Negotiating With Batteries: The Unfortunate Tetrahedron

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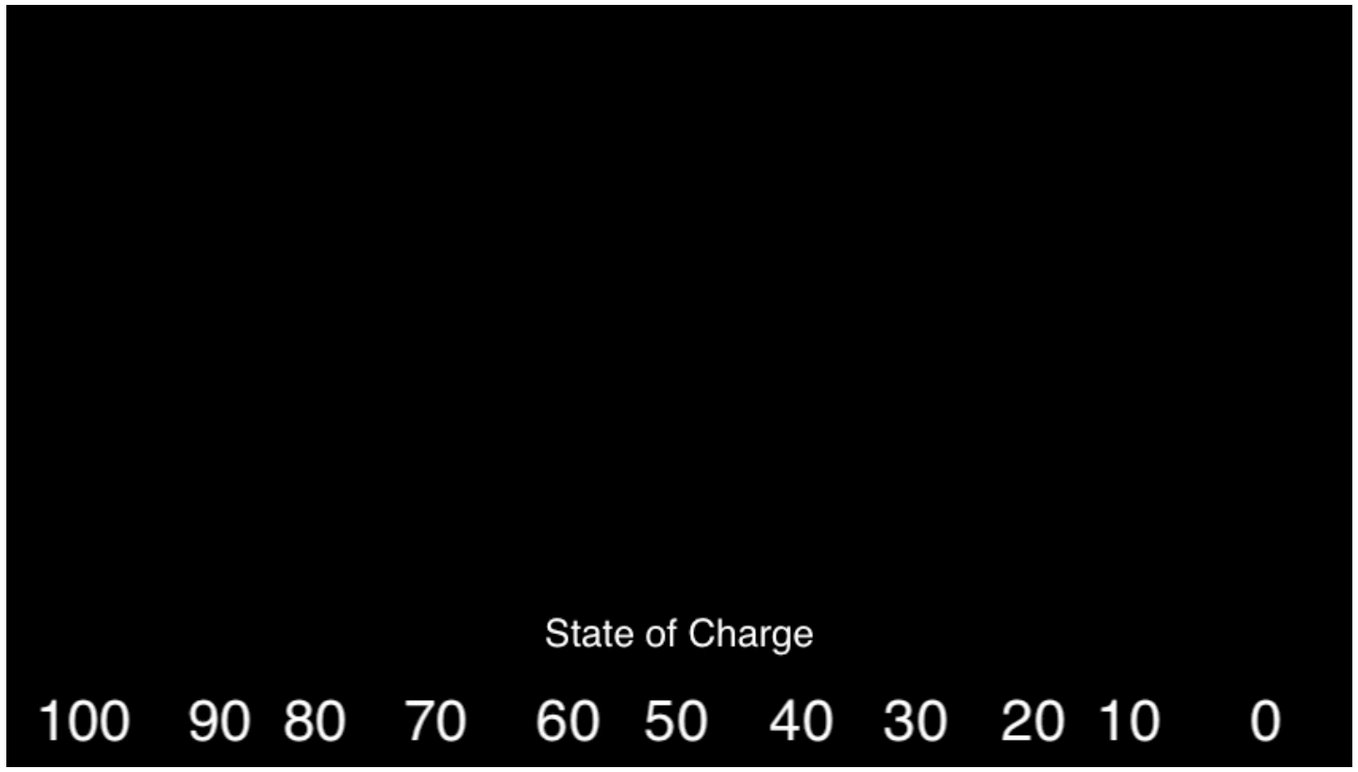
LESC 2017

Brief Introduction To Me

If a battery falls does it make a sound?



(Yes and it's really telling)

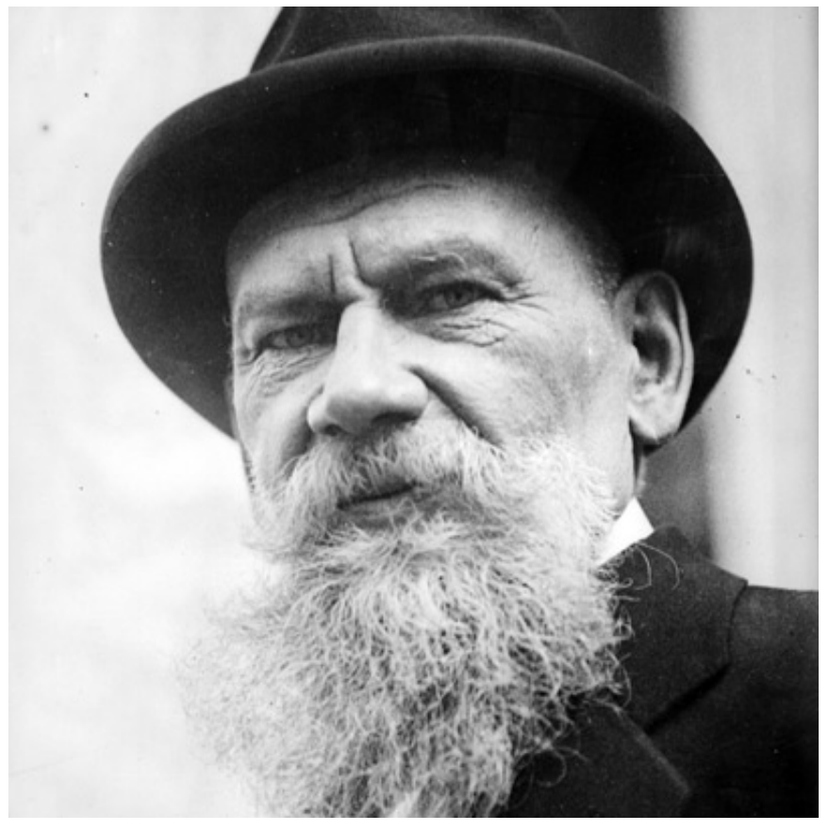
Can a battery constantly short circuit and not kill us?

