Development of Asymmetric Capacitors for Stationary Applications

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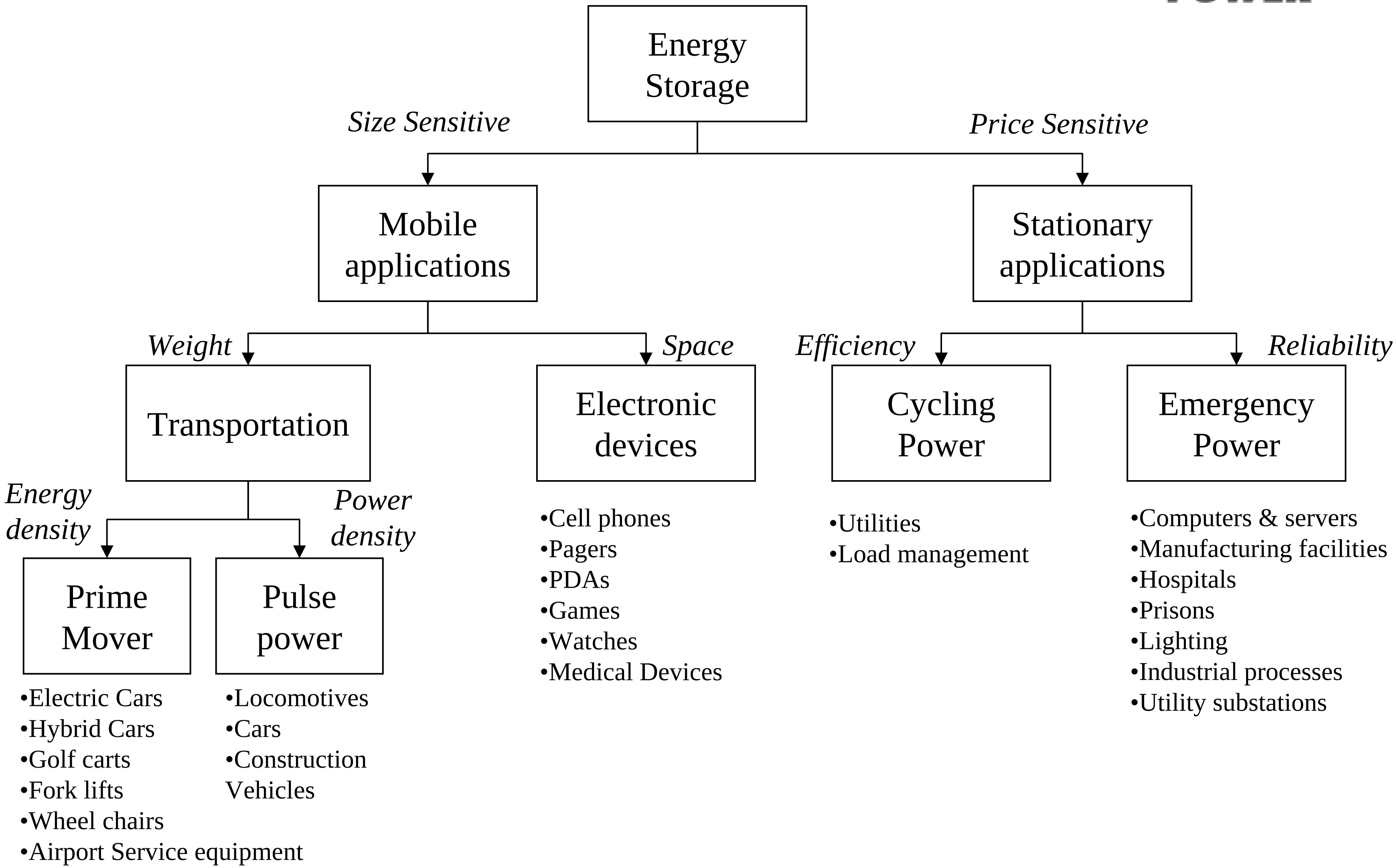
Outline

