Capacitors for Power Grid Storage

(Multi-Hour Bulk Energy Storage using Capacitors)

John R. Miller

JME, Inc. and Case Western Reserve University

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Trans-Atlantic Workshop on Storage Technologies for Power Grids

Washington DC Convention Center, October 19-20, 2010

Cost of Storing Energy is the Important Metric

Storage system cost per unit of delivered energy over application life

($/kWh/cycle) or **($/kWh/year)** over total life of the application

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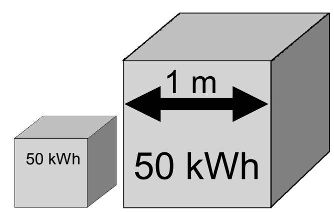

Li-ion Pb-C capacitor

Pb-C capacitor 50 Wh/liter
Li-ion battery 420 Wh/liter

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Cost of Storing Energy is the Important Metric

(Not Energy Density of the Storage System)

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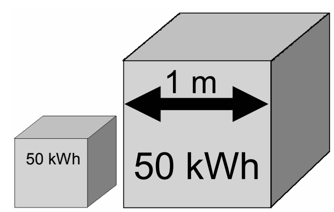

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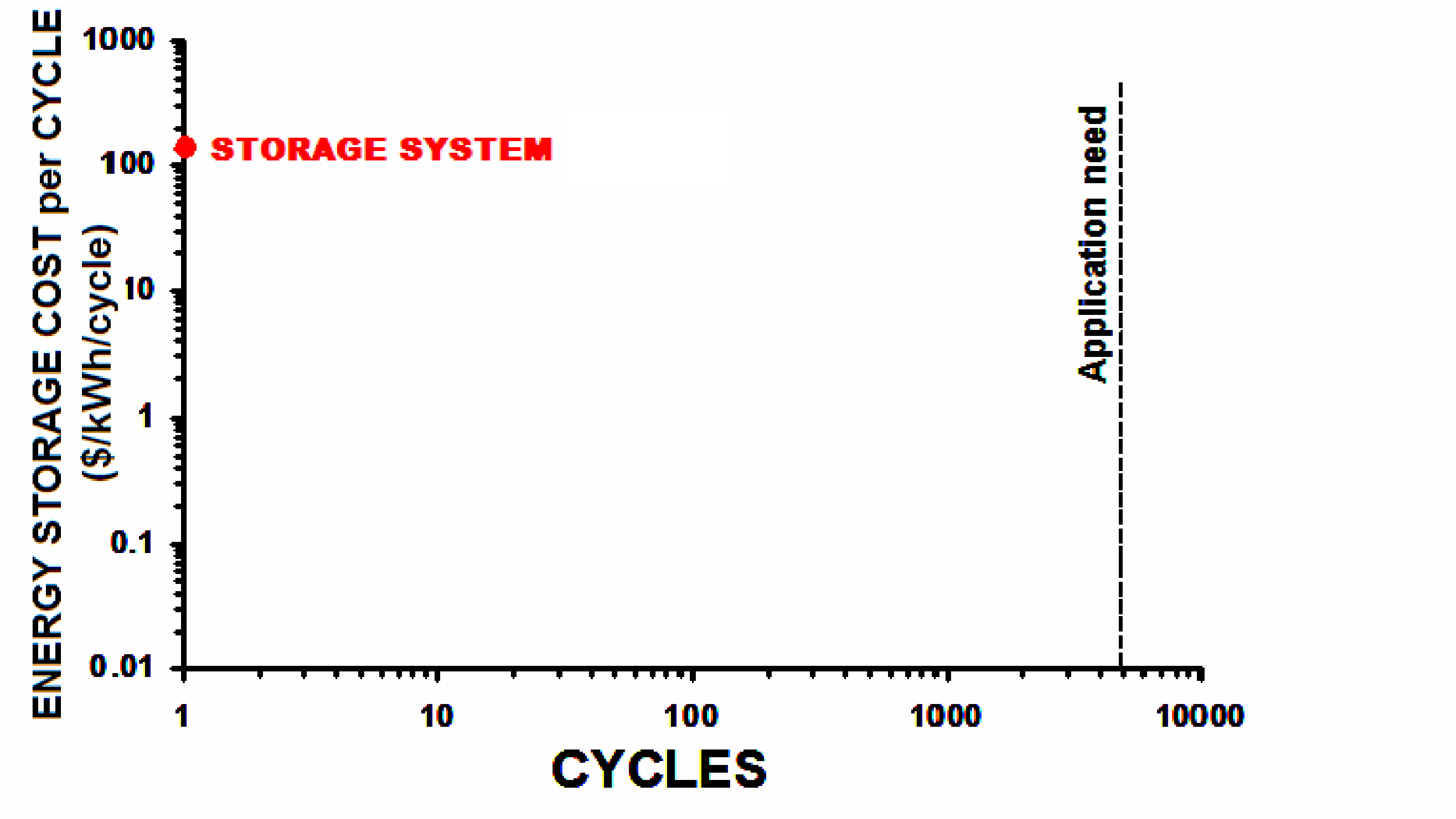
Storage Costs



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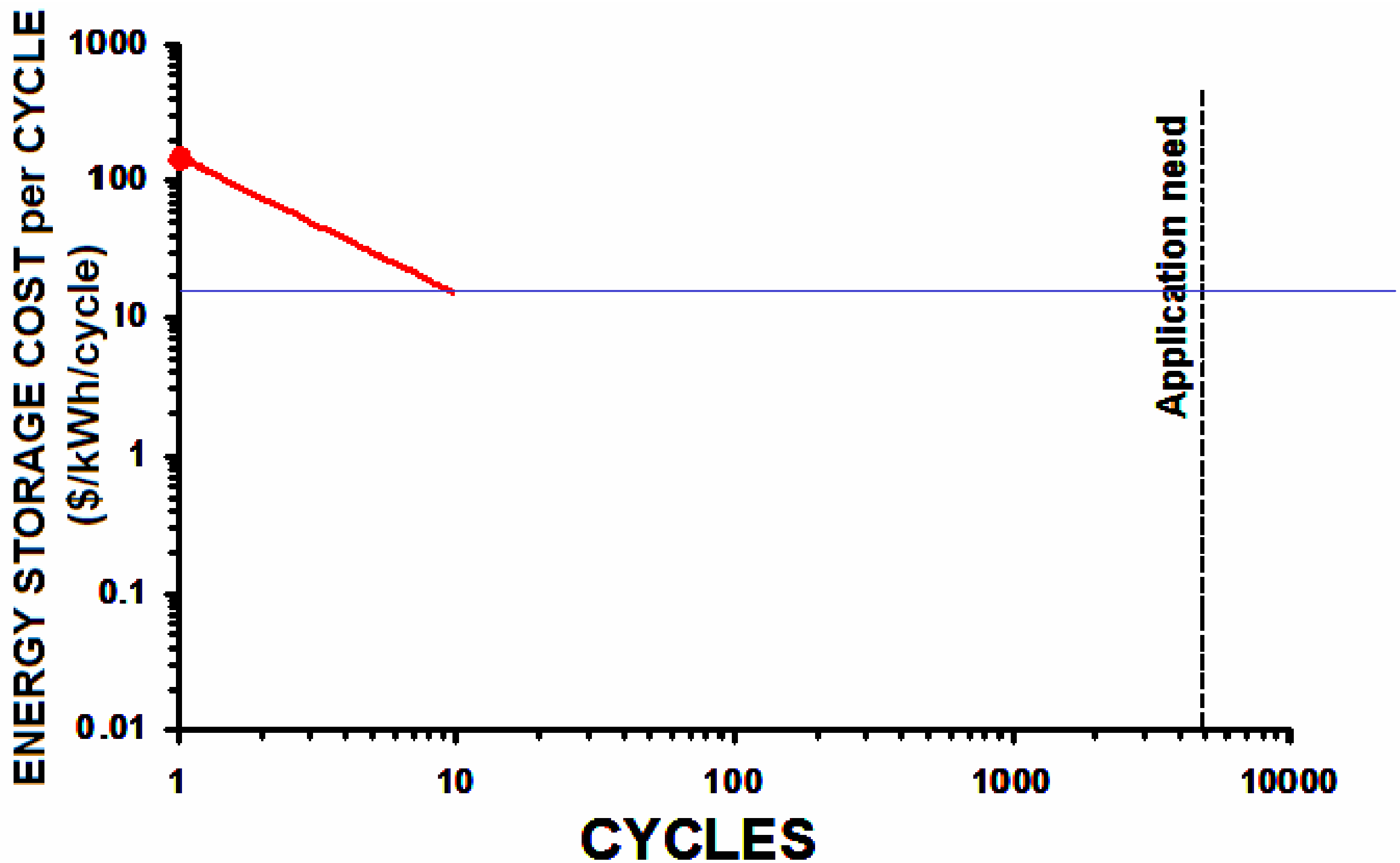
Storage Costs



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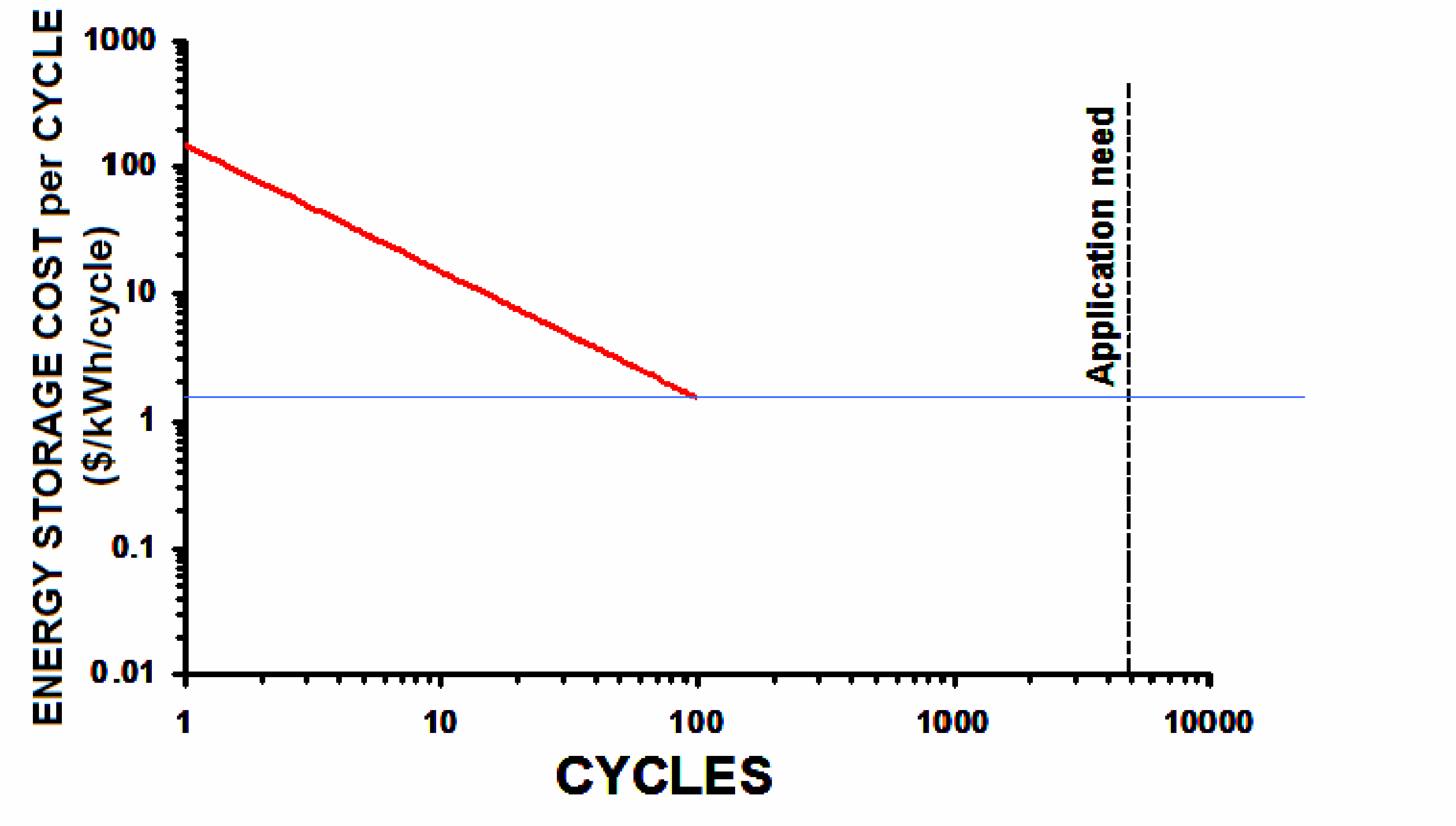

