge profiles; corrosion, sulfation, and active material shedding as traditional issues
- New Areas in 200 Year Old Technology:
  - Innovative Lead-carbon Electrodes
  - Advanced Power Conditioning Systems

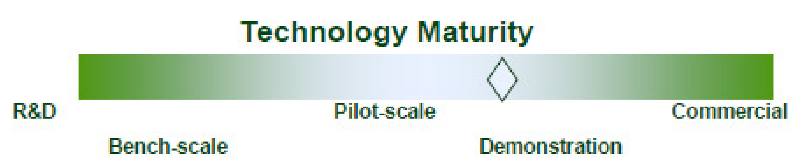
Grid-Scale Energy Storage, Mark Johnson, David Danielson, Imre Gyuk, 3/1/2010, ARPA-E Pre-Summit Workshop

Battery Storage

Sodium β-alumina Battery



Sodium sulfur battery schematic



Description

- High-temperature (~300°C) liquid sodium cathode and sulfur anode with a β-alumina solid electrolyte (BASE)
- Heat produced by charging and discharging cycles maintains operating temperature, but:
  - Need utility scale reliability
  - Beyond sodium-sulfur for β-alumina
- Systems offer high efficiency (89-92%) and high cycle life (5000+ cycles)
- Several grid-storage installations:
  - Japan has 25 at 500kW or higher
  - US projects in New York, West Virginia and California.

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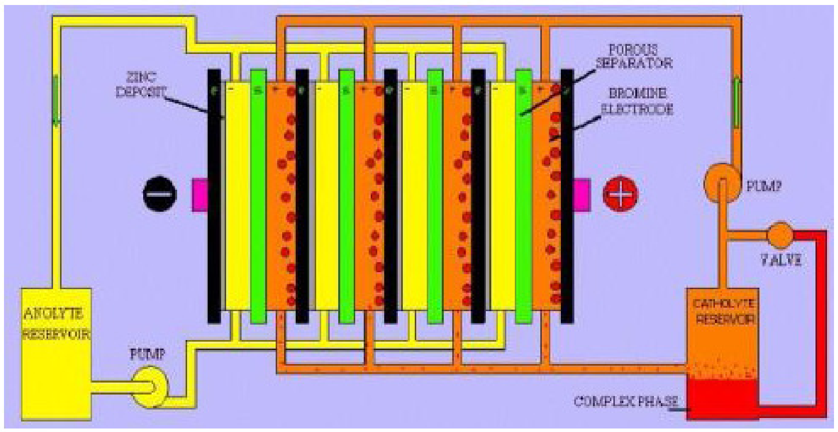
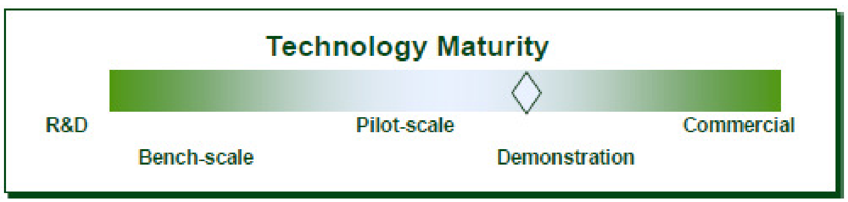
Battery Storage

Zinc Bromine (Zn-Br) Flow Battery



Zinc-Bromine Flow Battery Schematic



Description

- Solution of zinc-bromine in two tanks. Zinc is electroplated on anode and Bromine is evolved at cathode
- Power and energy can be scaled separately
- High roundtrip efficiency (70-80%) and potential for low cost
- Field tests in Japan, United States and Australia. Scaled 1MWh demonstration project in California
- Needs:
  - Interface, Membranes and Electrodes
  - Technology for Long Life Cycle (20yrs)

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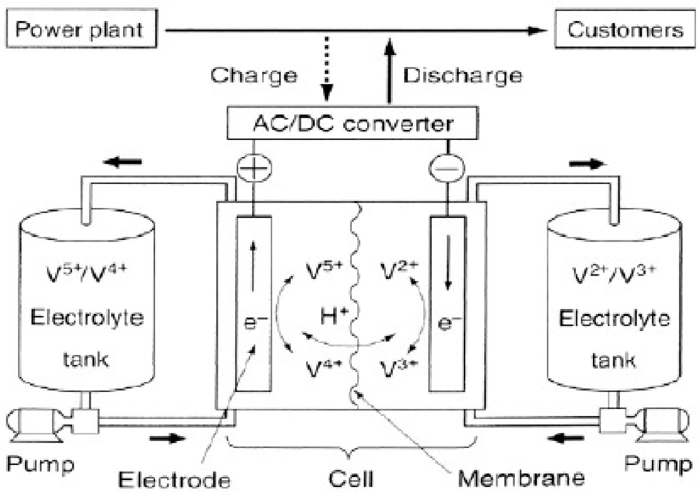
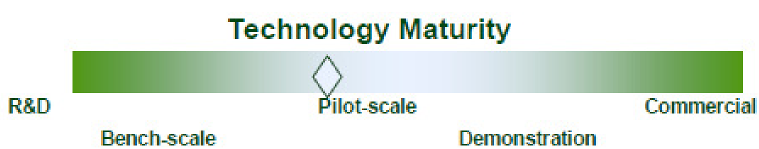
Battery Storage