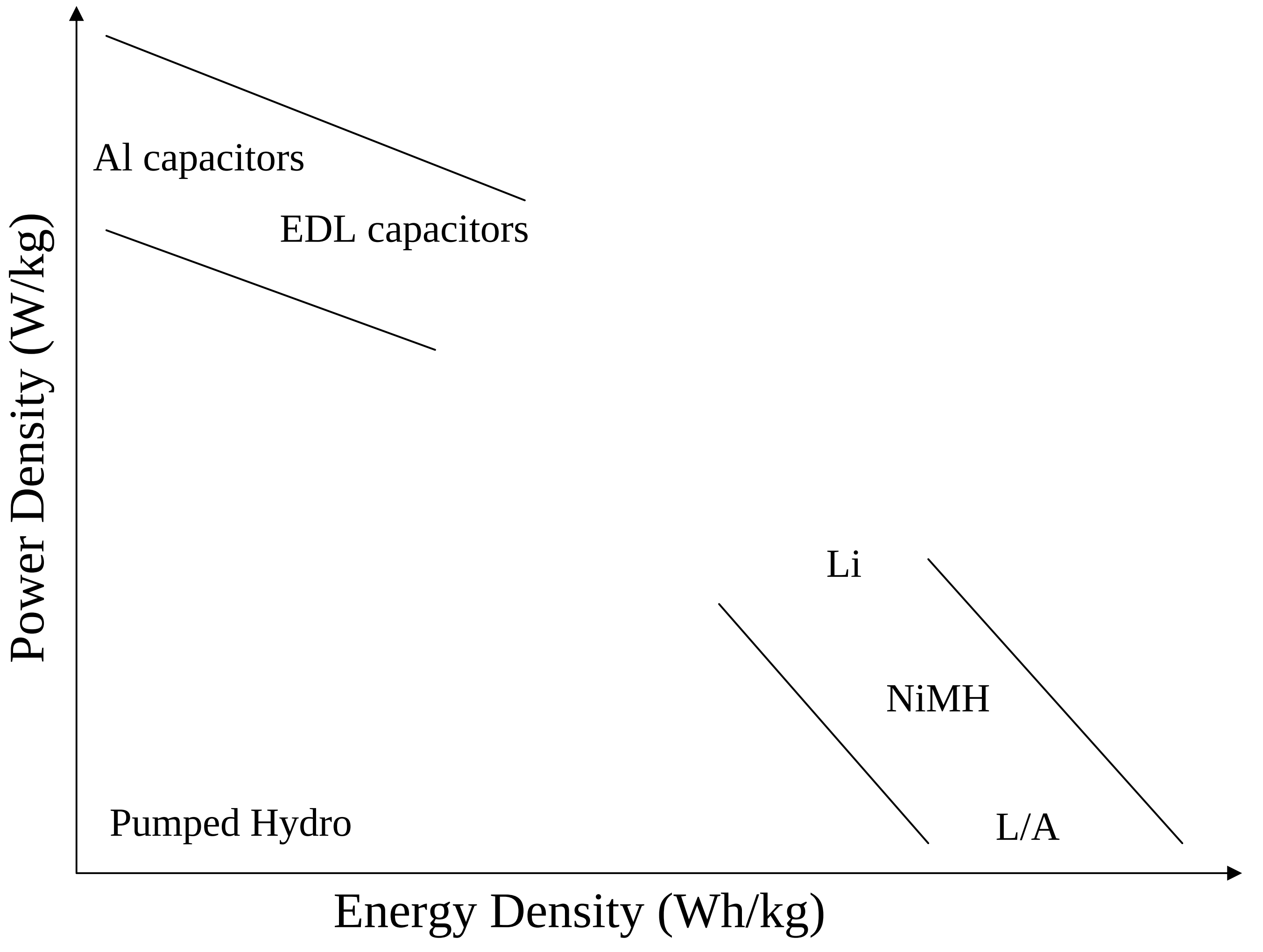
- Energy Storage
  - Applications of energy storage
  - AEP's interest/utility applications
- American Electric Power
- Asymmetric Capacitor background
- DOE Sponsored Program
  - Technical prove out
  - Commercial prove out
  - Successful demonstration