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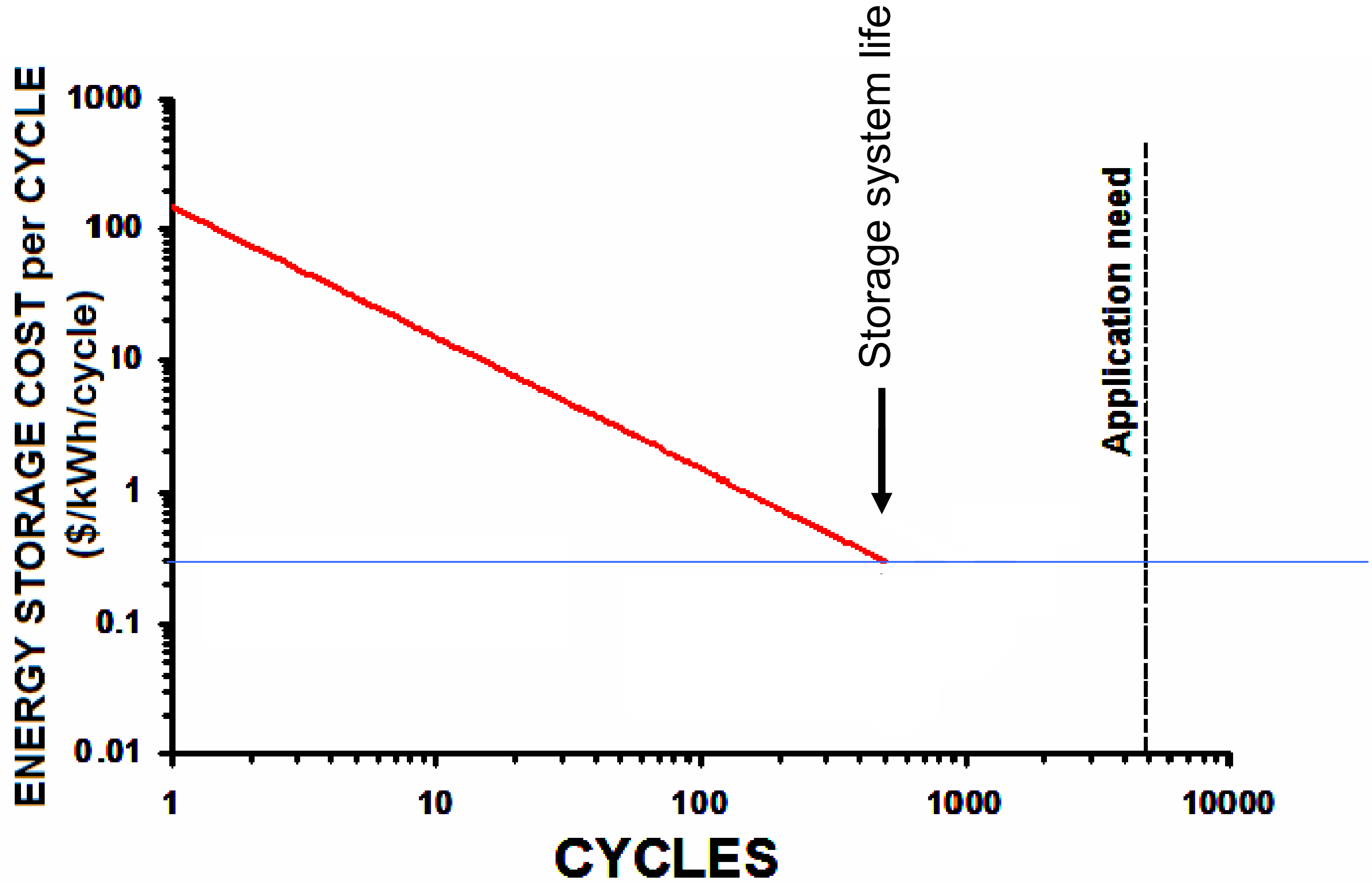
Storage Costs



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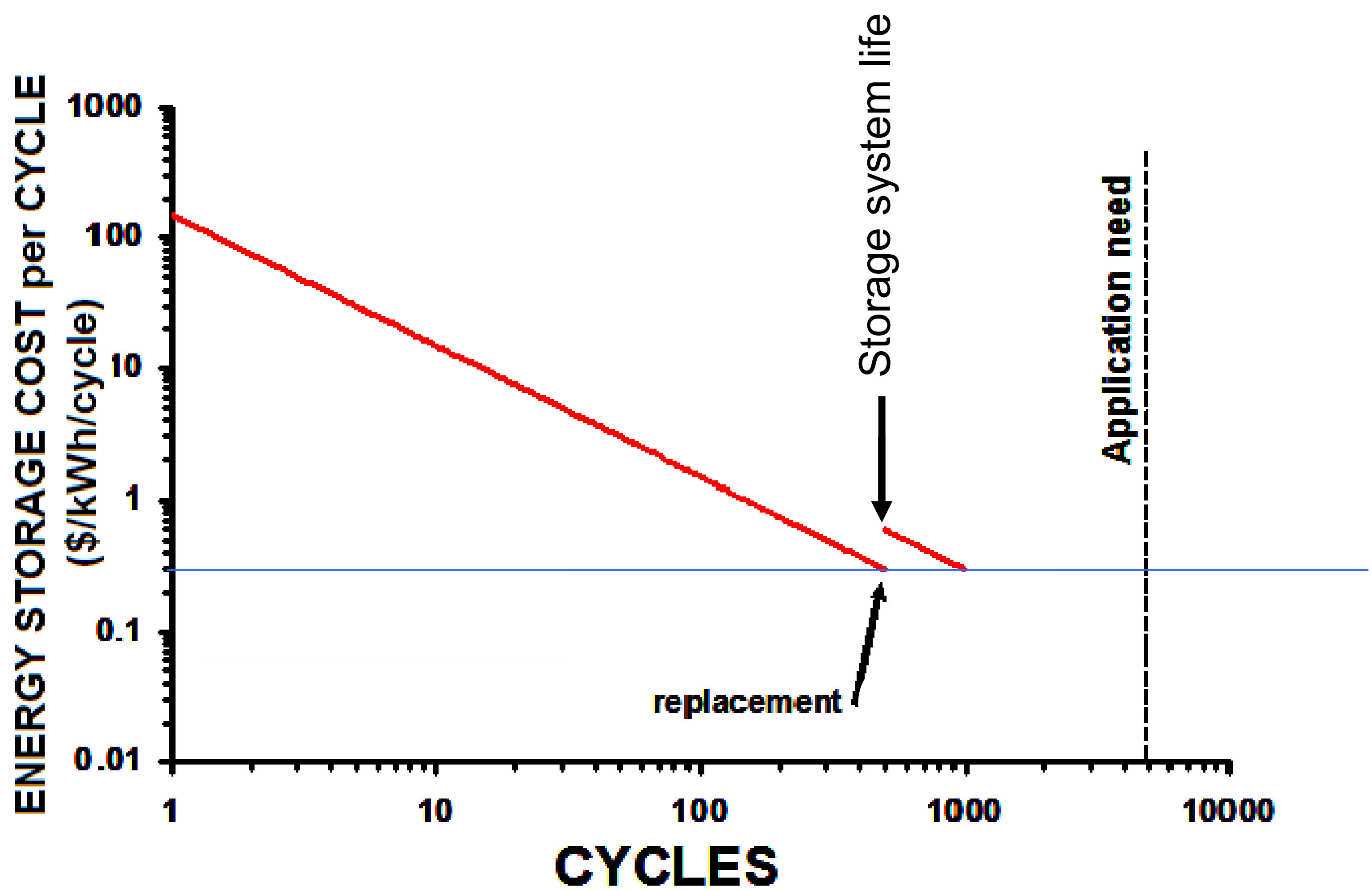
Storage Costs



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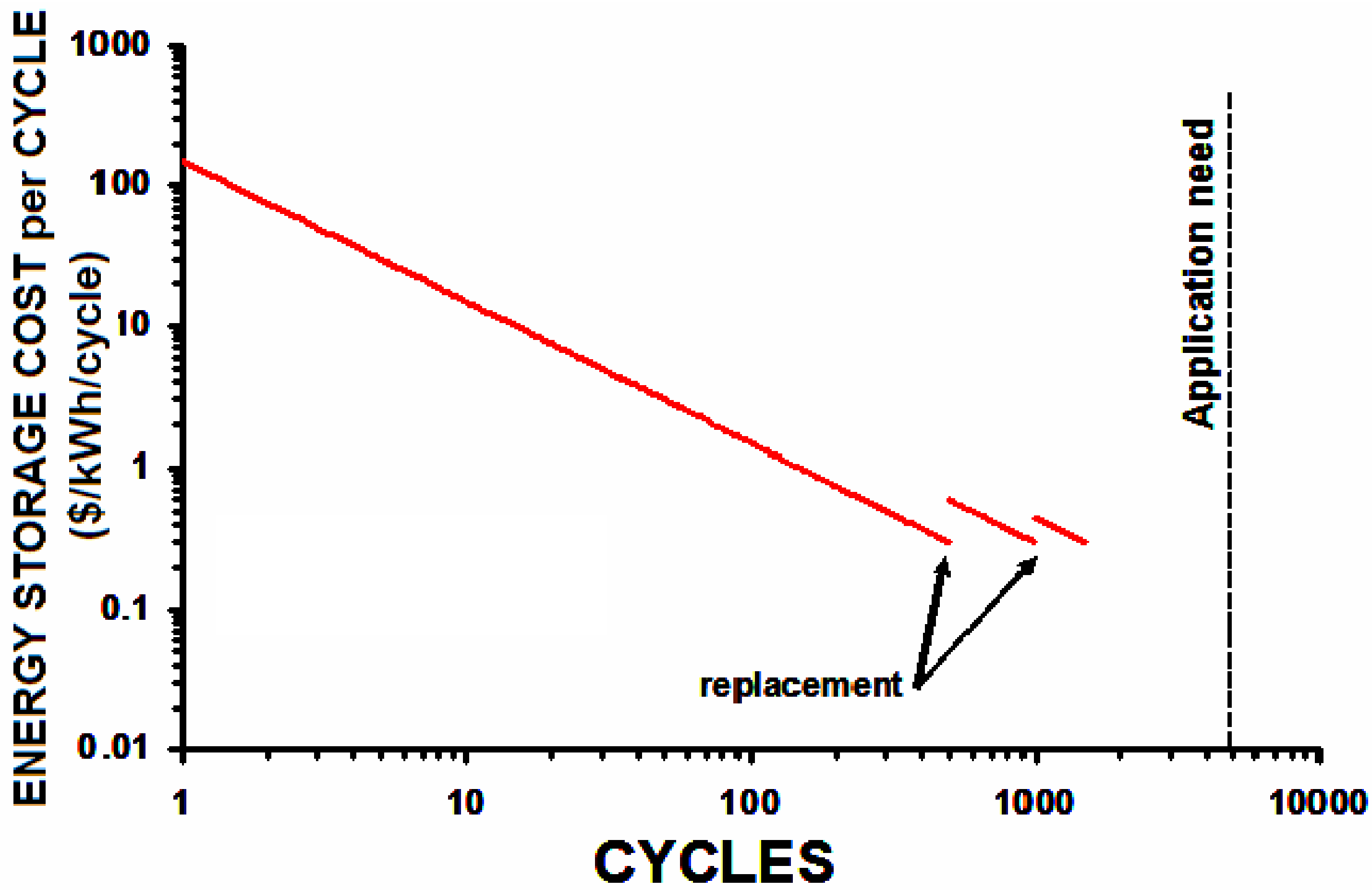
Storage Costs



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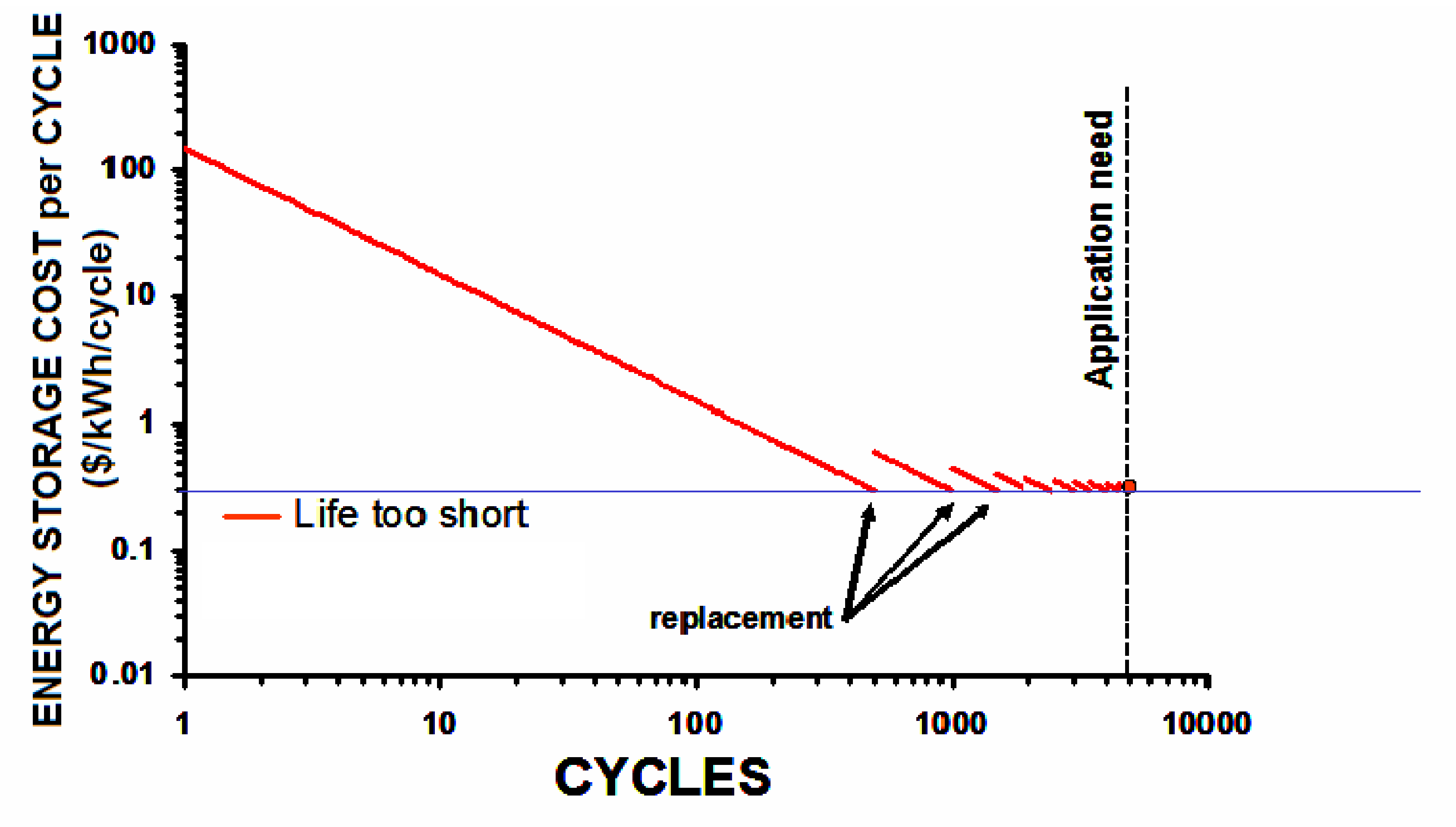