(Yes and it opens up new designs)

My group studies and exploits systemic behaviors in batteries

Tolstoy On Batteries

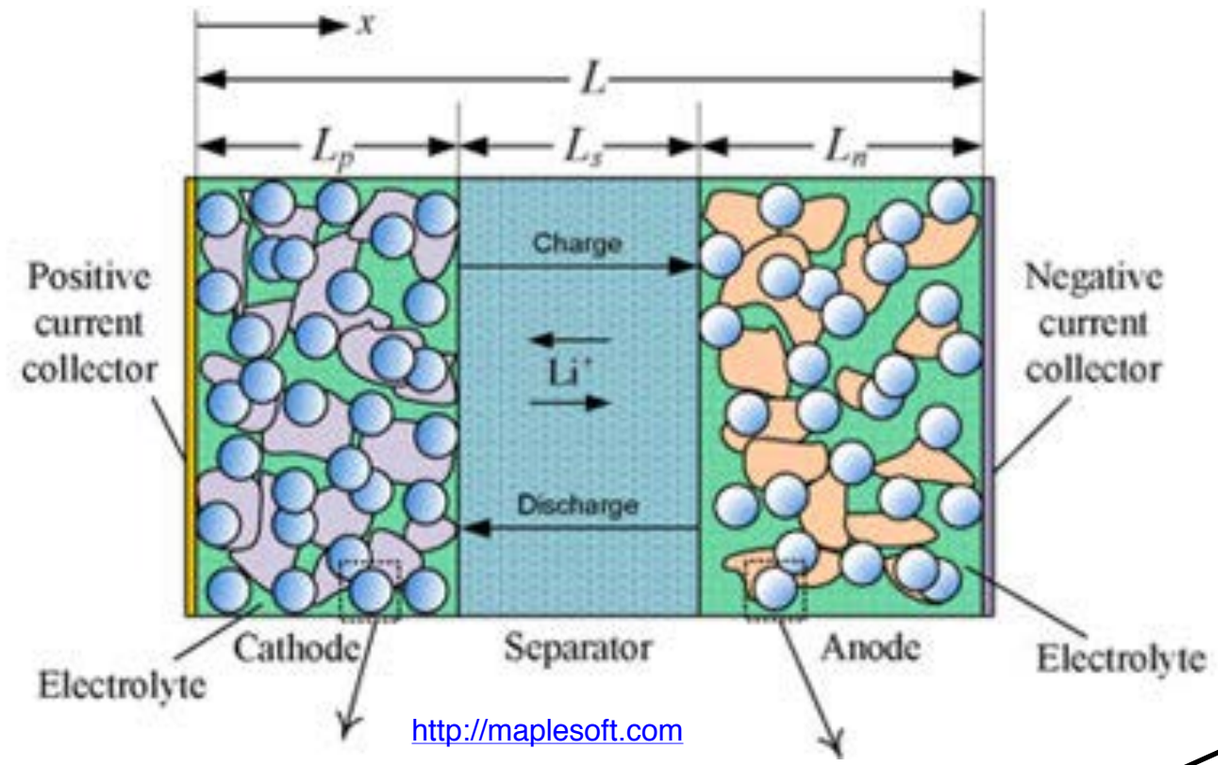
“All happy families are alike;
each unhappy family is
unhappy in its own way”



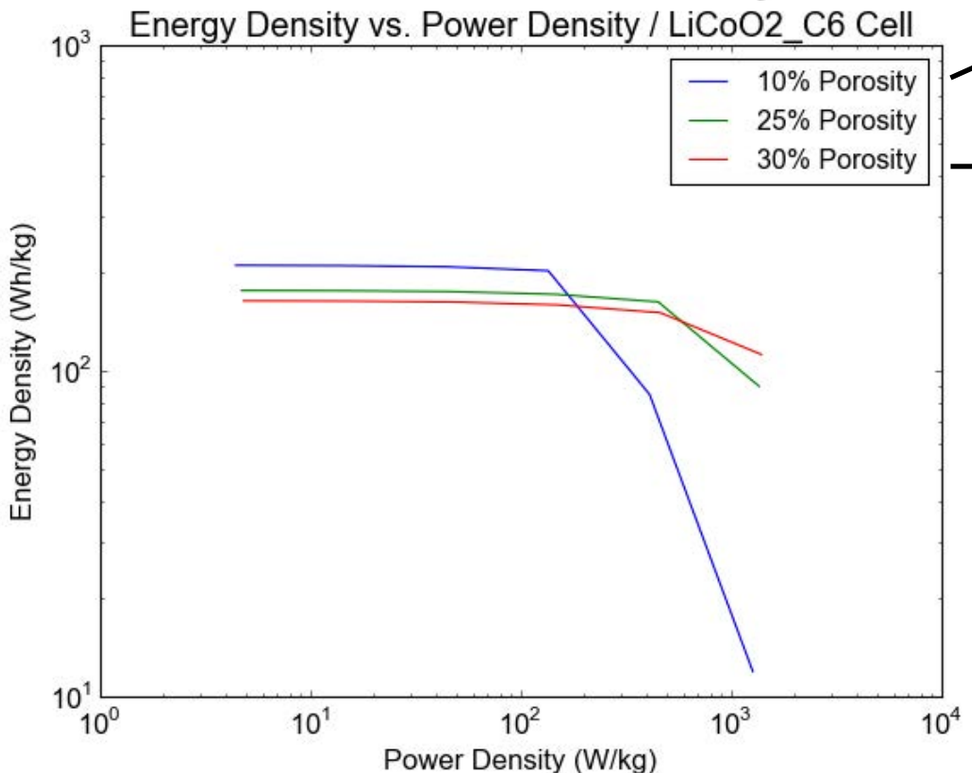
“If you look for perfection,
you'll never be content”

“Anything is better than lies and deceit!”