Storage Markets

AEP AMERICAN ELECTRIC POWER



Storage Characteristics



Transportation

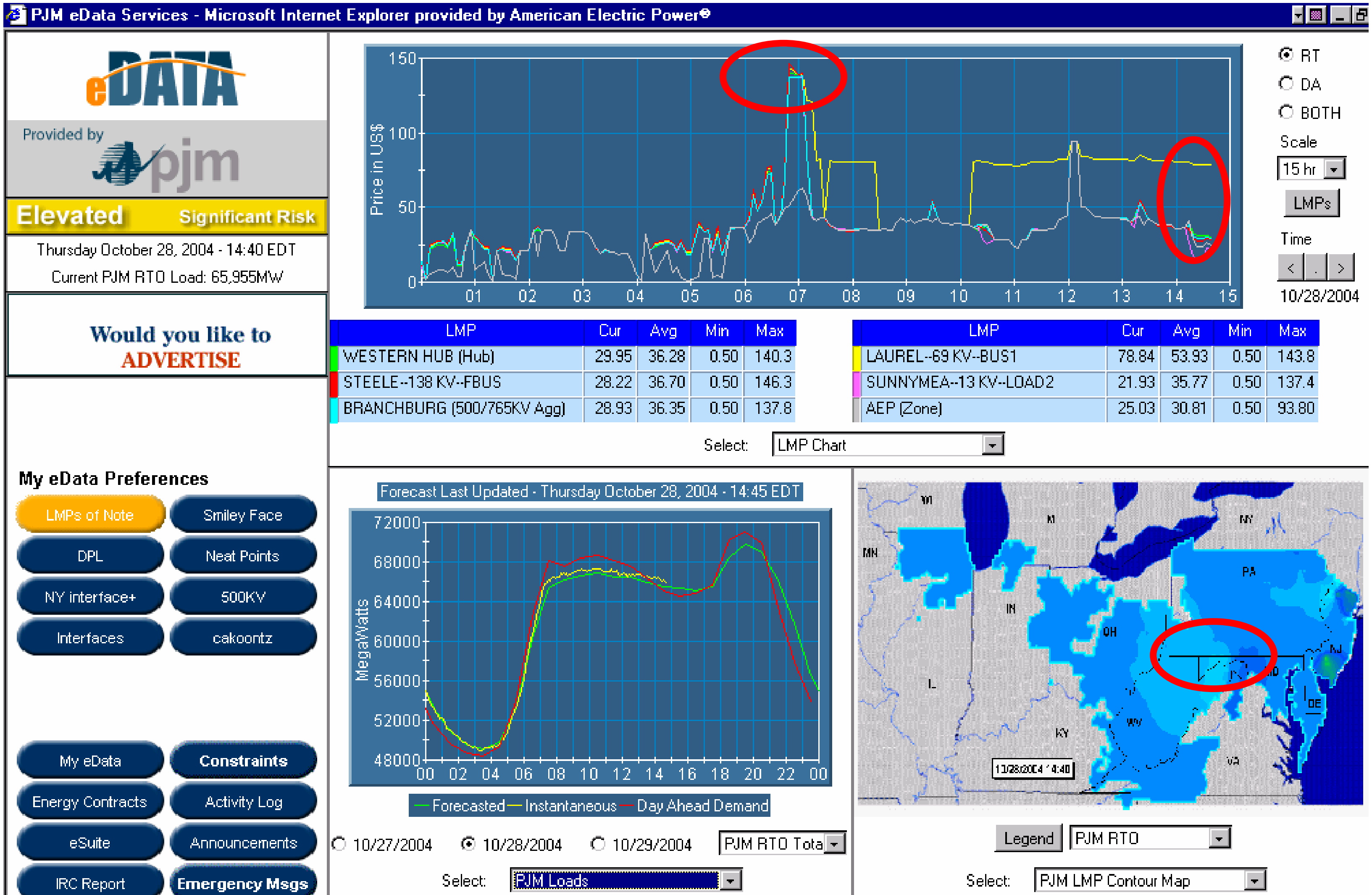
FreedomCar Mild Hybrid Targets

- Weight <25 kg
- Discharge Power – 13 kW (for 2 s)
- Regenerative Pulse Power – 8 kW (for 2 s)
- Available Energy > 300Wh
- Calendar Life – 15 years
- Price <$260

- Implied Energy Density >12 Wh/kg
- Implied Power Density>500 W/kg
- Implied Cost < $870/kWh

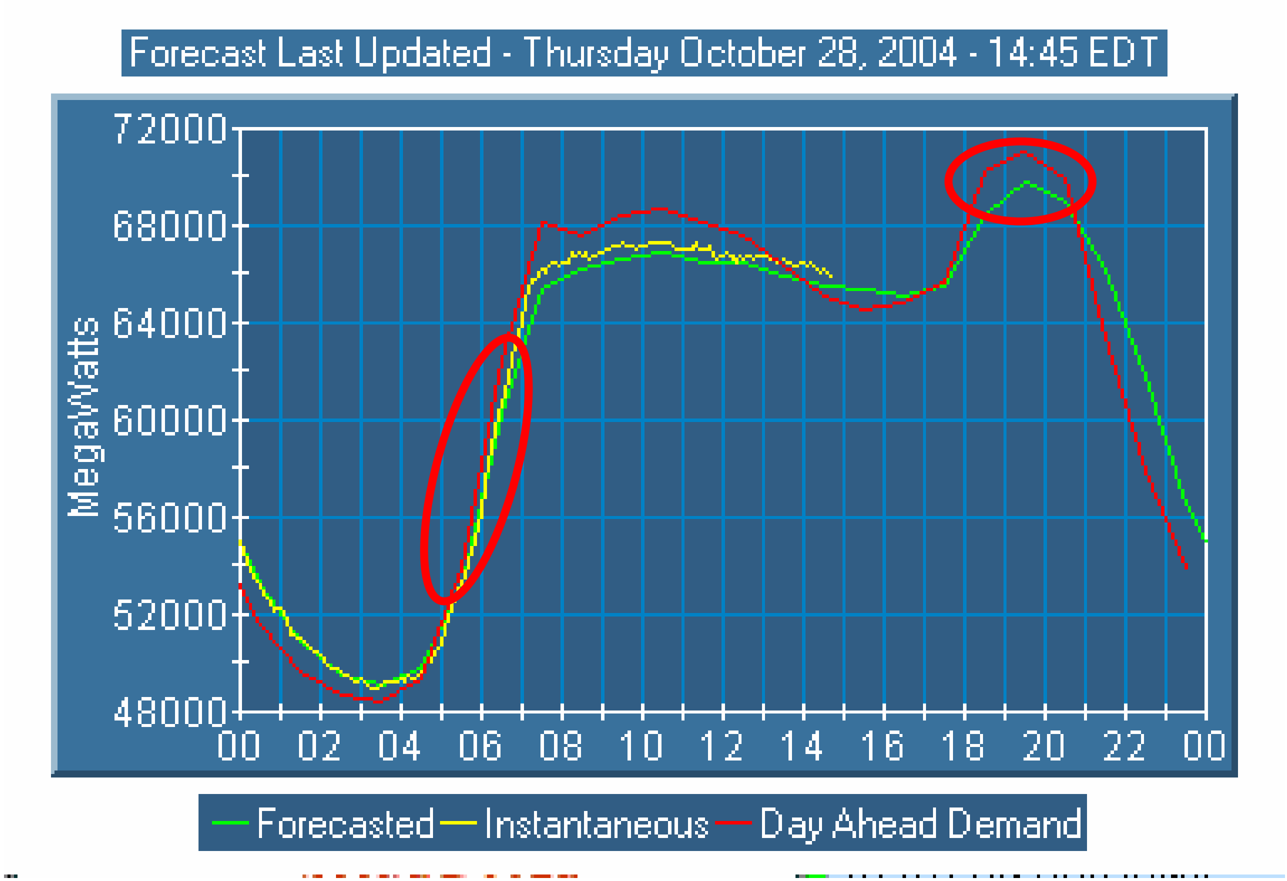
Source: Delphi Presentation to ESA in May of 2004