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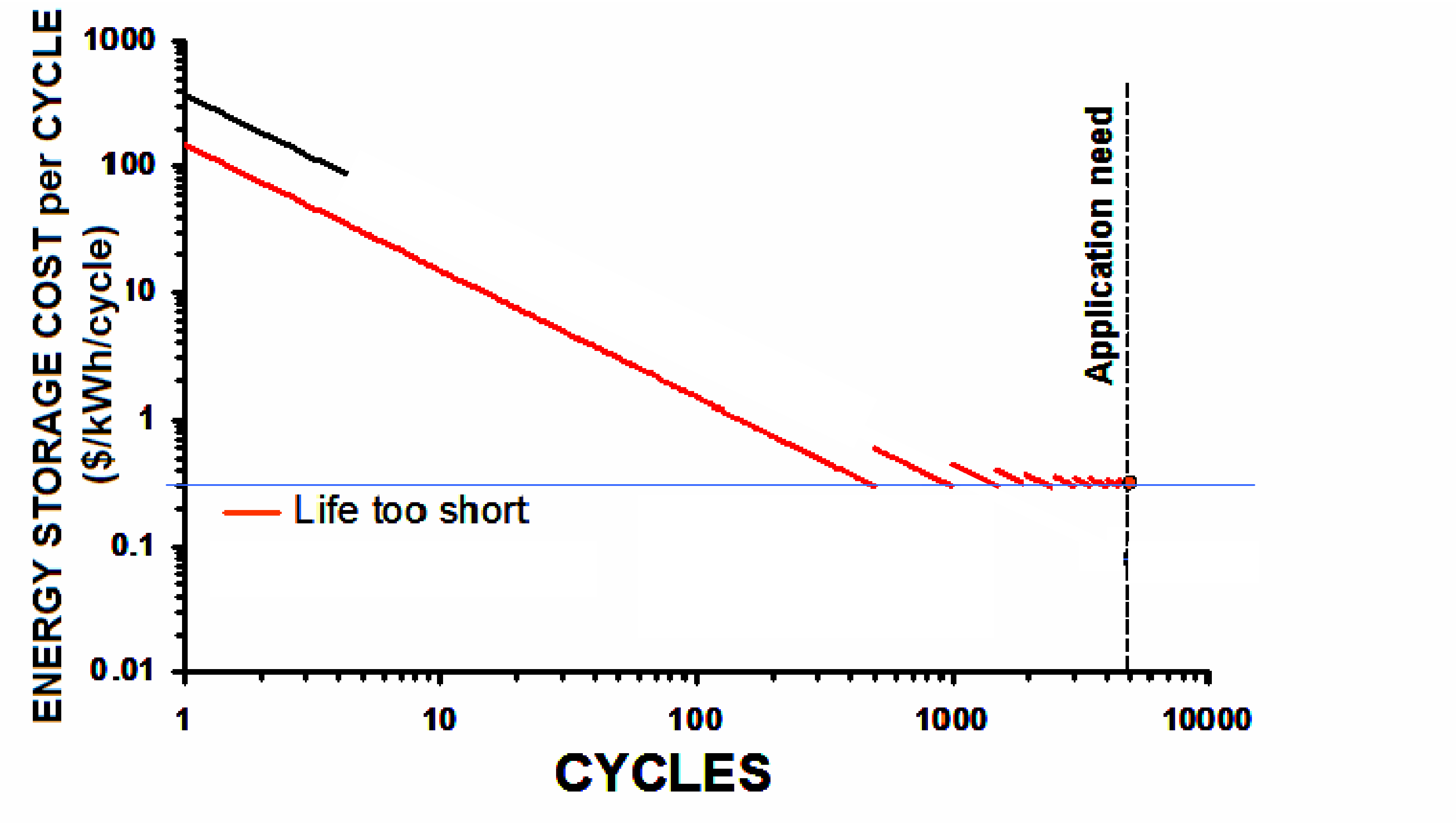

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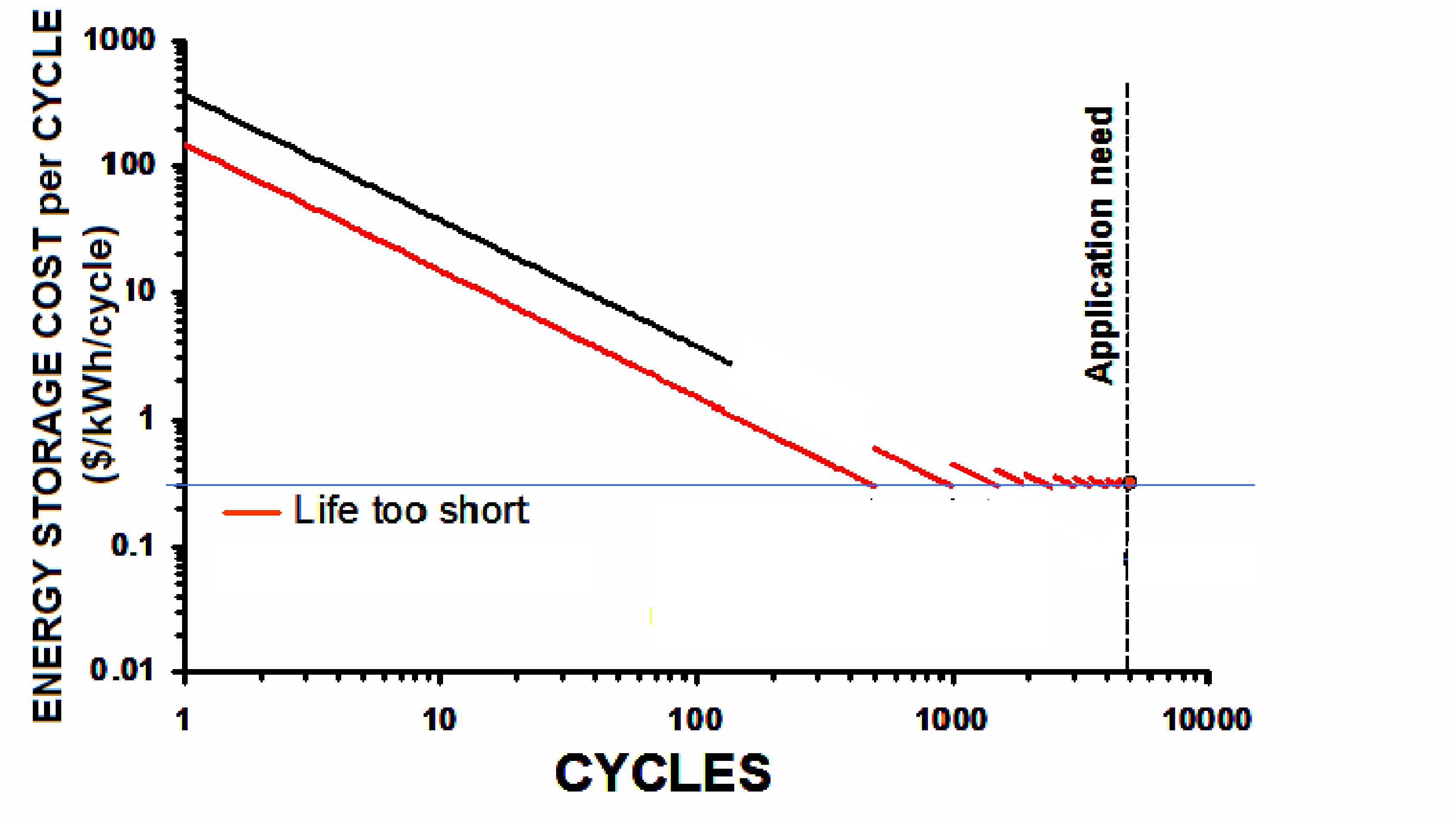

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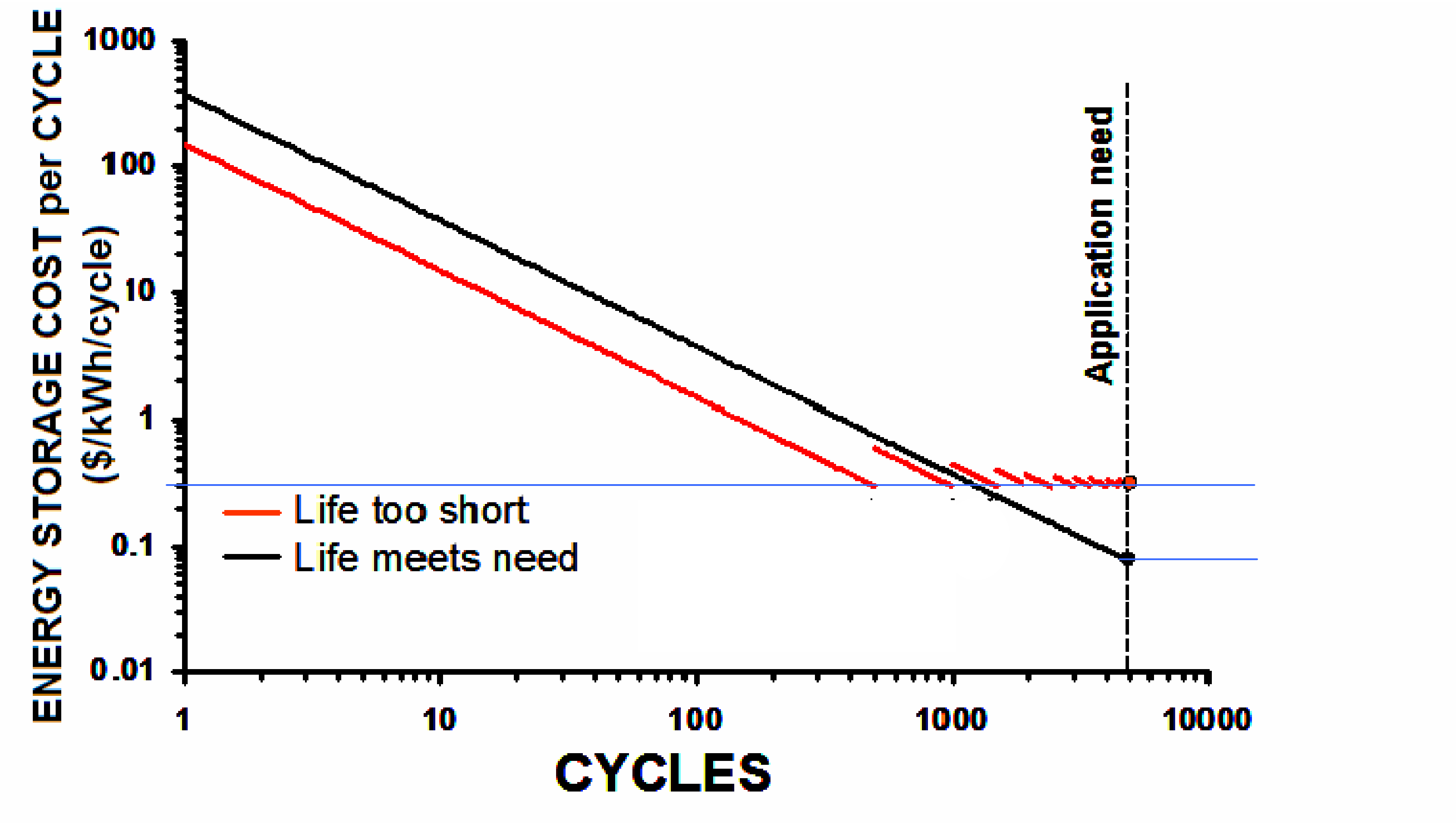