The Original Compromise

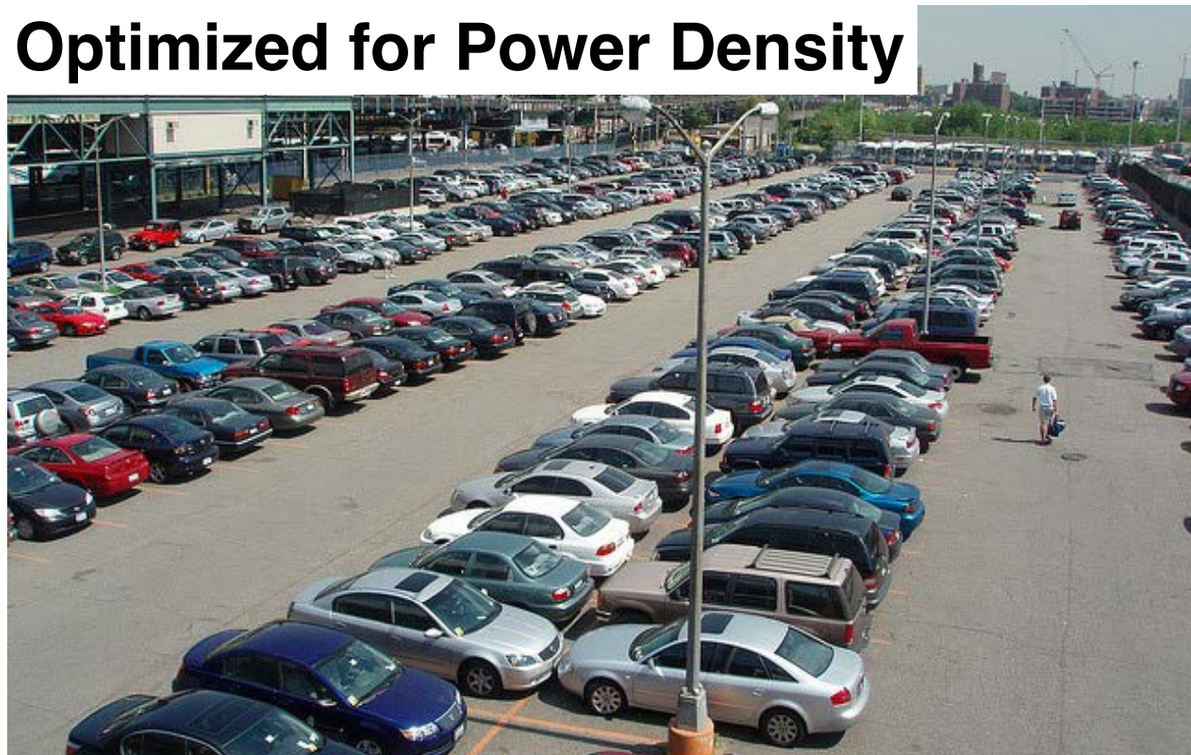


http://maplesoft.com

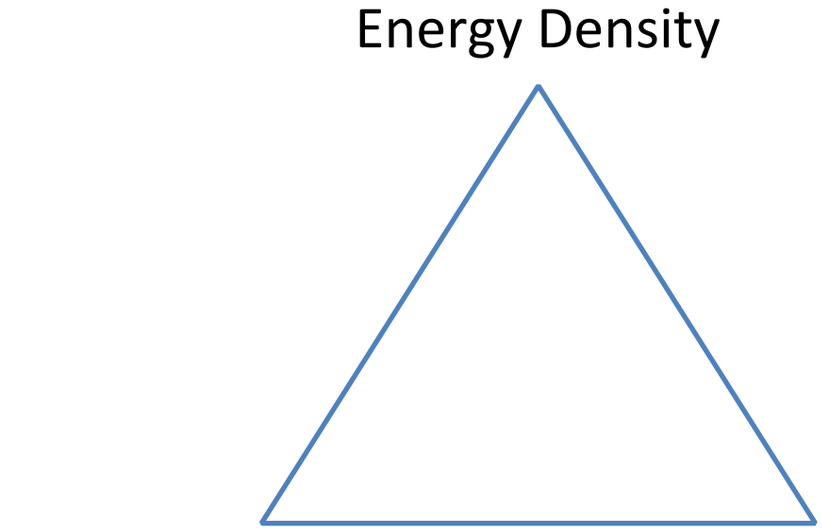


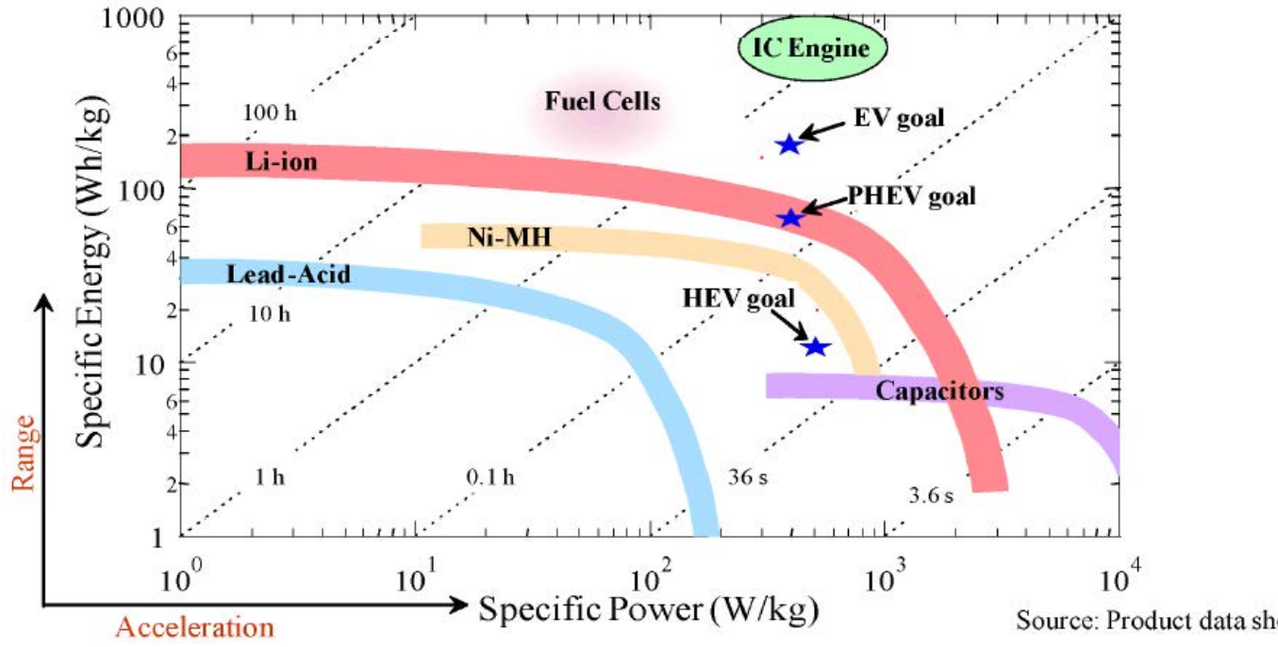
Optimized for Energy Density

Optimized for Power Density



The Hidden Metric in Ragone





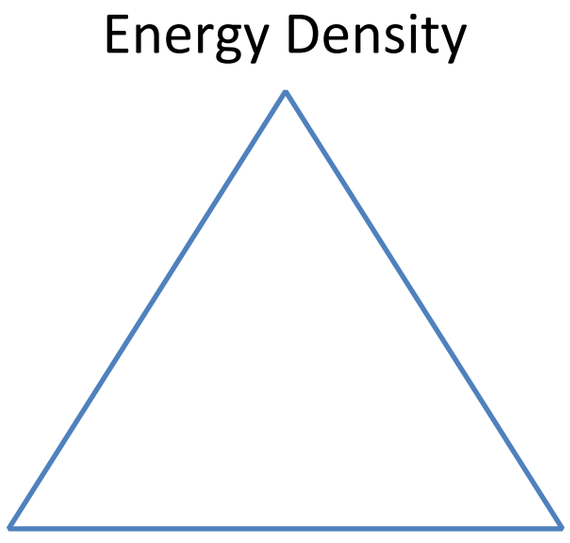
V. Srivansan, GigaOM, 2012