Flow Battery: Vanadium Redox



VRB Schematic



Description

- Two aqueous electrolytes with vanadium species in different oxidation states are pumped through reaction cell halves
- Energy determined by externally-stored electrolyte; Power determined by cell stack
- High roundtrip efficiency (70-75%) and potential for low costs
- Needs:
  - Doubling of Energy Density and Improved Power Management
  - Long Duration Membranes Materials
  - High Energy Density Chemistries

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Battery Storage

Metal Air Battery

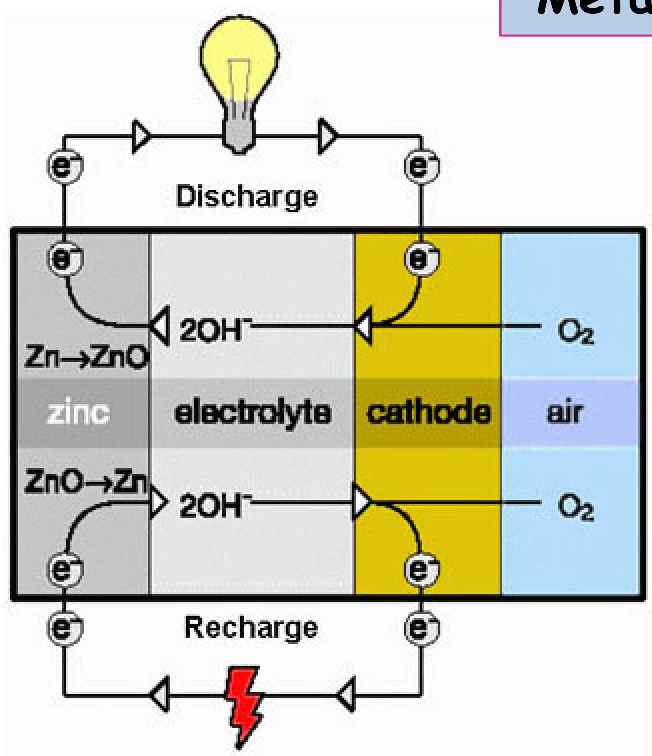
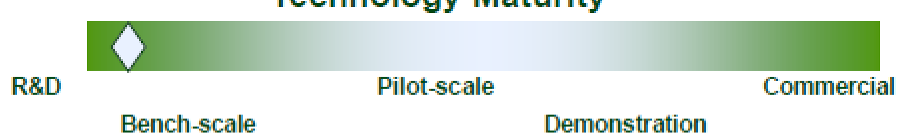


Photo Courtesy of EVonyx Inc.

Technology Maturity



Description

- Metal air batteries combine reactive metal anode (zinc, lithium, magnesium, etc.) with an air electrode
- Metal-air batteries have potential for very high energy density at a low cost
- Need:
  - Recharging from the Grid
  - Long Cycle Life Challenges
- Flow-type designs in which consumed metal is mechanically replaced and reprocessed separately

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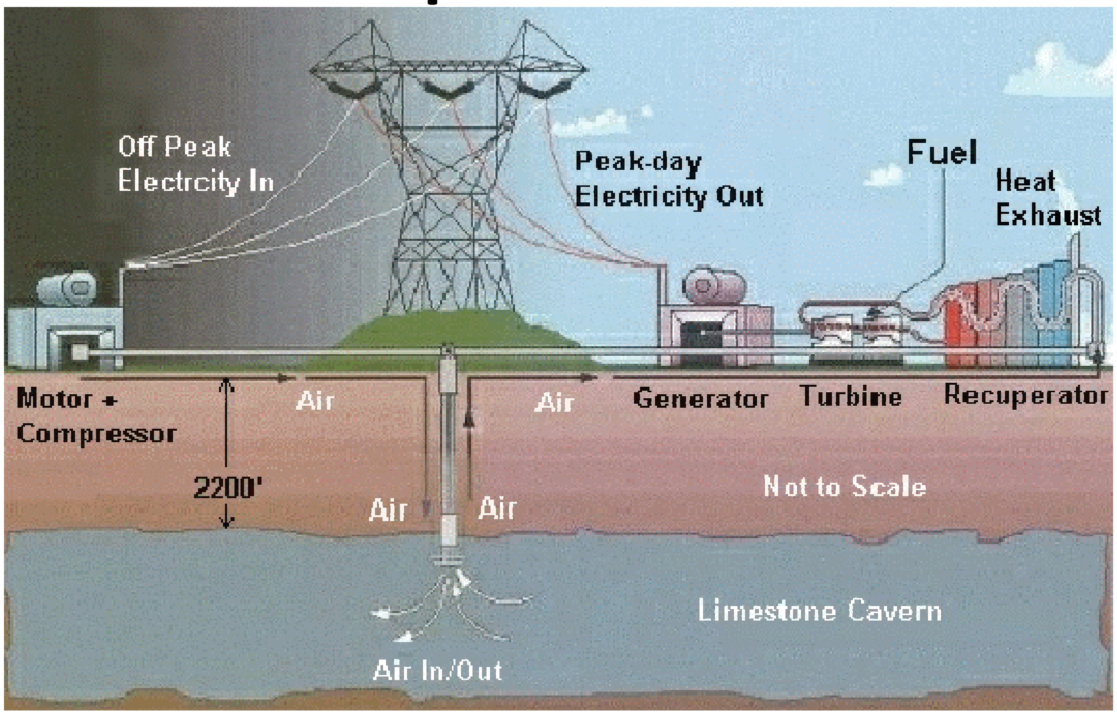
Compressed Air Energy Storage