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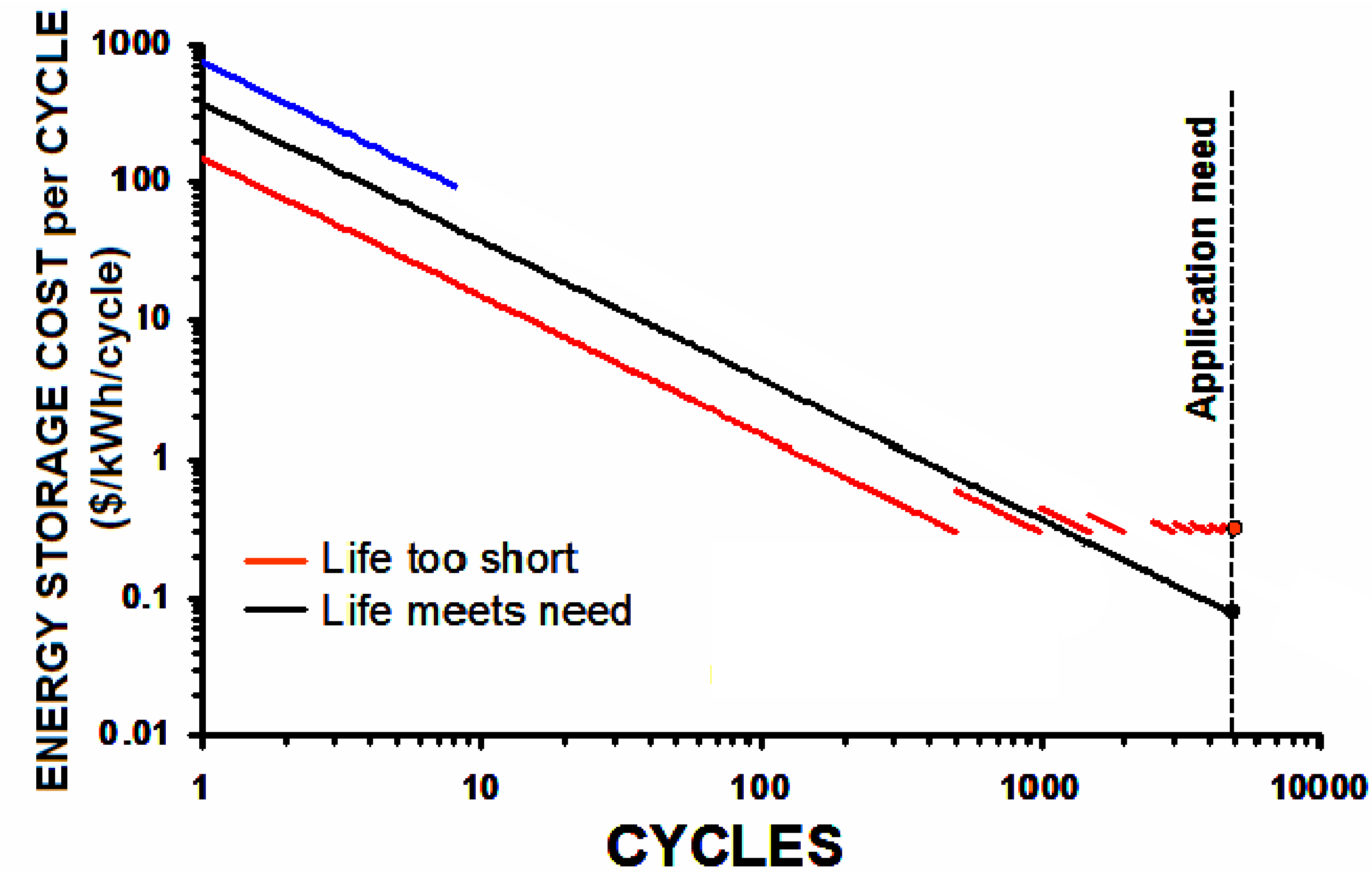

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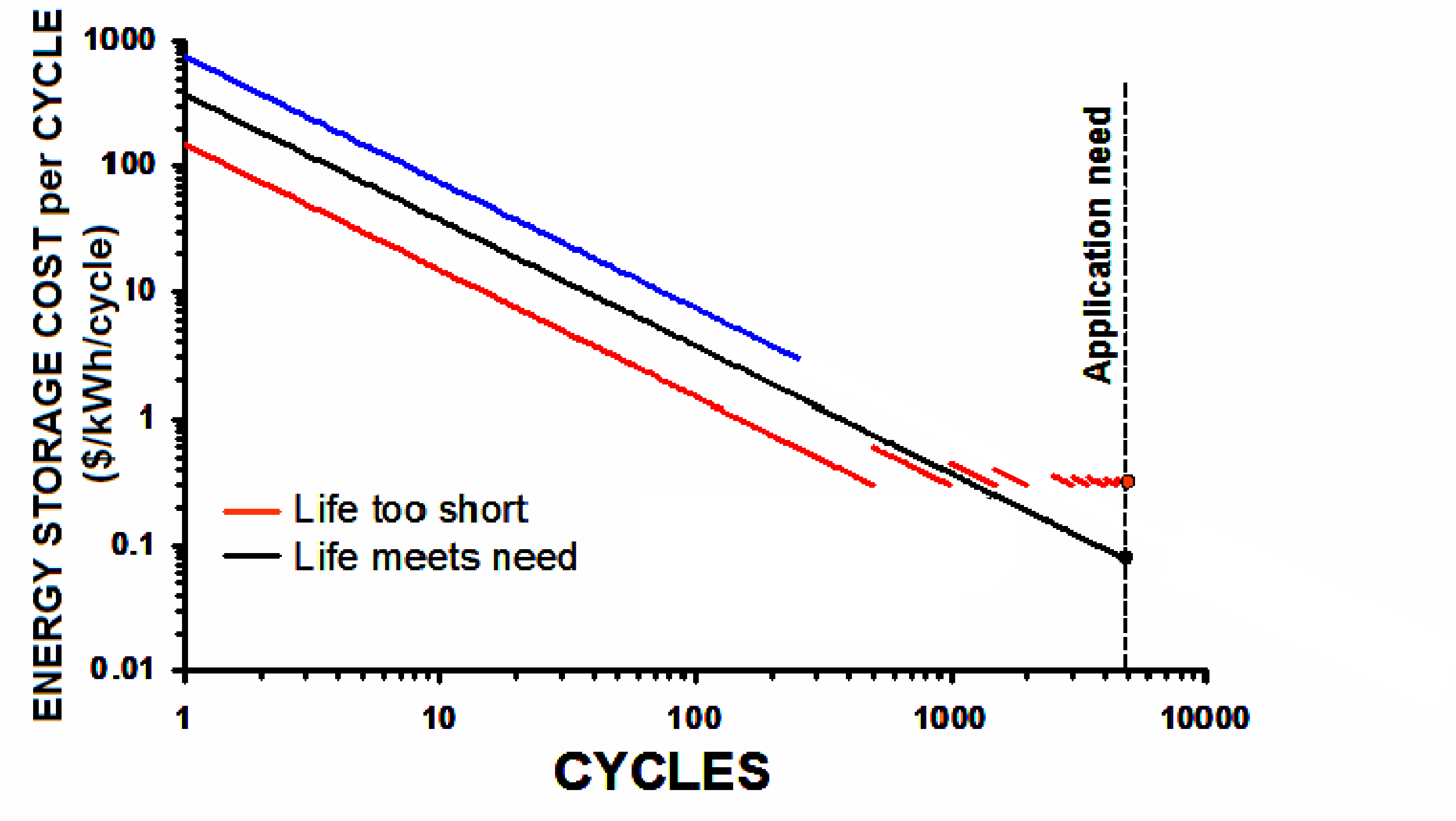

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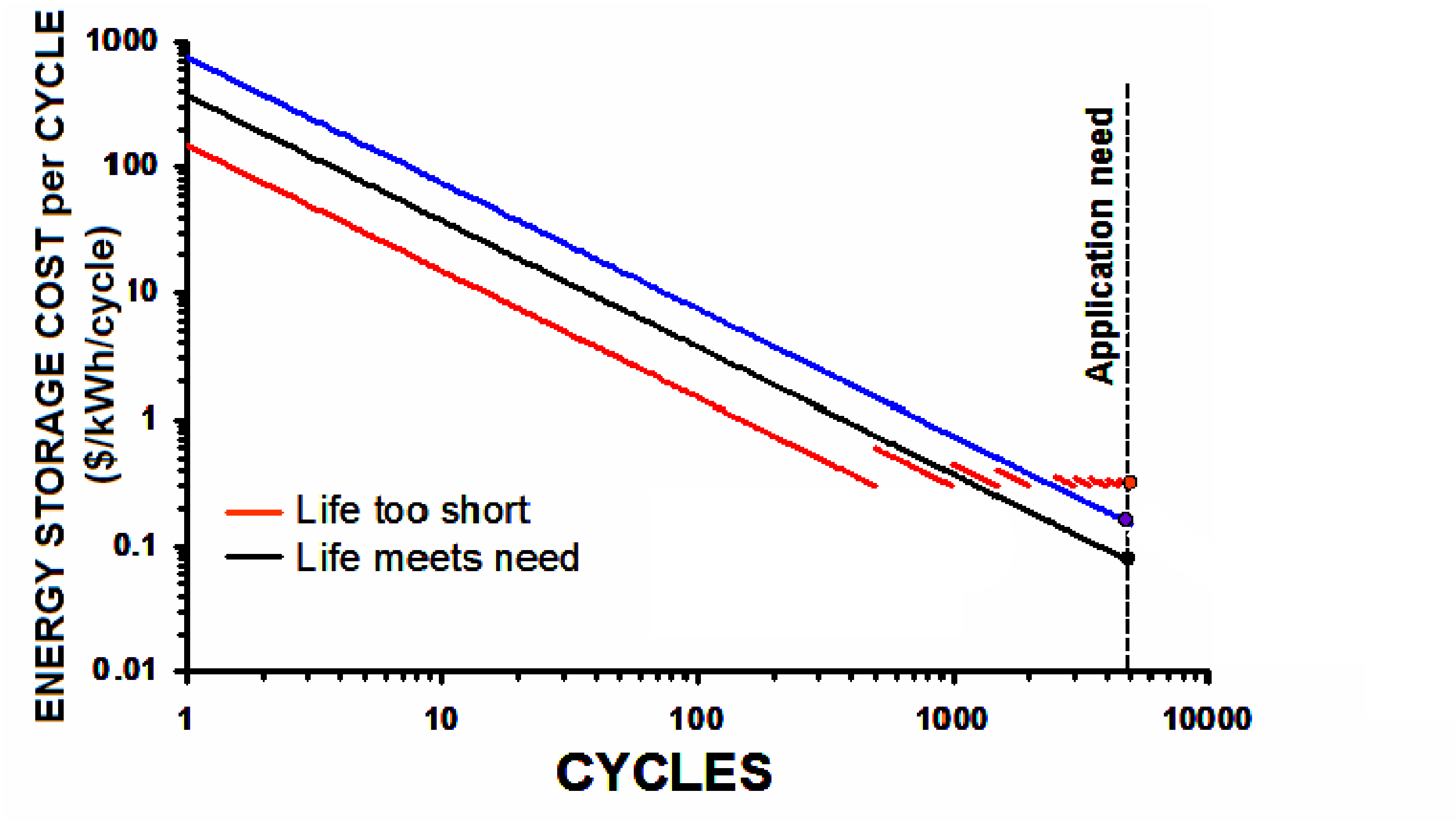

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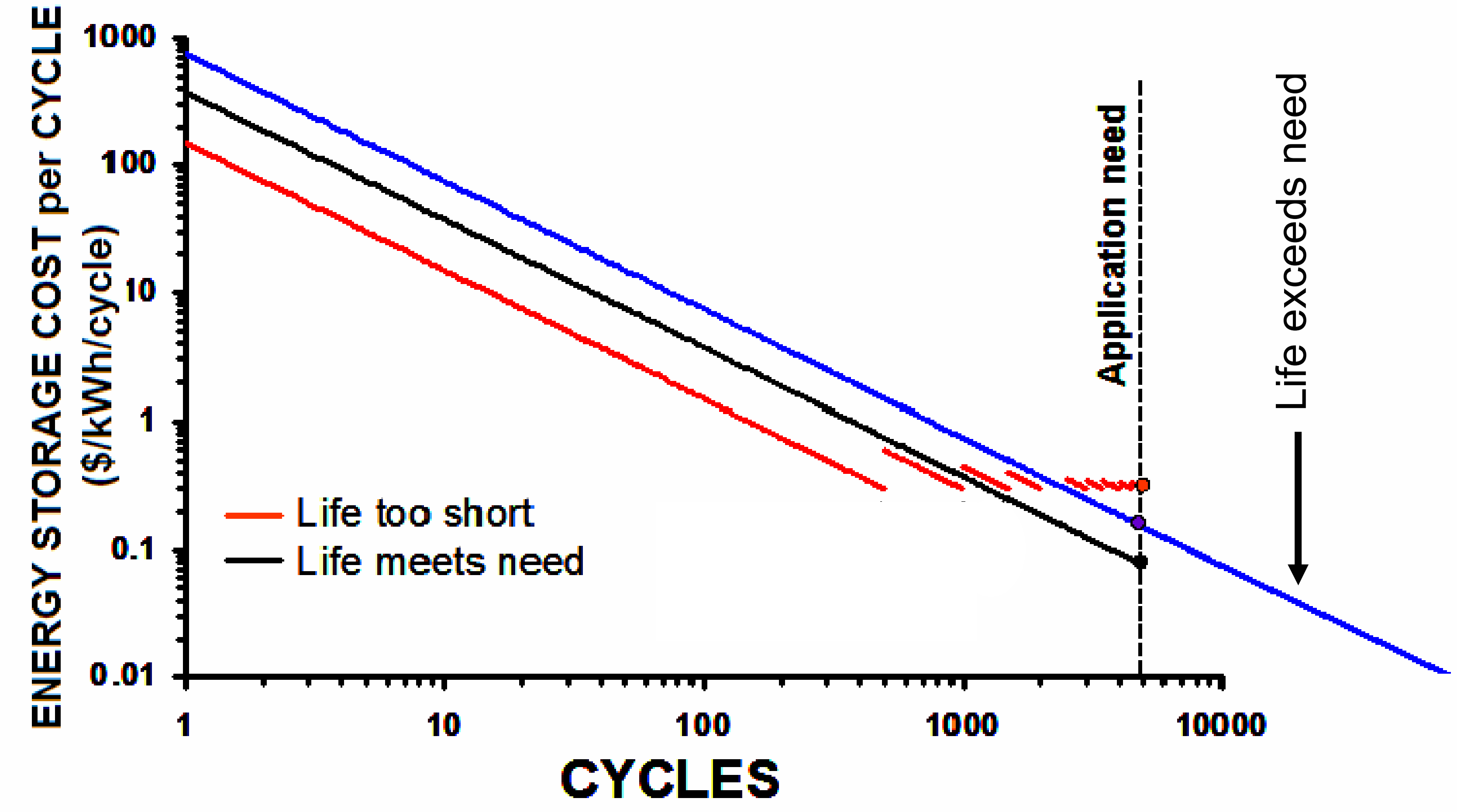