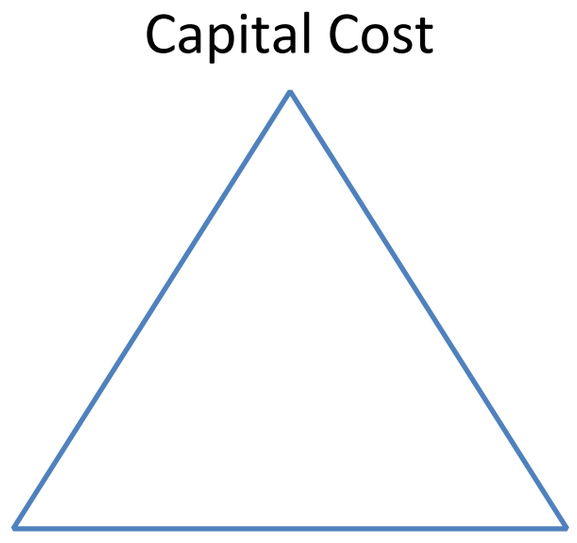
More Energy @ Unlimited Rate

$$\frac{\Delta E}{C_p * m} = \Delta T$$

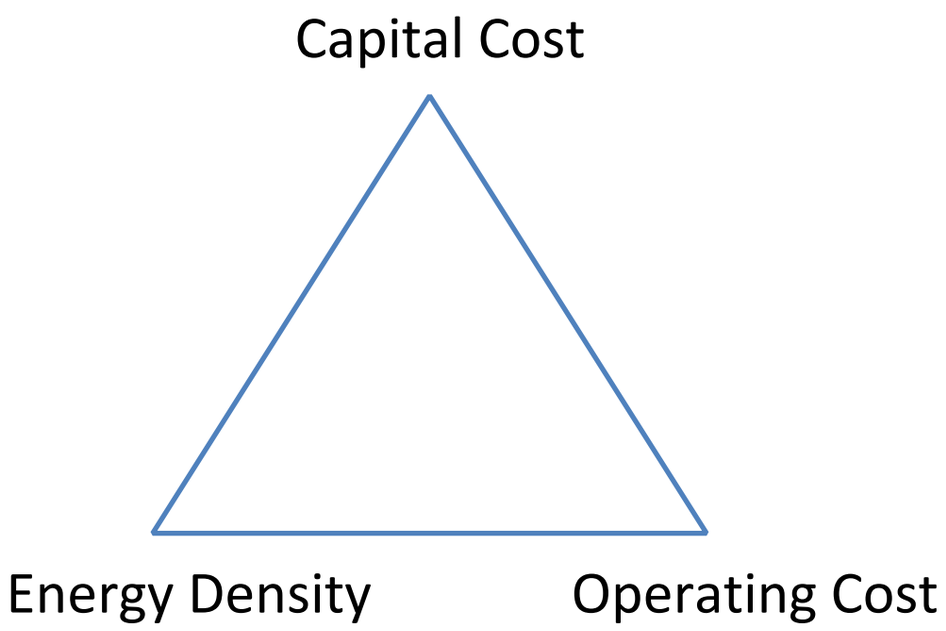
Less Mass

Pick Two Out Of Three





In any triangle pick two out of three



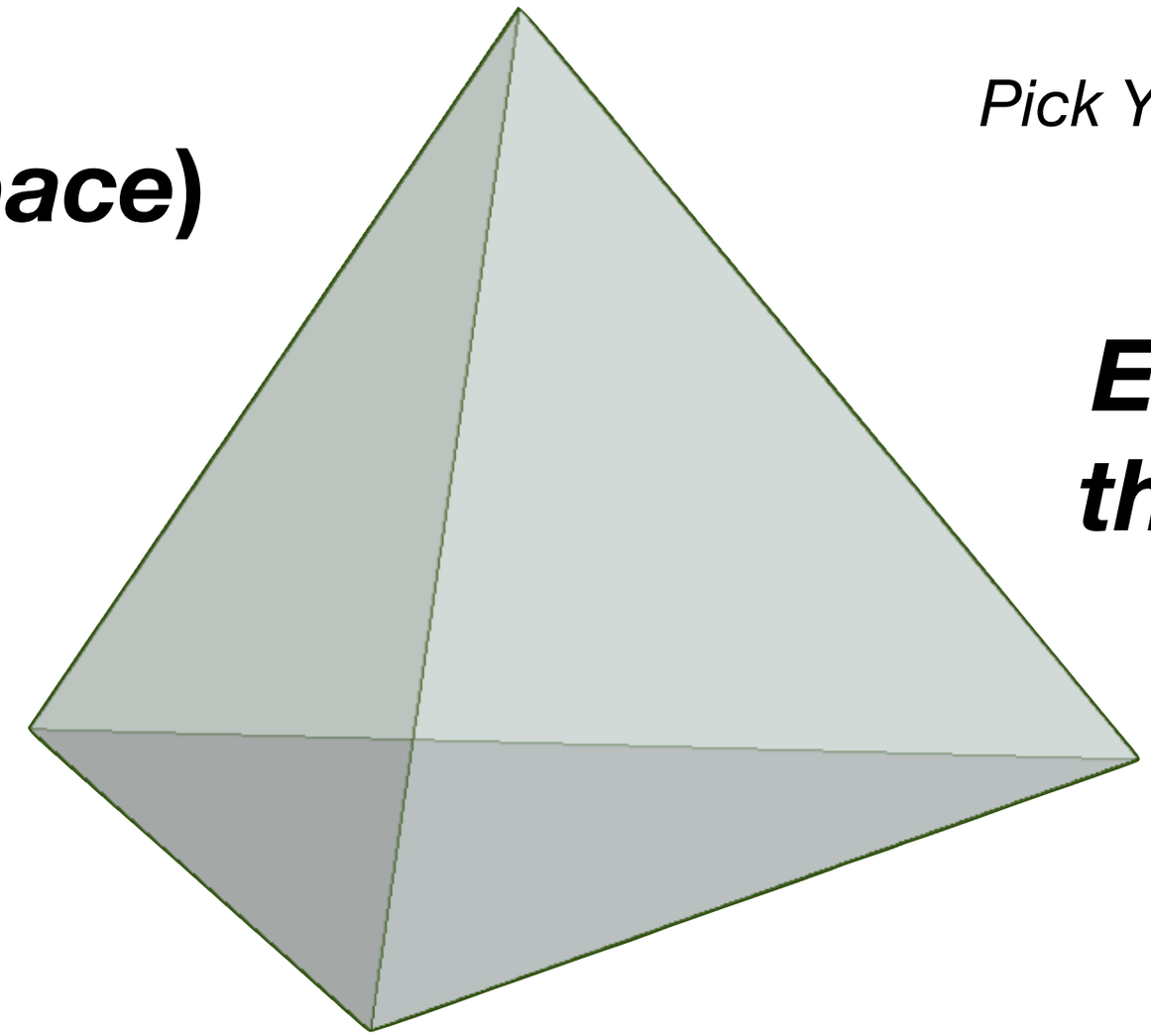
The Unfortunate Tetrahedron

Capital Cost

(***Utility Space***)