Energy Market



Market view

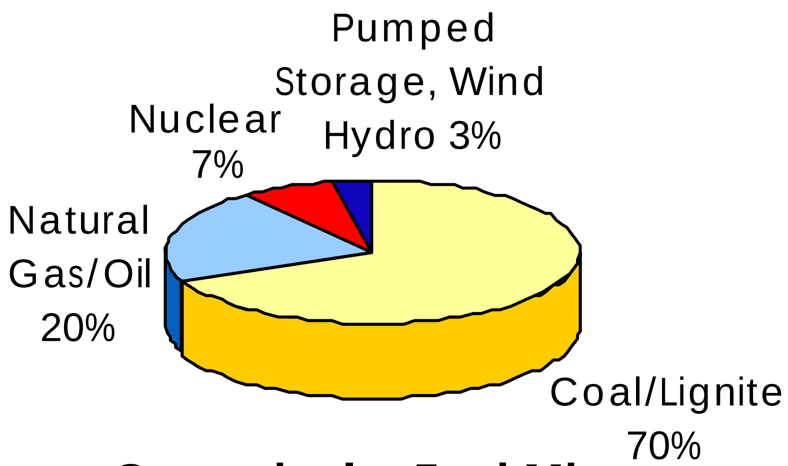
Load



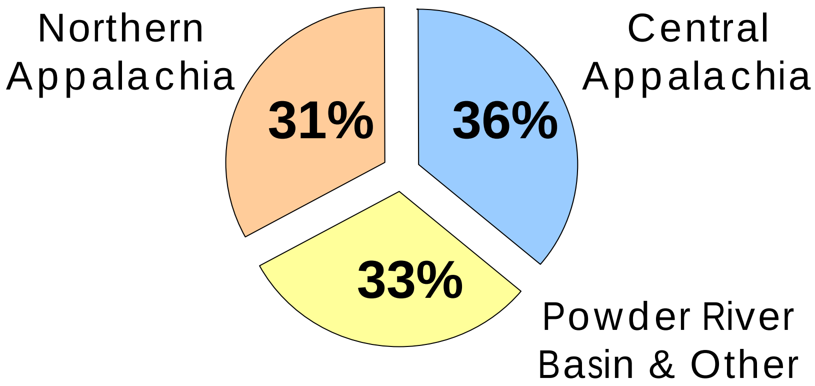
KEY NOTES

- Load deviating from day ahead forecast
- Significant difference between on and offpeak load
- Steepness of the morning and evening ramp

About AEP



Capacity by Fuel Mix



Coal Supply
(on average)

- 36,000 MW domestic capacity
- 85% system availability factor in 2003
- 65% system capacity factor in 2003

- Purchase 75-80 MM tons per year
- Average delivered price ~ $27/ton in 2003
- Well hedged over next 3 years

GENERATION FLEET IS SUBSTANTIAL AND LOW COST

AEP'S Technology Firsts

A History of Technology Development

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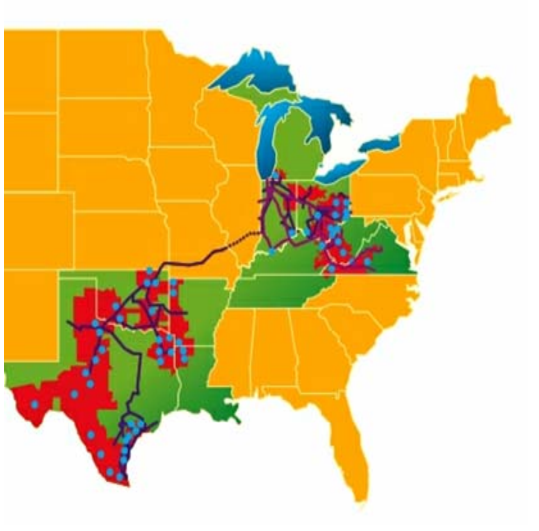
- 1917: Mine-mouth plant and long-distance transmission
- **1924: First reheat generating unit** (Philo 1)
- 1935: Ultra-high-speed, high-voltage reclosing circuit breakers
- 1950: First heat rate below 10,000 BTU/kWh (Philip Sport Plant)
- **1953: 345-kV transmission line**
- 1957: First power plant using supercritical high-pressure (4500 psig) and high-temperature, double-reheat (1150F/1050/1000) steam cycle (125 MW Philo 6 Plant)
- 1960: First heat rate below 9,000 BTU/kWh (Clinch River Plant) 1962: first natural-draft cooling tower in the western hemisphere (260 MW Big Sandy 1 Plant)
- **1969: 765-kV transmission line**
- 1979: Static Var Compensator using Thyristor Controlled Rectifier (TCR) and Thyristor Switched Rectifier (TSC)
- 1984: Use of 765-kV live-tank SF6 "puffer" type circuit breaker
- **1990: First pressurized fluidized bed combustion power plant in North America** (70 MW Tidd Plant)
- 1991: First conversion of a power plant from a nuclear facility to a coal-fired facility (1300 MW Zimmer Plant)
- 1997: Flexible AC Transmission System (FACTS) at Inez
- 1998: FACTS/UPFC at Inez Station, KY
- 1999: World's First Premium Power Park Awarded
- **2001: With NGK and TEPCO, first US test of NAS battery**
- 2002: "Energy Storage Demo Park"

Coming soon: first utility scale IGCC (Integrated Gasification Combined Cycle) plant