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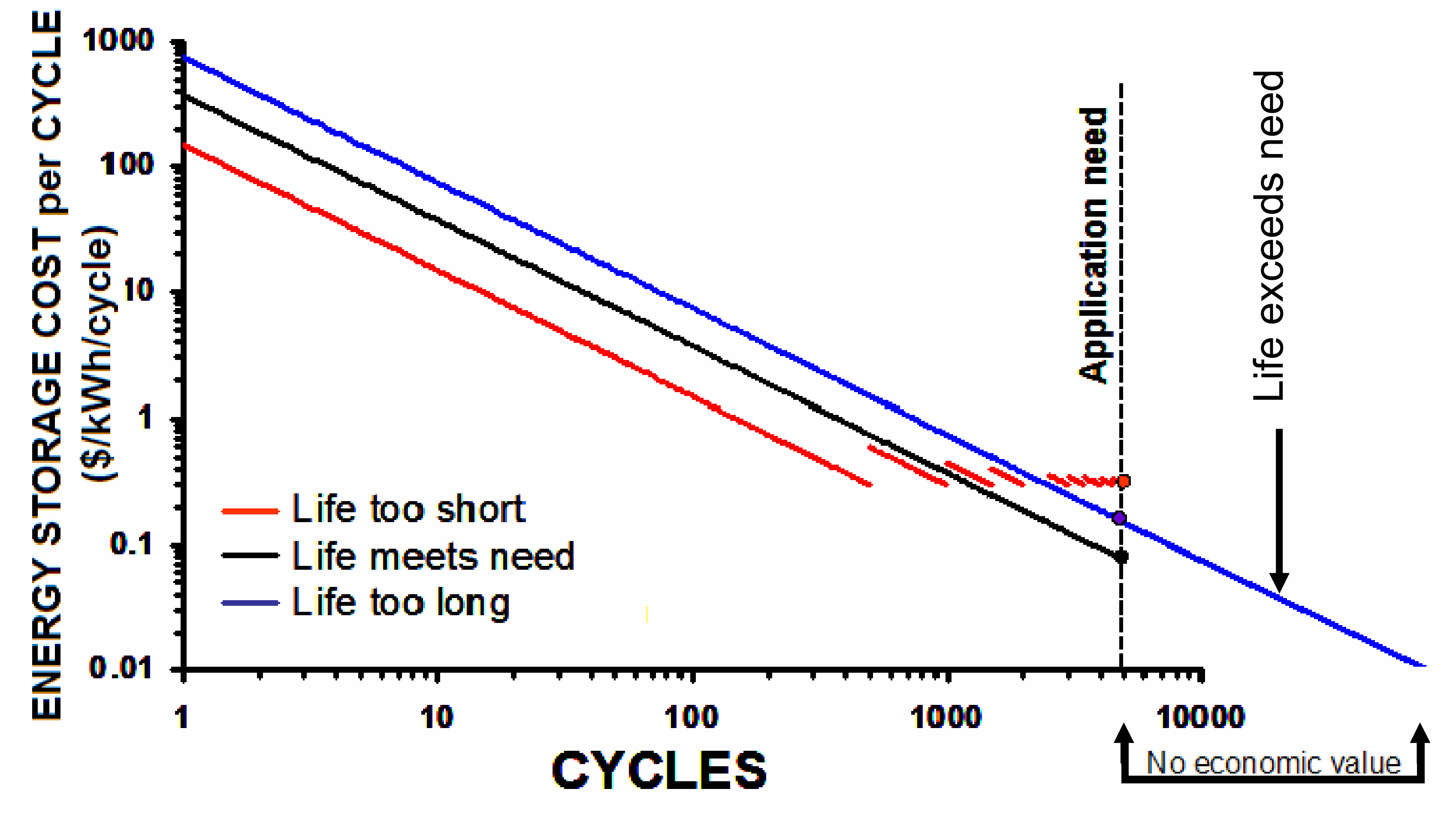

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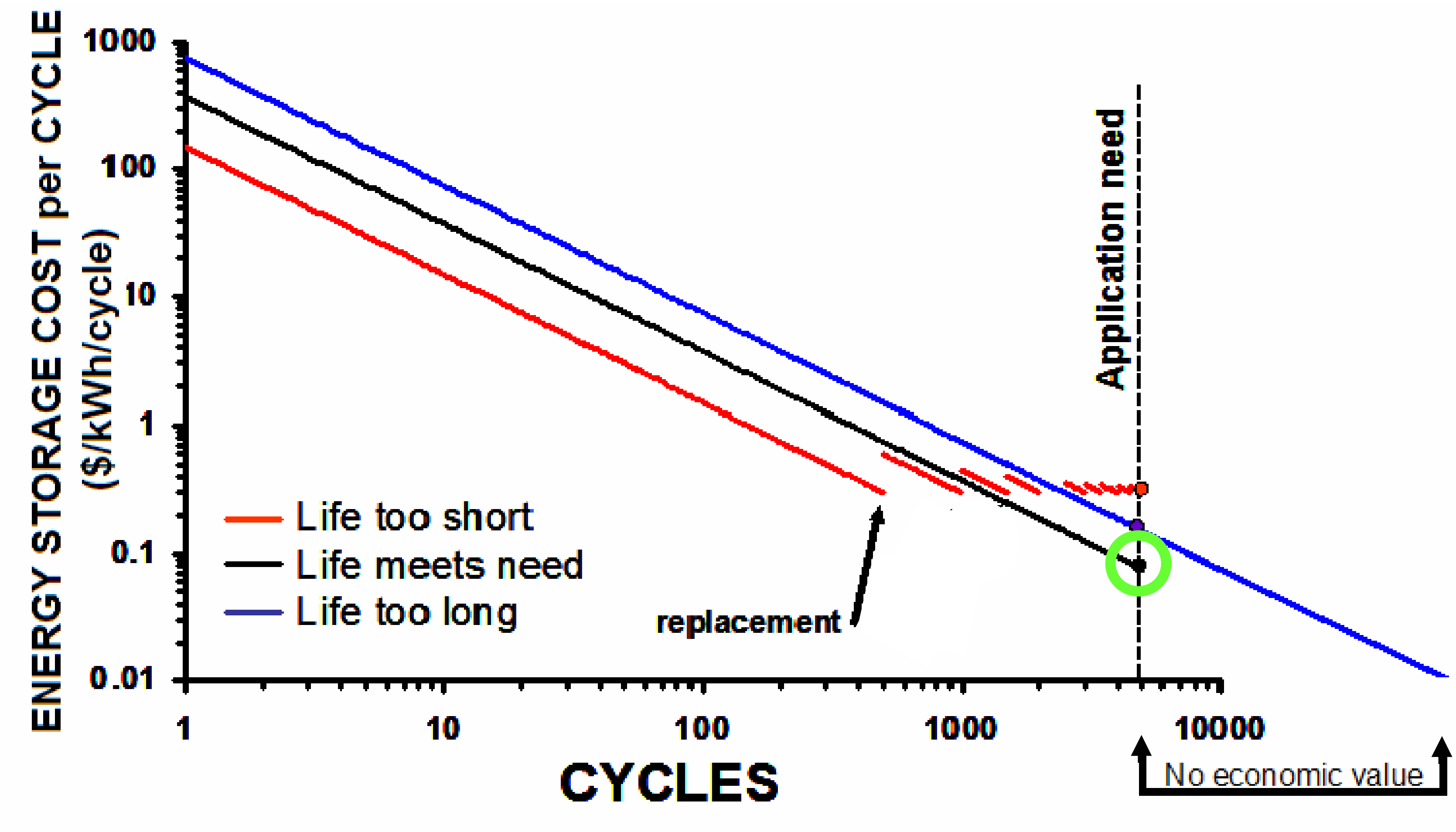
Minimum Storage Costs achieved when:
"Storage System Life" = "Application Need"



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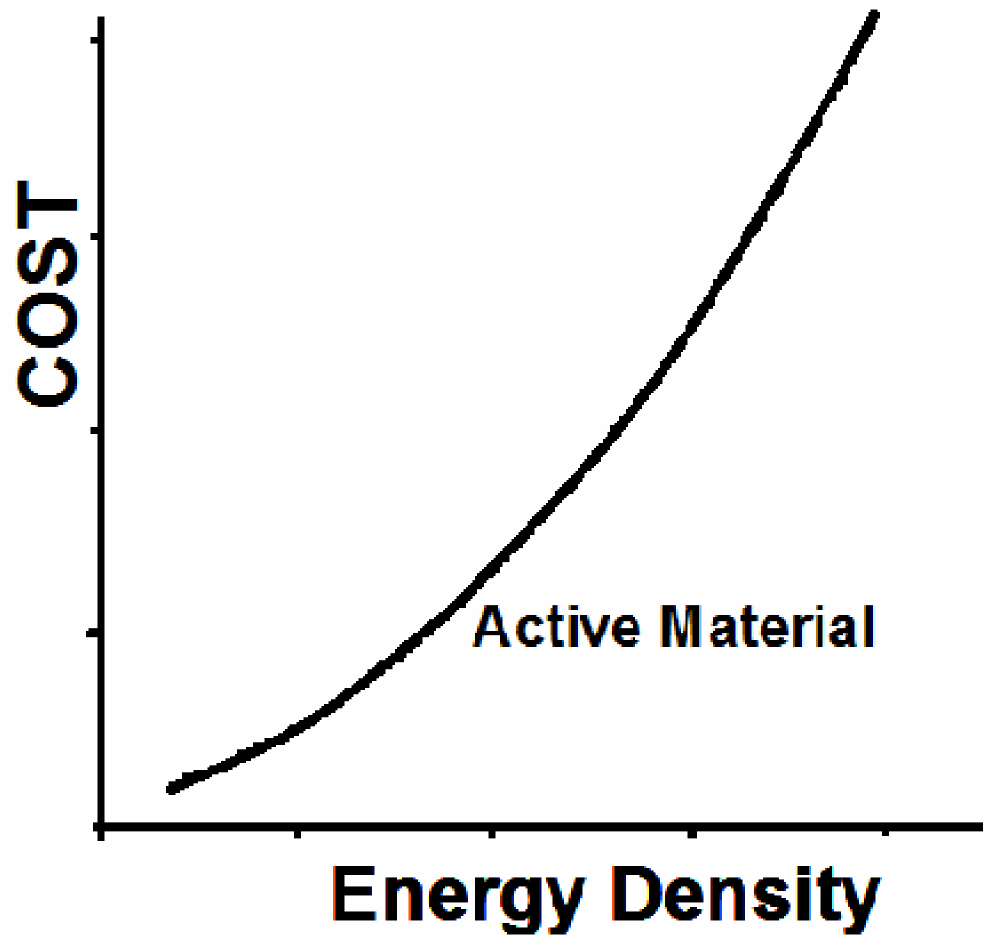
Grid Storage



Active materials
Electrode
Electrolyte

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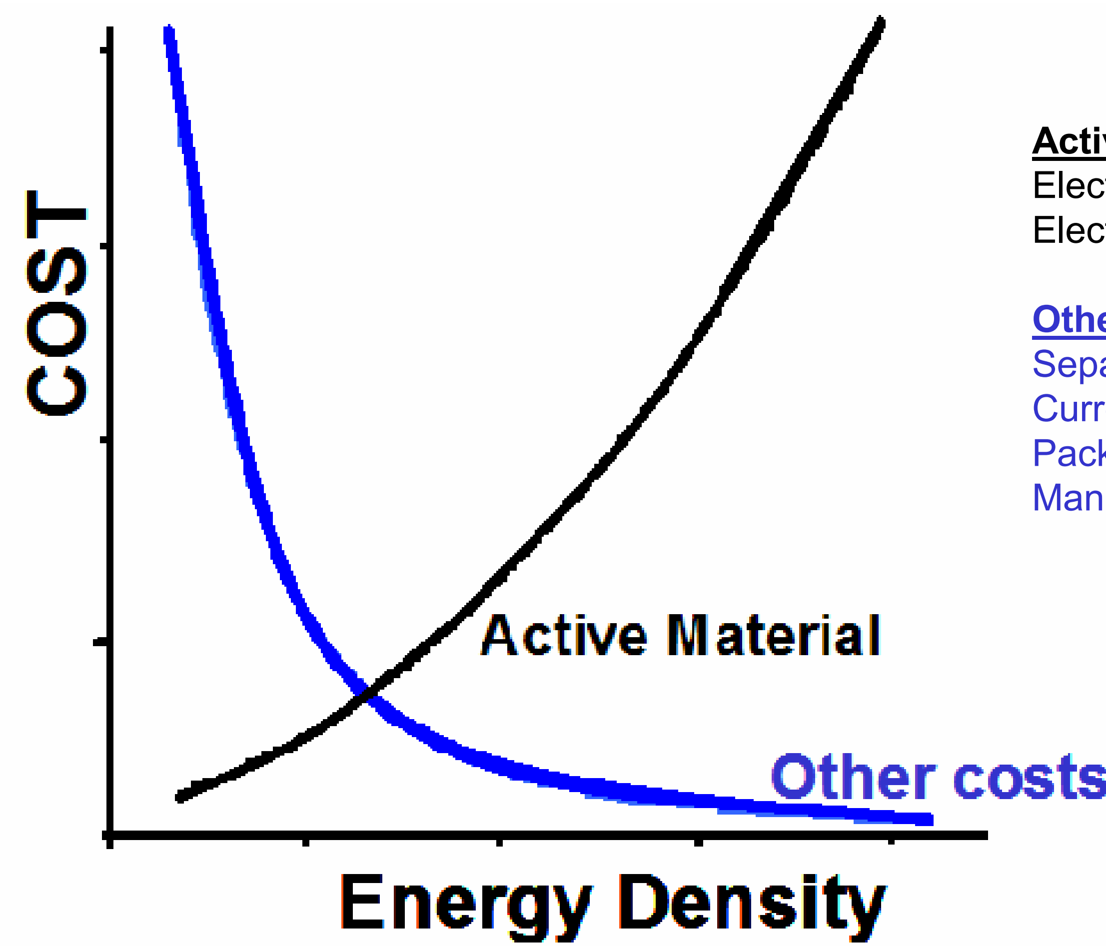
Grid Storage