Pick Your Corners

EVs are in the middle



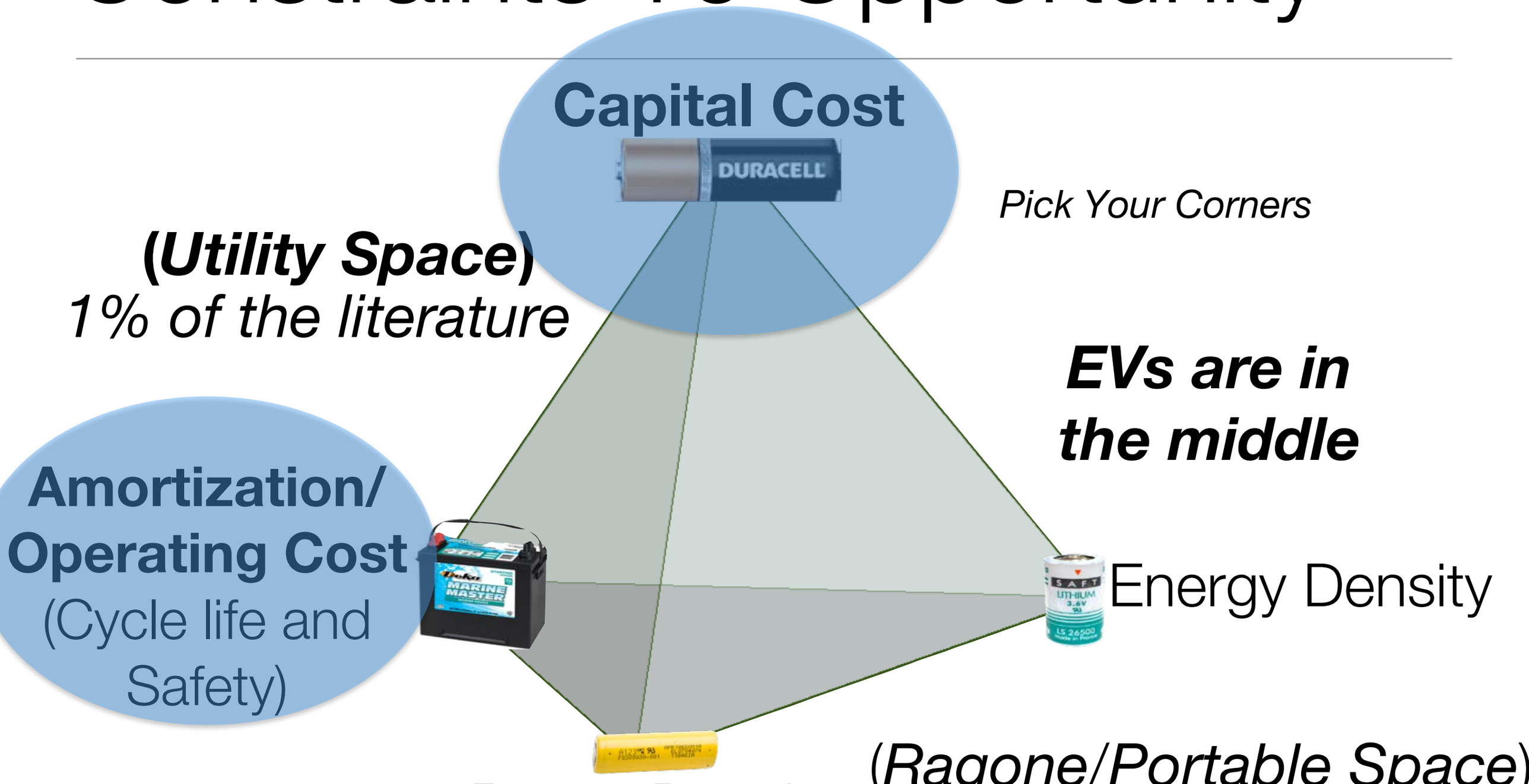
Amortization/ Operating Cost
(Cycle life and Safety)

Energy Density

Power Density

(*Ragone Space*)

Constraints To Opportunity



Pick Your Corners

EVs are in the middle

(*Ragone/Portable Space*)
99% of the literature

How Much Can It Cost?