Energy Storage

Strategic interest

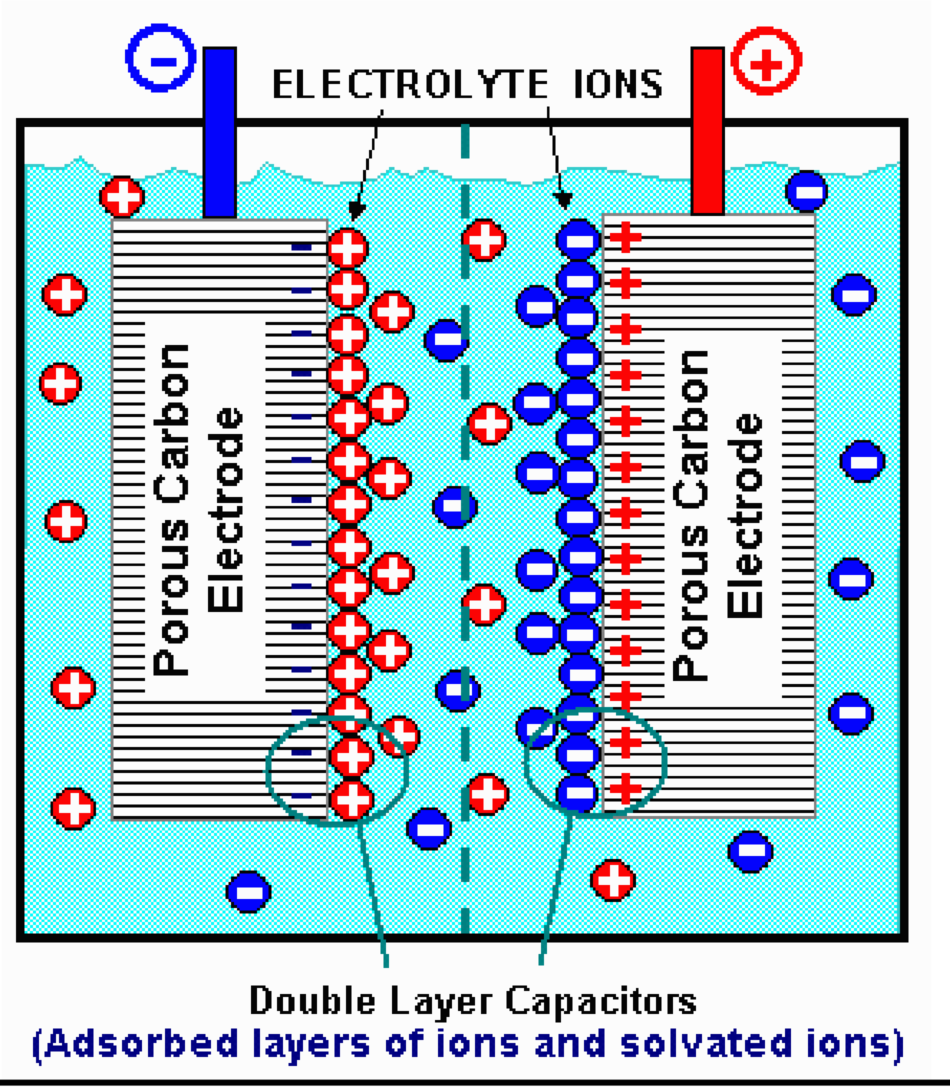
- Today
  - Own and understand pumped hydro
  - Actively monitoring emerging technologies
  - Targeted investing
  - Studying impact of distributed resources
- Future
  - Consider leading new technologies in long term plan
  - Will likely deploy when costs are in line with value



Generation	36,000 MW capacity
Transmission	39,039 miles
Distribution	210,239 miles
Customers	5 million