Active materials
Electrode
Electrolyte

Other costs
Separator
Current collectors
Package
Manufacturing

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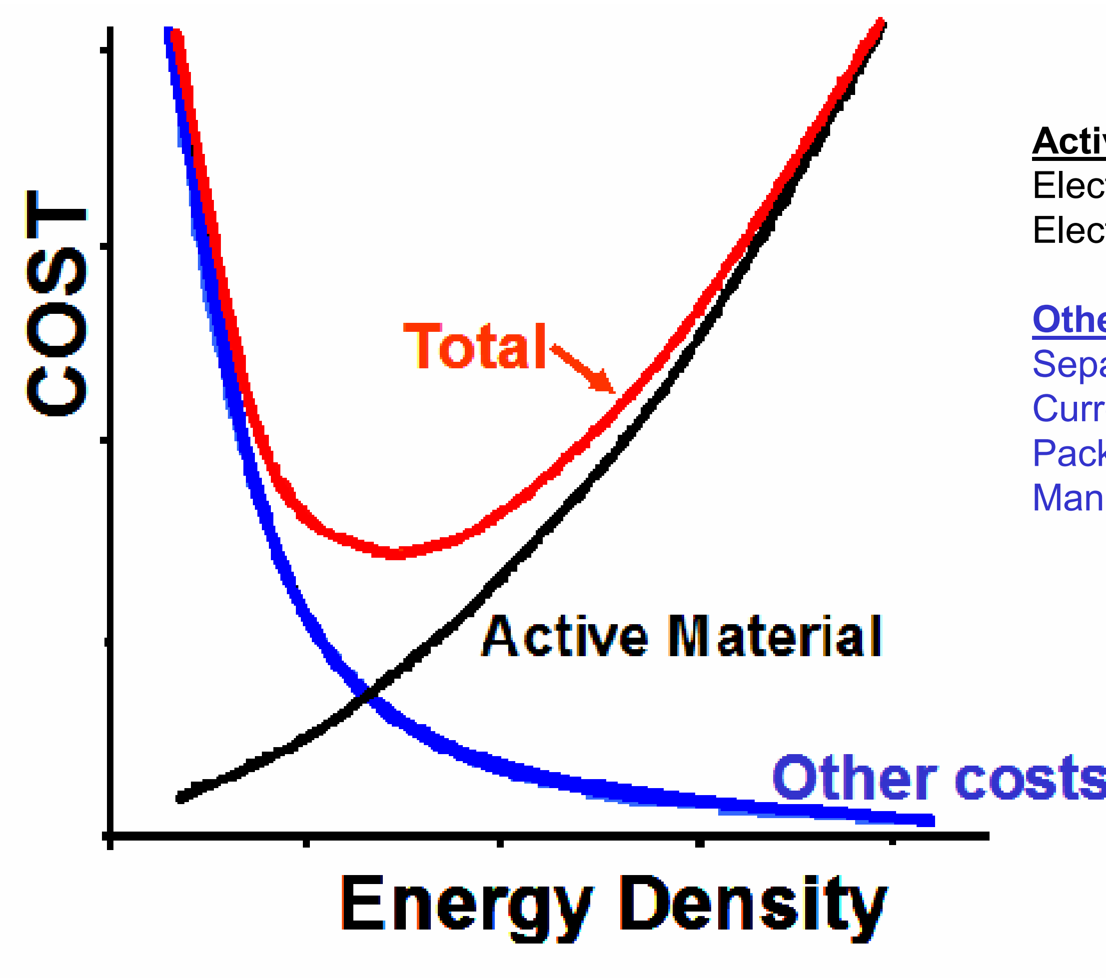
Grid Storage



Active materials
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Other costs
Separator
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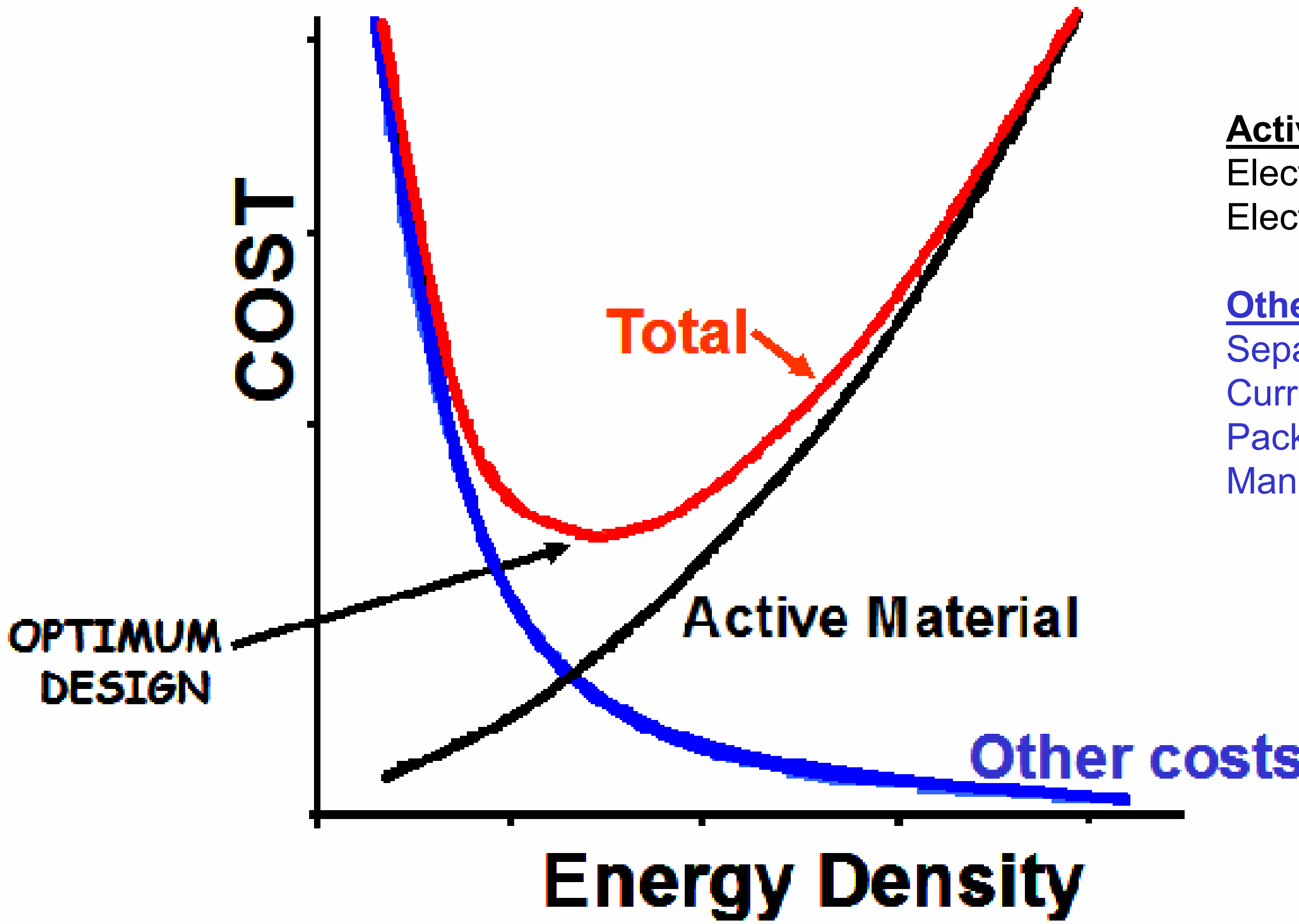
Optimum Grid Storage Will Not Have Highest Energy Density



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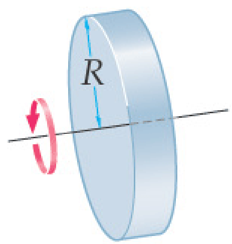
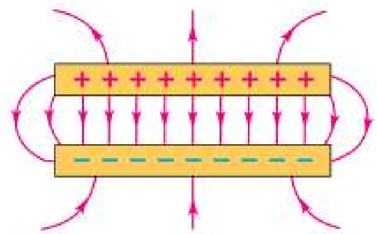
INHERENT ADVANTAGES GAINED USING

Storage That Relies on Physical Processes

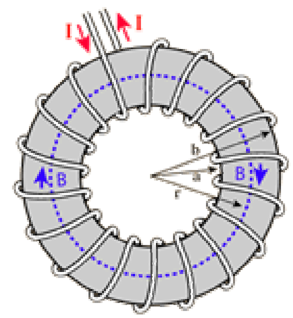
Gravity



Kinetic Energy



Electric Field



Magnetic Field

Mechanical

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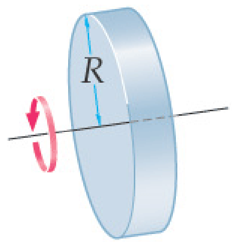
INHERENT ADVANTAGES GAINED USING

Storage That Relies on Physical Processes

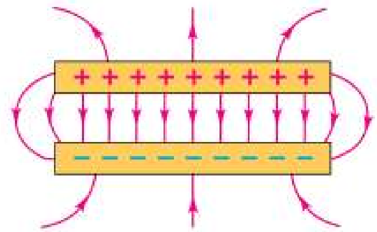
Gravity

Pumped Hydro



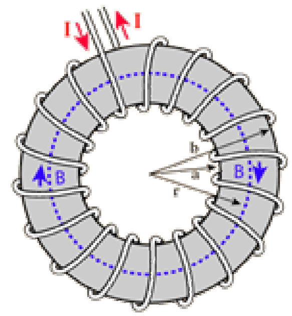
Kinetic Energy

Flywheel



Electric Field

Capacitor



Magnetic Field

SMES

Mechanical

CAES

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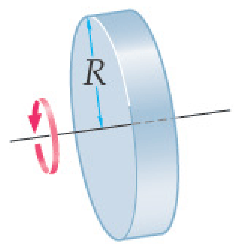
Storage That Relies on Physical Processes

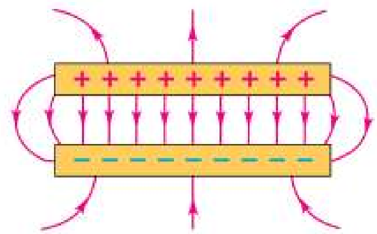
Gravity

Pumped Hydro



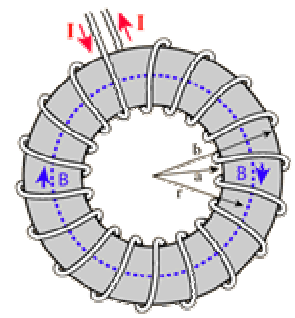
Kinetic Energy

Flywheel



Electric Field

Capacitor



Magnetic Field

SMES

Mechanical

CAES

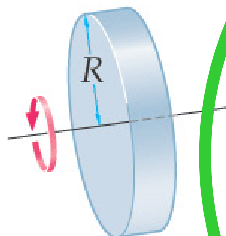
- High efficiency
- Long life (highly reversible)
- Good reliability
- Small temperature effects
- End-of-life waste stream
- Generally safe

INHERENT ADVANTAGES GAINED USING

Storage That Relies on Physical Processes

Gravity

Pumped Hydro



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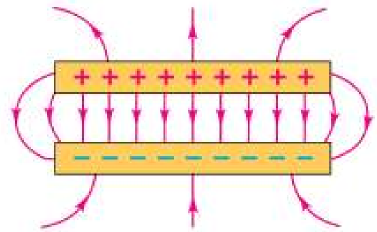

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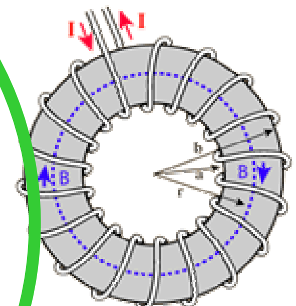

Magnetic Field

SMES

Mechanical

CAES

No moving parts

Essentially no maintenance

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Capacitors do not Necessarily Discharge Instantly

~1995 ESMA Bus

30 MJ, 190 V Capacitor Bank

15 km range, 15 minute charge

Circle route operation in large Moscow park

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Capacitors do not Necessarily Discharge Instantly

~1995 ESMA Bus

30 MJ, 190 V Capacitor Bank

15 km range, 15 minute charge

Circle route operation in large Moscow park

2010 Shanghai Bus

100% capacitor power

few km range, 20 s charge

Shanghai bus route #11

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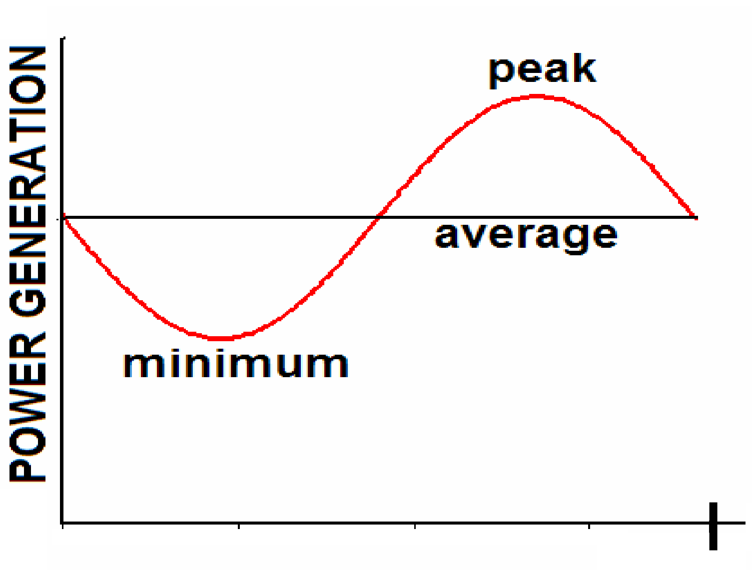
CAPACITOR STORAGE APPLICATION