“$100/kWh” <- Is this an effective target?

Global Upper Bound

GDP: $63,000,000,000,000

Consumption: 517,000,000 TJ *(on fuel basis)*

Max $/E: $120/TJ or **$0.44/kWhr**

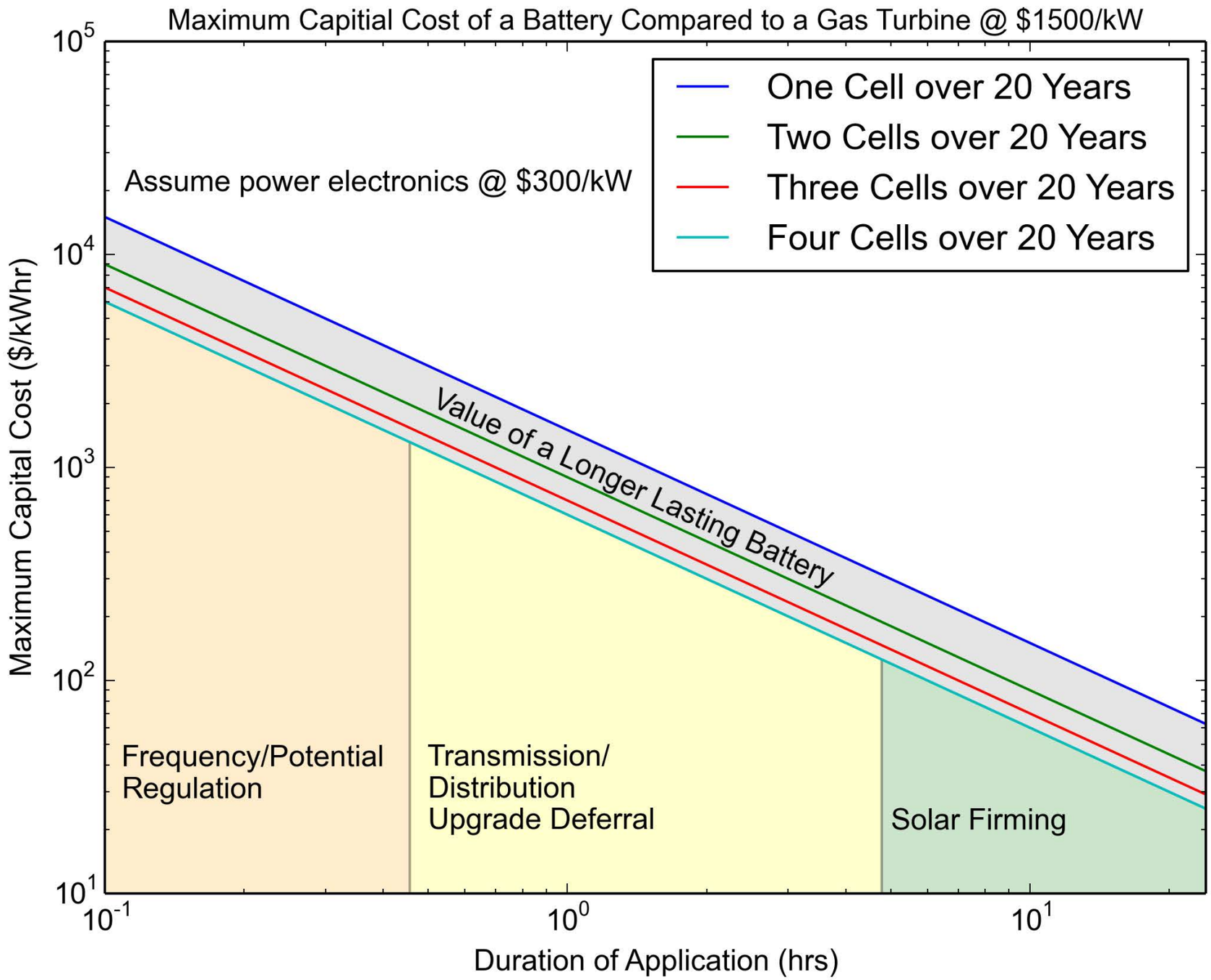
(there are, of course, massive local fluctuations)

Cell Cost Comparison

System	$/kWhr	Cycle Life @ 80% DOD	LCOE $/kWhr-Cycle	Notes
Lead Acid	$250.00	300	**$0.83**	Exide
Nickel Zinc	$350.00	500	**$0.70**	EEI
Lion (“Weekly”)	$320.00	500	**$0.64**	Tesla
V Redox	$1,000.00	5000	**$0.20**	PNNL
Lion (“Daily”)	$430.00	3600	**$0.12**	Tesla
Nickel Zinc/Modified	$500.00	5000	**$0.10**	CUNY
Na-Ion	$250.00	3000	**$0.08**	CMU/Aquion
NaS	$400.00	5000	**$0.08**	Difficult
NaMCl	$400.00	5000	**$0.08**	GE
ZnMnO2/ Modified	$100.00	2000	**$0.05**	CUNY/Princeton
Group Target	$50.00	5000	**$0.01**	Crazy?

Battery vs. Turbine

Carbon cost is 0 and gas price passed directly to consumer



So a 10 year battery (to grid) can cost $50/kWhr for 15 hours, $100/for 7.5 hours, etc.

Case Study: Home Powerwall

Without knowing anything else about the battery, as Tesla held the power density constant we can s

Technology
Wall mounted, rechargeable lithium ion battery with liquid thermal control.

Models
10 kWh $3,500
For backup applications
7 kWh $3,000
For daily cycle applications

Warranty
10 years

Efficiency
92% round-trip DC efficiency

Power
2.0 kW continuous, 3.3 kW peak

Voltage
350 – 450 volts

Current
5.8 amp nominal, 8.6 amp peak output

Compatibility
Single phase and three phase utility grid compatible.