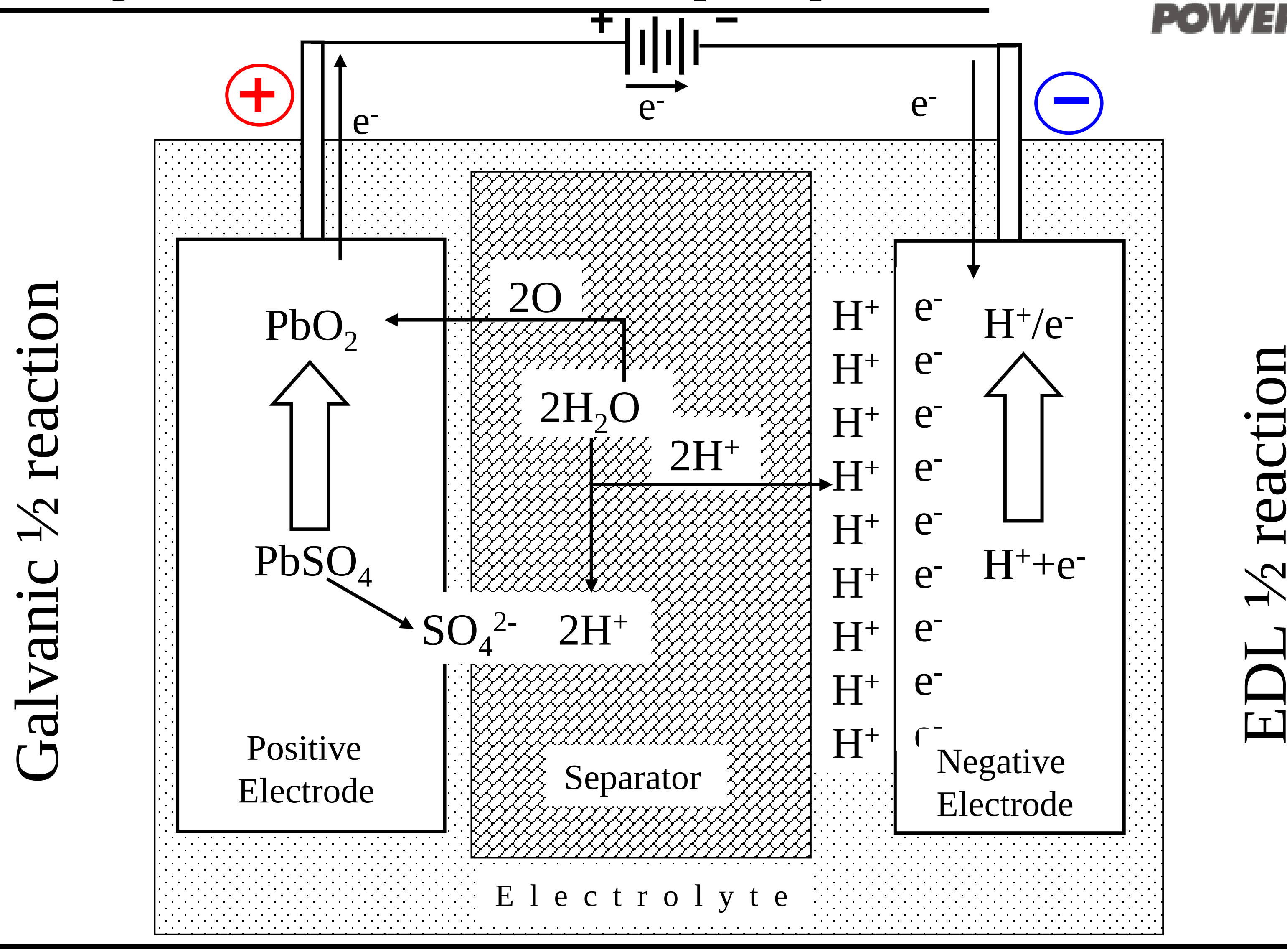
Symmetric Capacitor

EDL ½ reaction



EDL ½ reaction

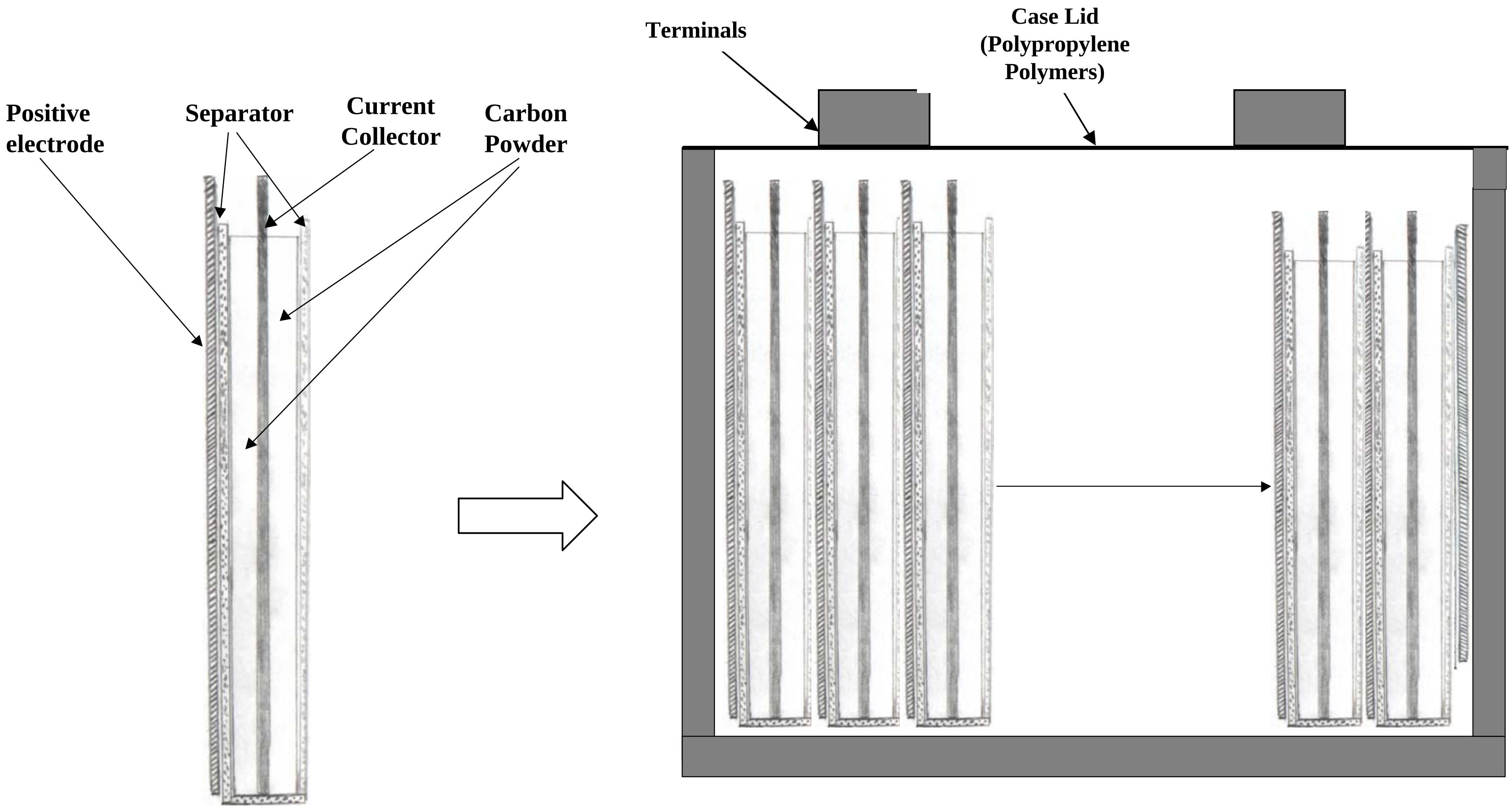
Heterogeneous electrochemical supercapacitor