TIME SHIFTING—DAY/NIGHT STORAGE



24 hours

NO STORAGE

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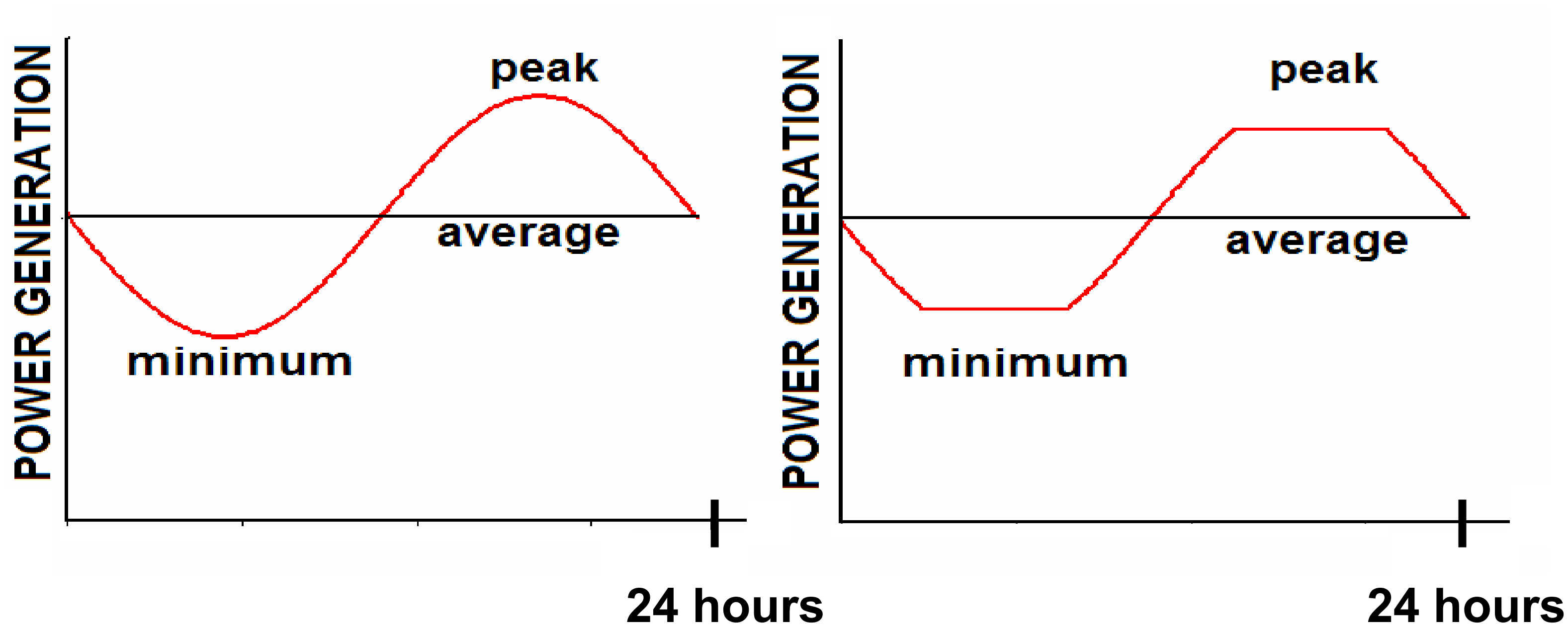
CAPACITOR STORAGE APPLICATION

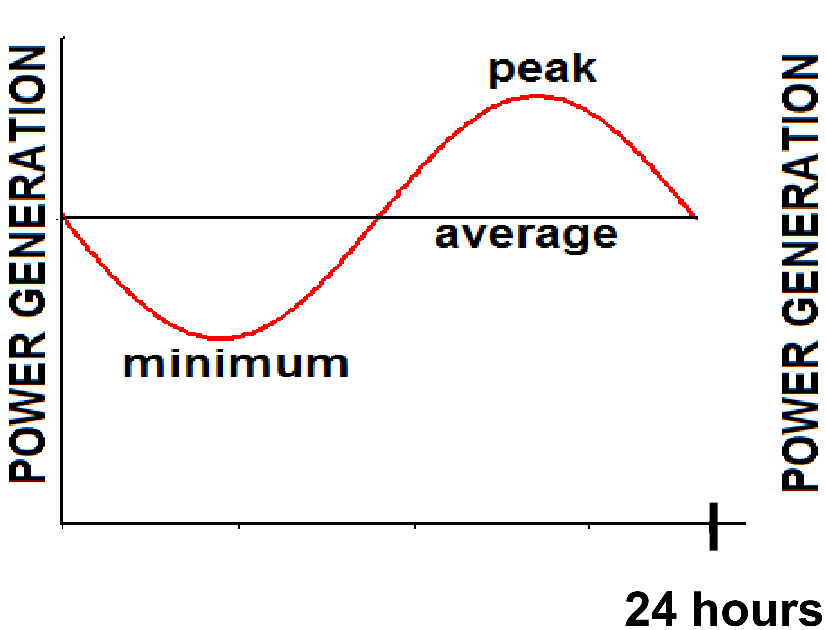
TIME SHIFTING—DAY/NIGHT STORAGE



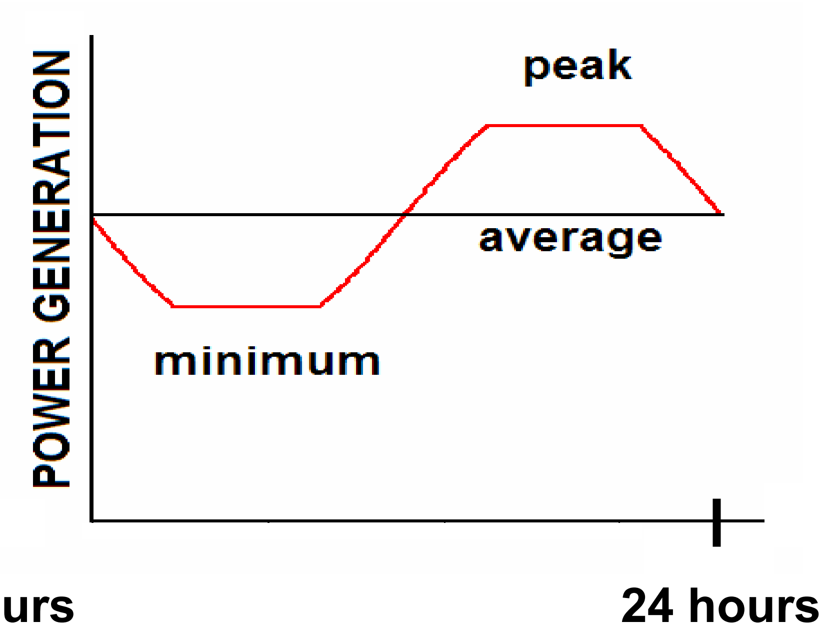
NO STORAGE **WITH STORAGE**

CAPACITOR STORAGE APPLICATION

TIME SHIFTING—DAY/NIGHT STORAGE



NO STORAGE



WITH STORAGE

20 years at 1 cycle per day, five days per week requires ~5000 cycles

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Capacitor Technology for Bulk Energy Storage

Available today! Breakthrough discovers not needed.

Capacitor Technology for Bulk Energy Storage

- **Available today!** Breakthrough discovers not needed.
- Engineering development and implementation underway

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Capacitor Technology for Bulk Energy Storage

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- Asymmetric electrochemical capacitor design
  - first electrode activated carbon (natural source)-EDLC storage
  - second electrode Faradaic or pseudocapacitive storage
  - aqueous electrolyte
  - polymer package

Capacitor Technology for Bulk Energy Storage

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- Asymmetric electrochemical capacitor design
  - first electrode activated carbon (natural source)-EDLC storage
  - second electrode Faradaic or pseudocapacitive storage
  - aqueous electrolyte
  - polymer package
- Optimized for ~C/5 charge/discharge rate
- Cycle life is controlled by electrode capacity asymmetry ratio
- Typically designed for ~5000 cycles (100% DOD)
- Energy storage cost projections < $0.05/kWh/cycle

(Lead acid battery at 80% DOD ~$0.30/kWh/cycle)

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Cyclic Voltammogram of Carbon Electrode

Exceptional Charge Storage at Far Negative Potentials in Aqueous Electrolyte

Note all of the area (capacitance) that becomes available at very low potentials (<0 V SHE).

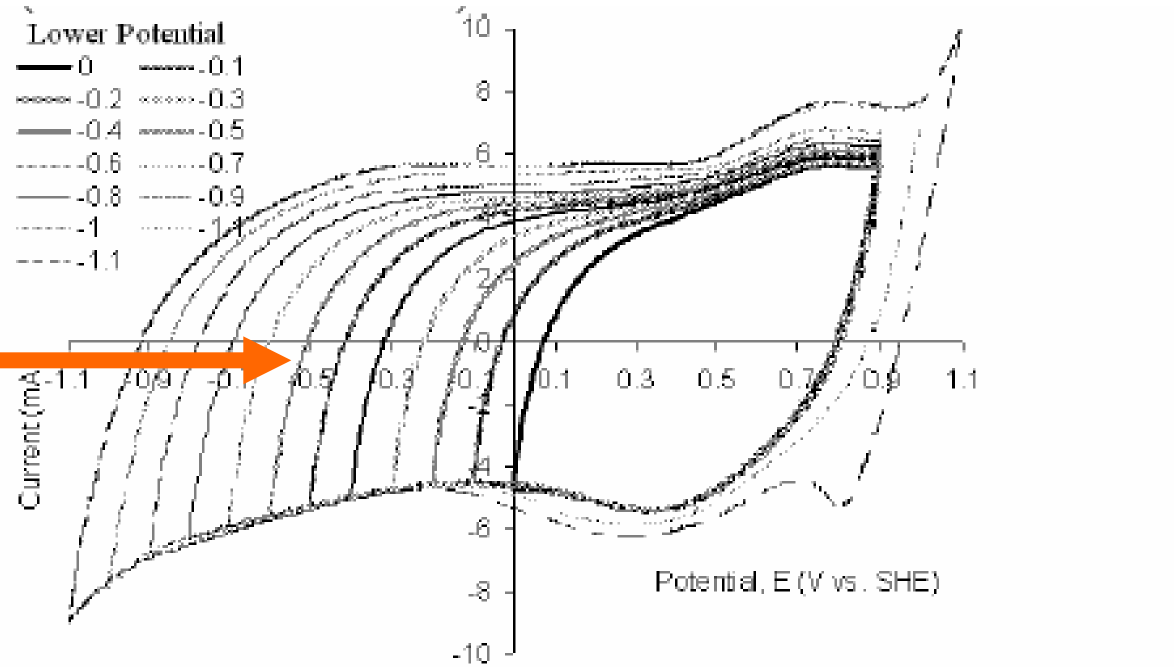

Figure 19: Series of CVs for the C-electrode in proprietary electrolyte BHW726C, successively scanned from 0.9 V (SHE) to progressively more negative reversal potentials out to -1.1 V (SHE). (Note the reversibility of the CV upon potential reversals.). Sweep-rate 10 mV s^{-1}.

Specific Ion Effects on Double-Layer Capacitance of a C-Cloth Electrode Showing Extended Charge Acceptance B.E. Conway, H. A. Andreas and W. G. Pell

Double Layer Capacitor Seminar, Deerfield Beach, FL, Dec. 6-8, 2004

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AQUION ENERGY

Jay Whitacre <jwhitacre@aquionenergy.com>

Aqueous Sodium Ion Asymmetric Energy Storage Device

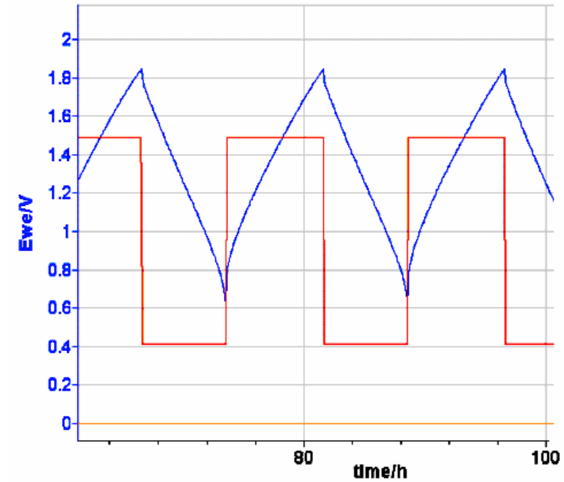
$NaMnO_2$-Na_2SO_4-C

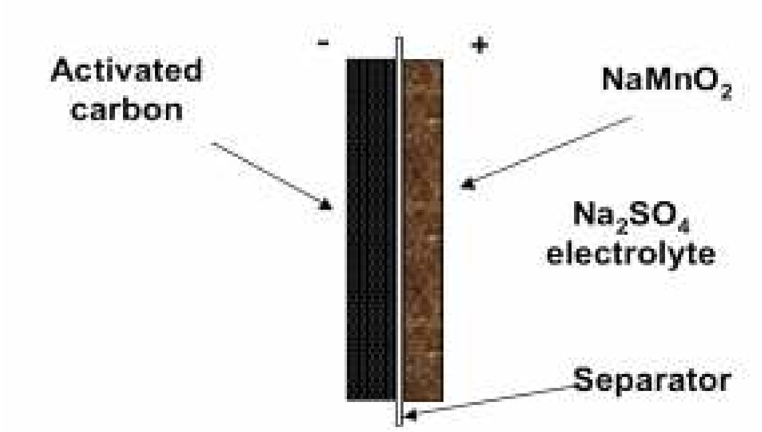
1.8 V sealed cell

High efficiency

Optimized for >4 hr charge/discharge rate

~30 Wh/liter





Early stage start-up company

DOE and VC support

Cost goal <$250/kWh

Storage costs @ 5000 cycles <$0.05/kWh

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MegaJoule Storage, Inc.