Operating Temperature
-4°F to 110°F / -20°C to 43°C

Enclosure
Rated for indoor and outdoor installation.

Installation
Requires installation by a trained electrician.
DC-AC inverter not included.

Weight
220 lbs / 100 kg

Dimensions
51.2" x 33.9" x 7.1"
1300 mm x 860 mm x 180 mm

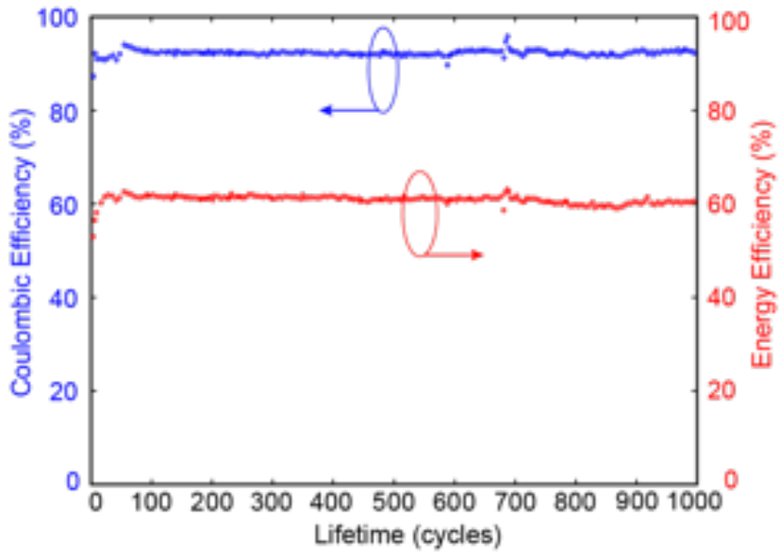
Certification
NRTL listed to UL standards

	Weekly System	Daily System
$/kWh	$350	$429
$/kW	$1000	$1000
Cycle Life	520	3650
$/kWhr-cycle	$0.67	$0.12

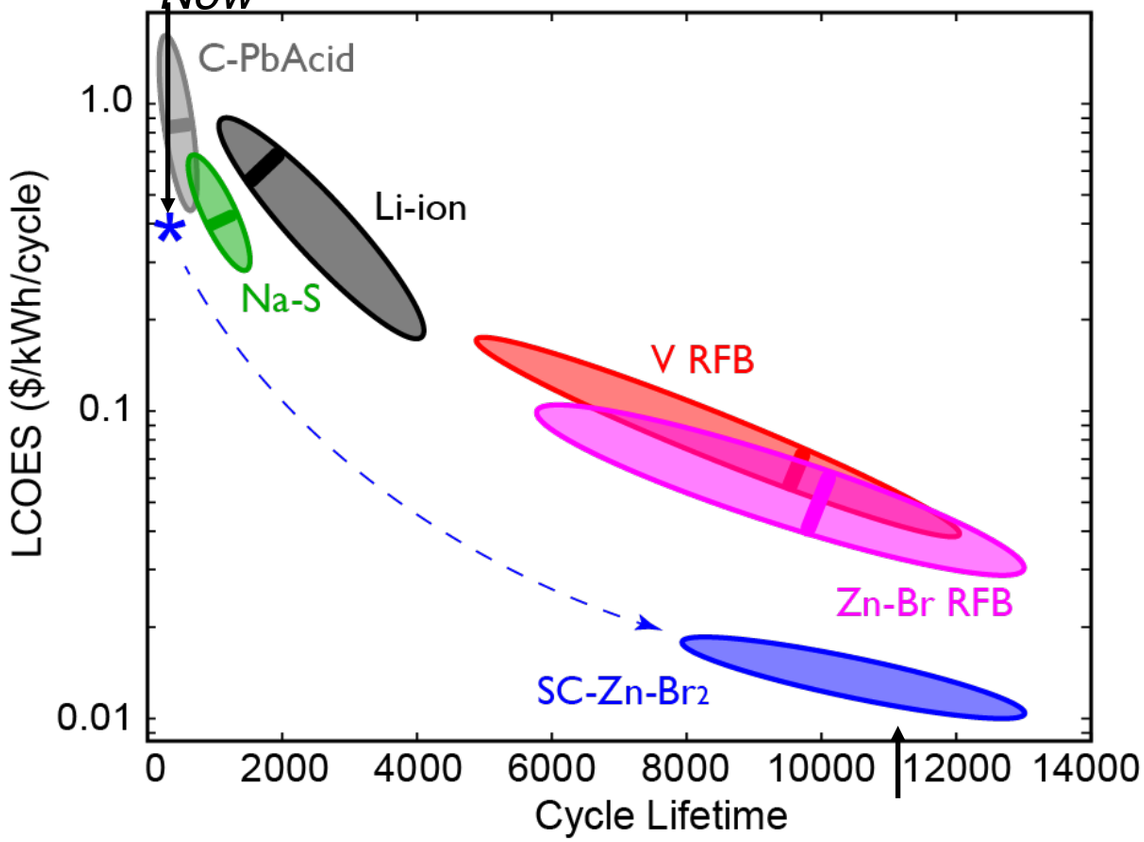
Electricity in NYC is $0.22/kWhr
$0.11/kWhr is just the *distribution cost*

Can Batteries Be Cheaper?

- Probably much cheaper, but at a performance penalty



Estimated Cost of Our Cell Now



Biswas E&ES 2016

Where we can go if there's little carbon degradation and we can make bigger cells

How Long Should It Last?