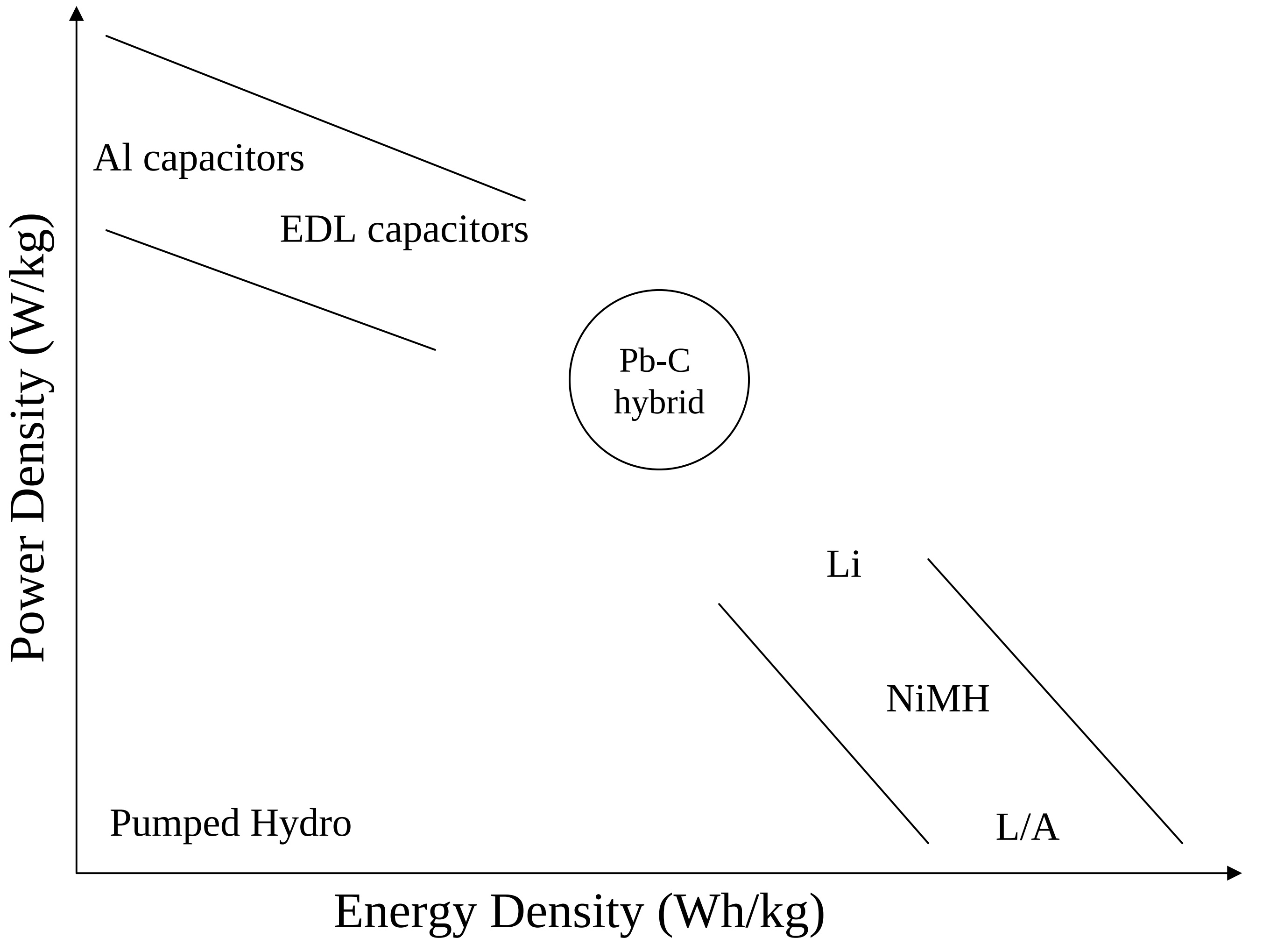
Charging

Technology

Prismatic Cell Structure



Energy Storage



Development Progress

Established the practicable feasibility of Capacitive Energy Storage in 2002-2003 work

- Successful demonstrations with both the HES-340 (1 kWh) and HES-370 (5 kWh) modules
- More then 250 charge/discharge cycles performed on the 1 kWh module at the DTC Lab

HES-340α 0.2 kW, 5 Hour Module

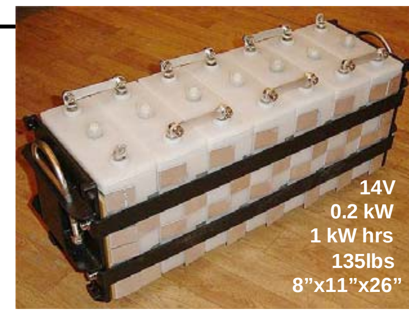
HES-340α	7 cells
Power (kW)	0.2 kW
DC voltage (V)	5.6 – 16.5 V
Weight (lbs)	135 lbs
Dimensions	9” x 11” x 26”

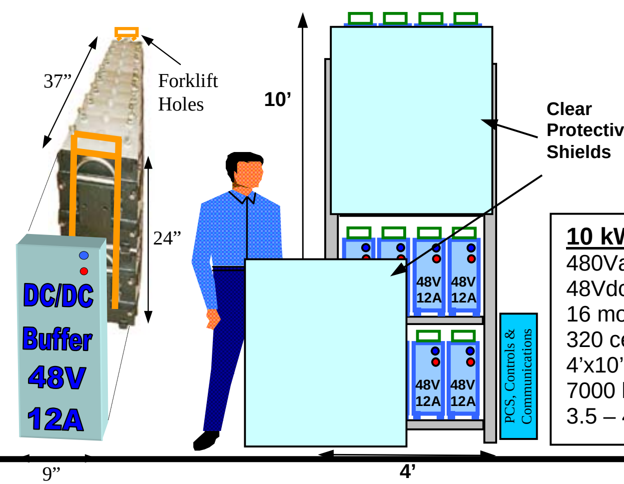
Development Plan

- The development process
  - ***2002-2003: Proof of concept***
    - *It worked!*
    - *1 kW, 5 hour module!*
  - ***2003: Cell development and demonstration***
    - Cell validation, cell economic refinement
  - ***2004: Materials & System Optimization***
    - Choose optimum carbon
    - Optimize other cell components