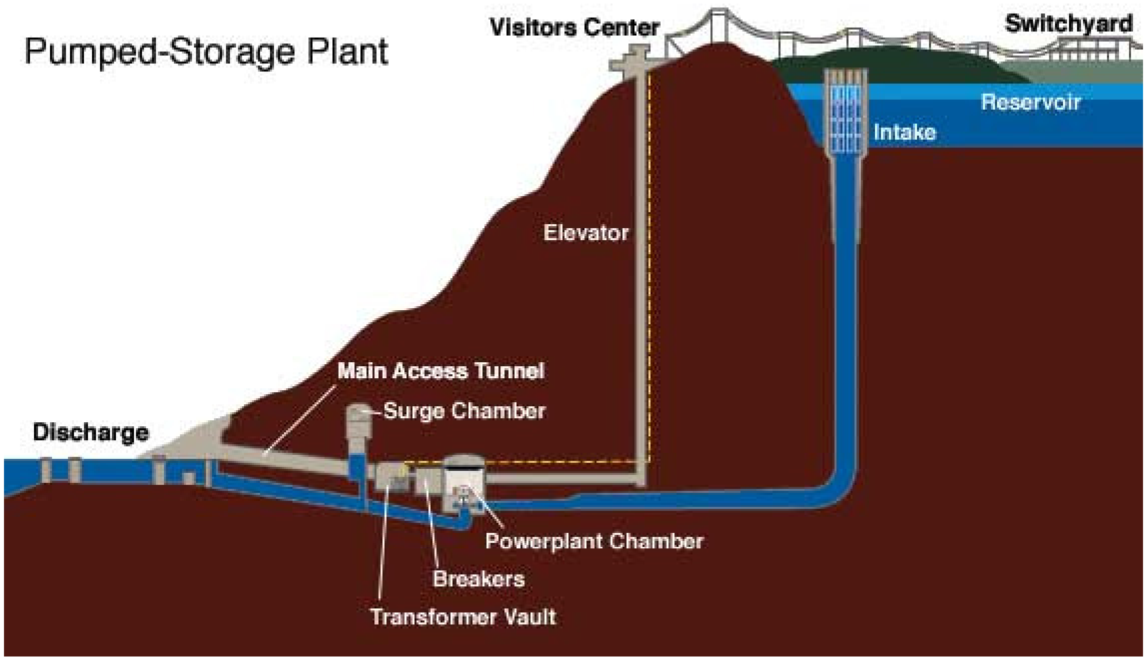


- Deployment where favorable geological formations are available
- Power and energy from improved efficiency in coupled gas turbine generation systems
- New approaches:
  - Above ground (to MWh scale)
  - Adiabatic or Isothermal systems
  - Novel storage media
- Economically acceptable: $100 /kWh

A CAES operates by means of large electric motor driven compressors that store energy in the form of compressed air in the mine. The compression is done outside periods of peak demand. As part of the compression process, the air is cooled prior to injection to make the best possible use of the storage space available. The air is then pressurised to about 75 bar.

To return electricity to the customers, air is extracted from the cavern. It is first preheated in the recuperator. The recuperator reuses the energy extracted by the compressor coolers. The heated air is then mixed with small quantities of oil or gas, which is burnt in the combustor. The hot gas from the combustor is expanded in the turbine to generate electricity.

Pumped Hydro



http://www.tva.gov/power/hydro.htm

A pumped hydroelectic storage system consists of two large reservoirs located at different elevations.

During peak demand, water is released from the upper reservoir. It drops downward through high-pressure shafts where it passes through turbines and ultimately pools up in the lower reservoir. The turbines drive power generators that create electricity. Therefore, when releasing energy during peak demand, a pumped hydroelectric storage system works similarly to traditional hydroelectricity. When production exceeds demand, water is pumped up and stored in the upper reservoir, ready to be released as needed.