Herbert Crowther, <hcrowther@megajouleinc.com>

PbO_2-H_2SO_4-C

2 V sealed cells

>70% energy efficiency

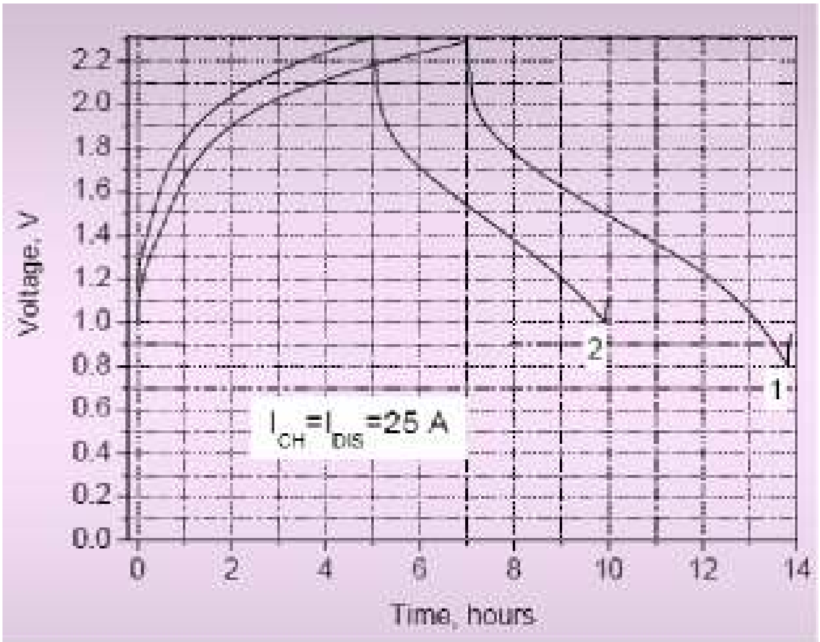
Optimized for C/5 operation

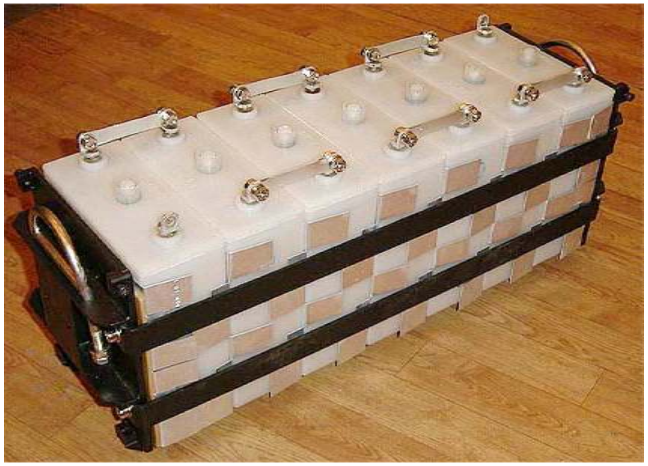
~50 Wh/liter

5000 cycle design

Recyclable materials

Natural cell voltage balance claimed





7 Cell Module (35"L x 7" W x 11"H)

Early stage start-up company

Cost projections <$200/kWh

Storage costs @ 5000 cycles <$0.05/kWh

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Decommissioned Power Plant

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Decommissioned Power Plants could be filled with Capacitors

- Store significant quantities of energy
- Transmission switchyards often intact
- Extends life of capital investment
- Promotes removal of inefficient plants
- Permitting should not be difficult

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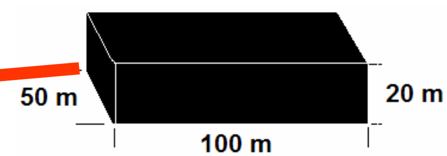

50m x 100m x 20m = 100,000 m^3

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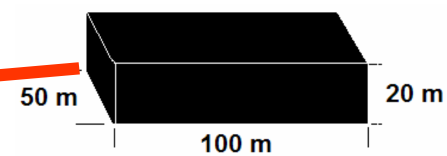
Decommissioned Power Plants could be filled with Capacitors

Note:

- Significant quantities of energy stored
- Transmission switchyards often intact
- Extends life of capital investment
- Promotes removal of inefficient plants
- Permitting should not be difficult



50m x 100m x 20m = **100,000 m^3**

Pb-C capacitor: **50 Wh/l** = 50 kWh/m^3

$\Rightarrow$ 100,000 m^3 storage volume could deliver **5,000** MWh of electricity

i.e. 1000 MW for 5 hours

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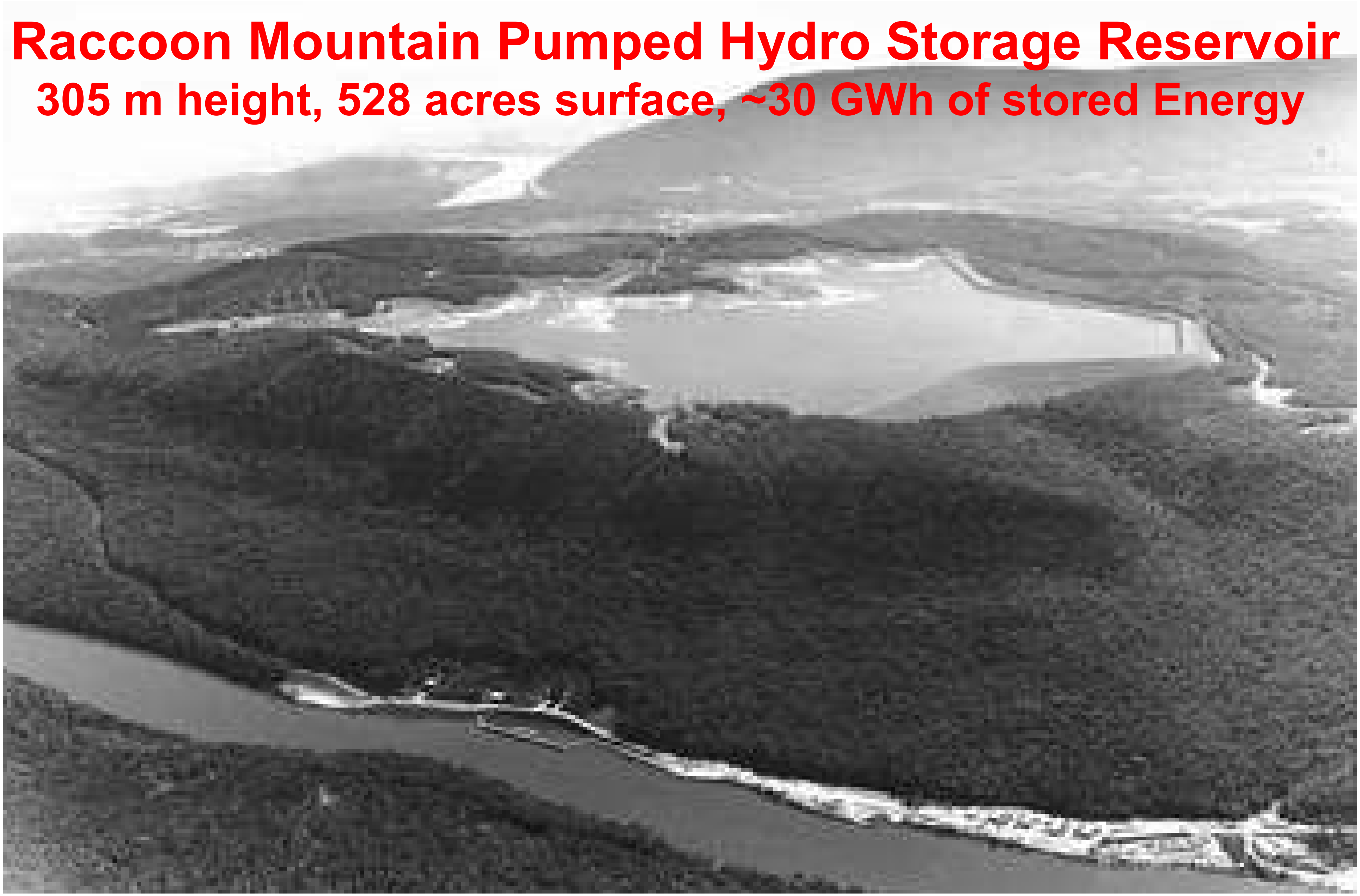
Raccoon Mountain Pumped Hydro Storage Reservoir

305 m height, 528 acres surface, ~30 GWh of stored Energy



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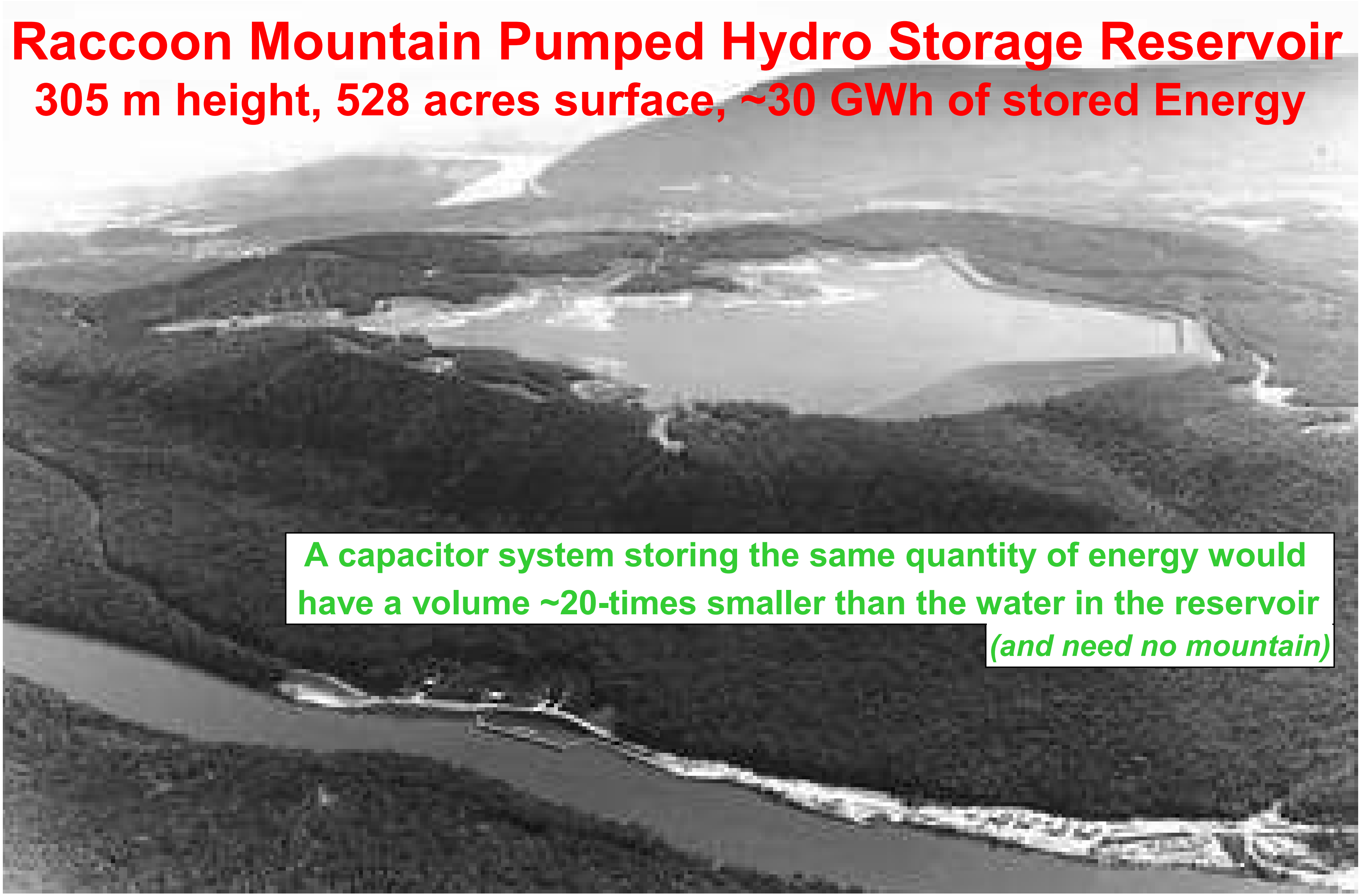

A capacitor system storing the same quantity of energy would have a volume ~20-times smaller than the water in the reservoir

(and need no mountain)

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Summary: Capacitors for Power Grid Storage

- **($/kWh/cycle)** or **($/kWh/year)** are the **important metrics** (not energy density)
- Lowest cost achieved when **"Storage System Life" = "Application Need"**
- Optimum grid storage will generally **not have the highest energy density**
- Storage that relies on **physical processes offers notable advantages**

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- Lowest cost achieved when **“Storage System Life” = “Application Need”**
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