Universal 1 kW, 5 hour Module:

HES-340 cells:	5x7 = 35
Power (kW):	35x0.032 = 1.12
DC voltage (V):	70-28





10 kW, 5 hour Storage
480Vac, 3phase
48Vdc regulated
16 modules in parallel
320 cells
4'x10'x3.5'
7000 lbs
3.5 – 4.0 kWh/sqft

Hypothesis

1. Life cycle cost advange (in certain applications)
   - Life advantage over lead-acid battery
   - Reduced failure of positive electrode
   - Ability to operate in maintenance free mode
2. Attractive performance paremeters
   - Energy density (not absolute, but relative to low cost devices)
   - Ability to measure state of charge
3. Scale manufacturing with known manufacturing techniques
   - Pb electrodes
   - Activated carbon electrodes
   - AGM separator materials, acid, cases, etc

⇩

The goal going forward is to validate the technology and economics of the Pb-C system

DOE Sponsored Program

1) Provide summary of the current understanding of the asymmetric capacitor and all its components. This task shall include AEP utilizing Lead/Acid battery industry consultants to summarize and apply the known state of the art to the issues of the positive electrode.

2) Develop and document a series of test procedures that allow testing of each hypothesized advantage of the Pb-C system
   - Life cycle improvement over comparable lead-acid battery
   - Cost advantage over other long-life batteries

3) Complete a prototype design specification for an alpha/test device that will support the tests procedures

4) Review prior research on materials selection and report on performance drivers in each of the following areas
   - Activated carbons
   - Graphitic Current Collectors and methods for connecting the terminals
   - Manufacturing methods of activated carbon electrodes

5) Review known operating modes and report on their affect on energy density, efficiency and device life.

Follow-on work

1) Build 25 alpha devices to use in tests
2) Complete tests and report on the results
3) Conduct gap analysis to predict the affect of identified areas of improvement on the overall performance of the system
4) Build a beta system with minimum size of 20kw

During this phase, AEP will be particularly focused on determining the manufacturability and eventual cost of the Pb-C asymmetric capacitor

Progress to date

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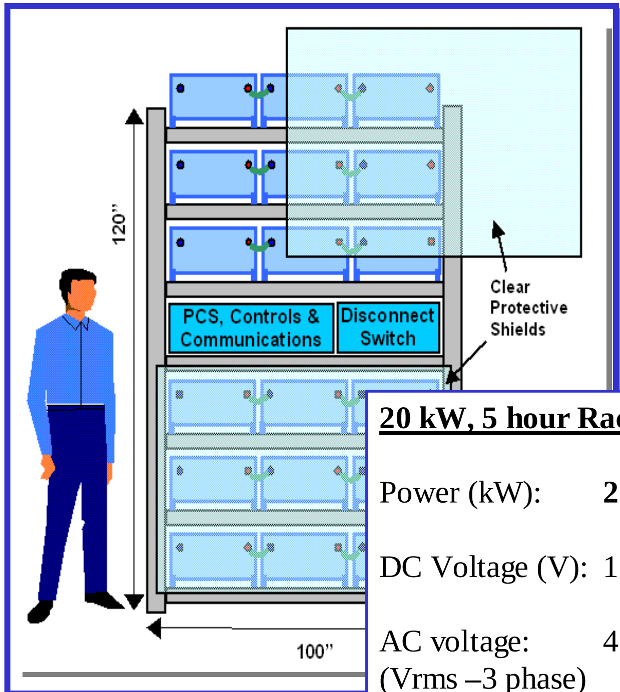
Initial Design Basis

Building Block

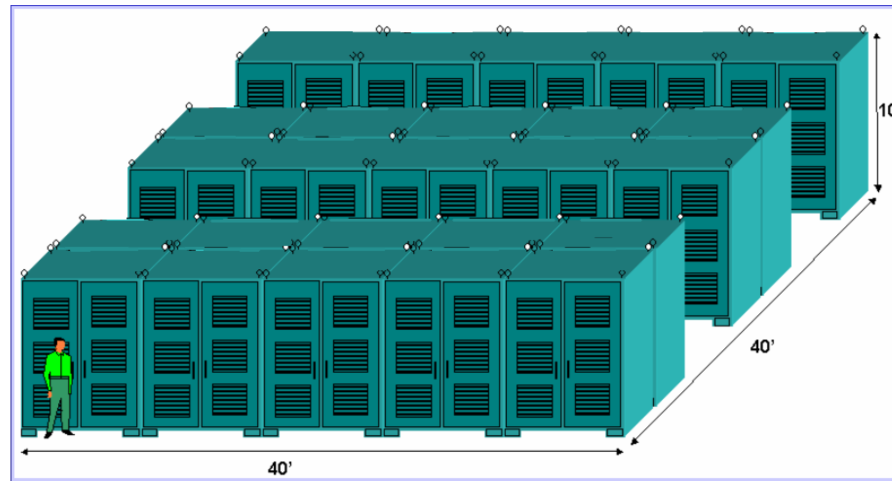
20 kW 3 phase AC Module



20 kW, 5 hour Racks:

Power (kW):	**20**
DC Voltage (V):	168-420
AC voltage: (Vrms –3 phase)	480 /277
Weight (lbs):	13,500 + Rack

*Scalable **upwards** (500 kW)*



*Scalable **downwards** (1 kW, 5 hour)*

Current "proof of concept" prototype module

Utility Storage Example