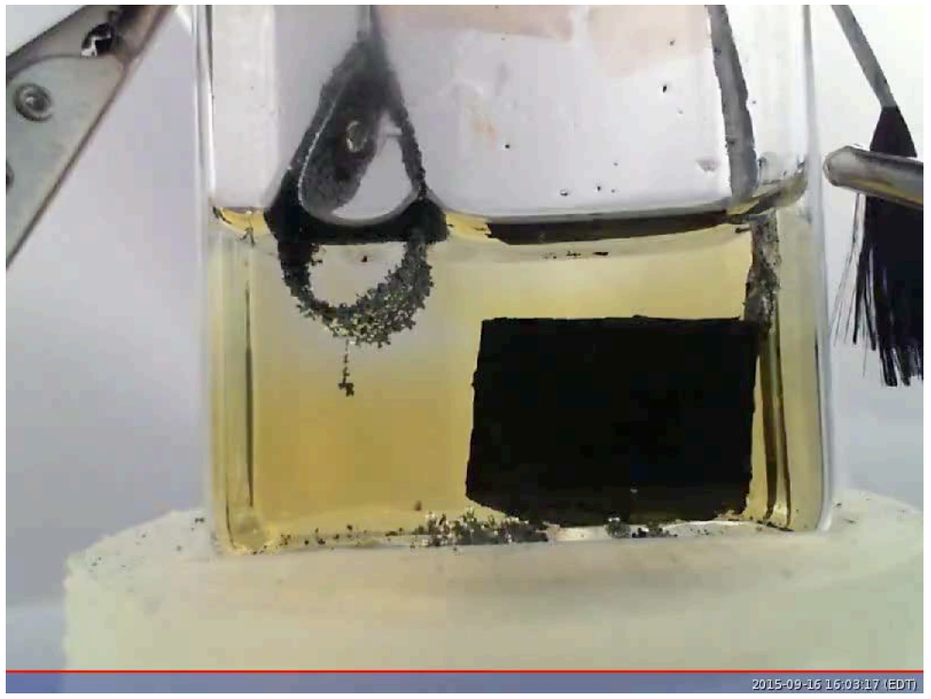
As in cycle life/calendar life, not run time

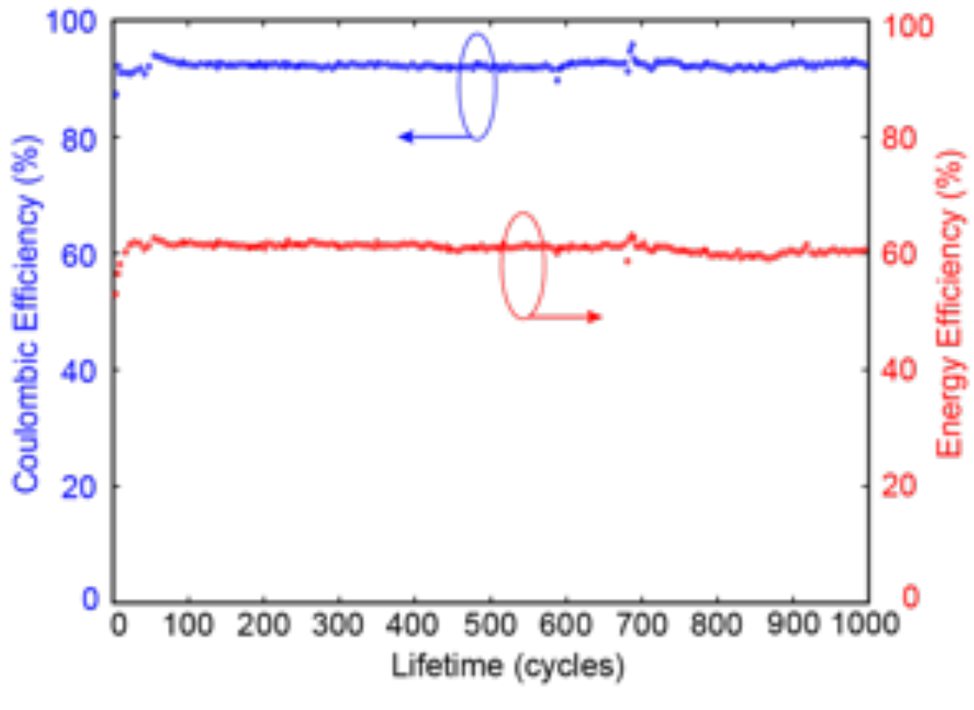
There are Hard Limits:

- Energy Density:
  - Lithium vs. ??
    - Flourine, Oxygen, Sulfur
      - Order ~3W/g in **theory**
      - More like 1 W/g in practice
        - Still far away
- Power Density
  - We can likely get to a 5 minute charge
    - With a lot of blood sweat and tears

There Are Not Hard Limits:

- Cycle Life
  - 1,000 cycles?
  - 10,000 cycles?
  - 100,000 cycles?
  - Maybe
- Calendar Life
  - 50 years? Forever?
  - Why not?





What’s the Catch?

The Catch 22

- Who wants to pay for it (any of it):
  - Electricity, at least in the US, is a bargain
    - **Short of backup power, as grid batteries get closer to the point of demand in 2017 they only make electricity more expensiv**
  - Power quality matters elsewhere
    - **Because power quality issues exist where batteries are required, they are “unstable” test beds**
- **This challenge is either instantly commodifying new technology in developing markets and or weathering black swan after black swan in developing markets**

Who’s going to make it?

- A lot more R&D and NRE is going to be required to realize such a cell
- The market has a nasty habit of driving companies with reasonable technologies into bankruptcy
  - A123, Alevo, Aquion (and those are just the A’s)
- The Fortune 500 response to date has been
  - “I’ll just wait for the battery to be cheap”
- **But its (likely) going to take a Fortune 500 (ish) company to get it there**

Someone Not Waiting?

Because….

The Takeaway

- Batteries can be big and cheap
- Batteries can be made to last a very long time, perhaps forever
- **But *who* is going to design and make these wonderful batteries, and what is in store for them? Riches or bankruptcy?**
  - **Because history indicates far more corpses than kings**

The Wanton Speculation

- "China" will do for Lithium Ion what it did for PV
  - Drive cost to materials + a dimiminus processing fee
  - This gets us to ~$130/kWh for a pack +/- $30
    - Unclear what balance of plant costs can do
- For grid scale storage, there are clearly markets this addresses
- Many it does not

The Wanton Speculation

- There is room, and capability for a radically different chemistry near below $100/kWh for a pack
  - Maybe even for a system
- If the “China” model can apply to lithium ion batteries, how far out can it push others?
- “Diesel gate” likely the best thing to happen yet for electrification of transport

Thanks!