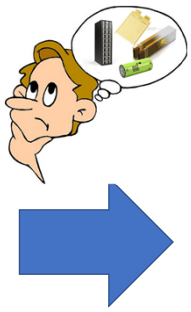
Thank you, ladies and gentlemen, for the opportunity to talk about how I see lithium-ion meeting the challenges of the future long-run energy storage needs of the planet. To set the record straight, I believe there's room in the market for many technologies and manufacturers with their various merits and advantages. If there's one thing I want you to remember from what I say, is that you need to consider the whole picture. How much will it cost you to purchase, install and operate your energy storage?

"If you are not careful, the cheapest thing about the purchase of your next energy storage project may be its price."

How do you get from Point A to Point B?

80 Wh and a lot of pep!



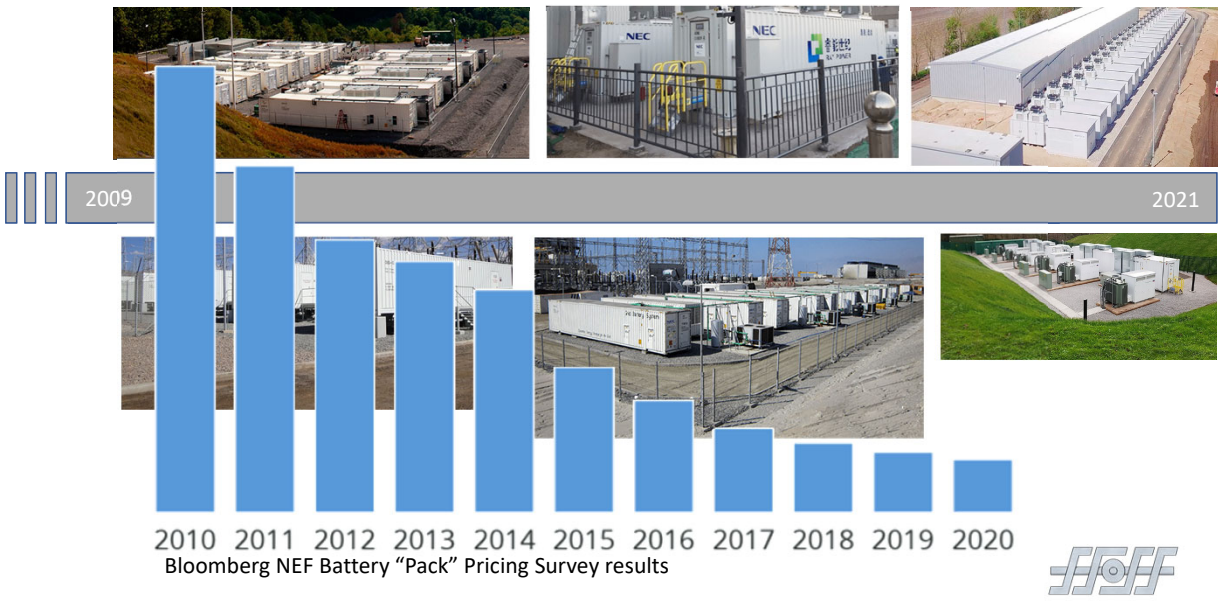
580 kWh and a lot of umph!

A123 System's first grid-storage product installed at Huntington Beach CA, Power Station

What does a scooter have to do with energy storage? Back in late 2007, energy storage visionary, Chris Shelton from AES, came to A123 with an idea. It started with the hacking of his son's scooter with powerful A123 cells mined from a Dewalt power pack. Powered by the new A123 cells, his son's scooter was faster and stronger than ever, and the envy of his son's neighborhood's friends. That got Chris thinking. What if these cells could power the grid and help stabilize it without the need for inefficient and partially ineffective fossil-fuel driven equipment.

Fast forward one year, and on November 25th, 2008, A123 powered up its first grid-scale energy storage unit at the Huntington Beach power plant in California. To A123 this was big. This was the most powerful system any of us had ever created. But, if you looked at the size of this unit in comparison to the power plant surrounding it, it looked like an outhouse on a farmstead. It was one small step for the industry, but an important one at that.

How do you get from Point A to Point B?



Bloomberg NEF Battery "Pack" Pricing Survey results

Since then, the prices of lithium-ion cells and packs have come down dramatically. Riding on the coat-tails of those cost reductions, the energy storage business developed and sold its product all over the world.

Where do we go from here?

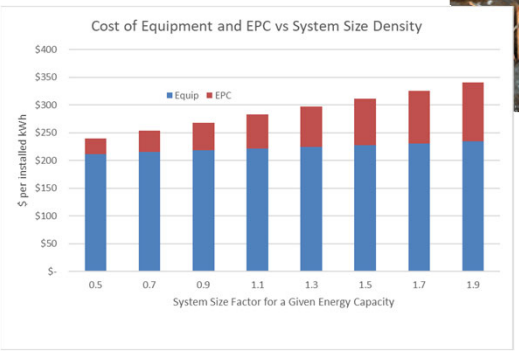
- What drives lithium-ion price reductions?
  - Volume-driven supply chains
    - Automotive market sales
  - Energy density inside the cell
    - More silicon
    - More lithium
    - More active vs inactive materials
    - Less empty space
  - Energy density outside the cell
    - Less empty space
    - Compact cooling apparatus
    - Higher energy to Power ratios
  - Research and Development

Over the past 10 years, what has primarily driven the battery price reductions have been high-volume leveraged materials purchases associated with the growing EV market.

Additionally, manufacturers are spending millions of dollars researching more energy dense materials such as silicon, metallic lithium, solid electrolytes and better cell and system designs.

What about the *other* costs?

- Construction and Installation (EPC)
- Cooling
- Safety
- Transportation
- Service
- Warranty
- Operating



"We have received quotes from legitimate EPC firms for anywhere from $25 to $125 per kWh to install our batteries"

- EPC efforts can add significant $ per installed kWh depending on a wide variety of site and technology factors - don't ignore them!
- EPC are dependent on ESS site *design,* NOT ESS technology *costs*
- EPC labor costs and materials rise with general cost of living

There's more to energy storage costs than just the battery though.

For one, the construction and installation of a *grid* energy storage system entails significant cost and effort. Land must be cleared, leveled, prepared, concrete formed and poured, conduit buried, wires pulled and connected, batteries assembled, equipment moved and positioned, fences laid, tests performed, and on and on.

More boxes, more land, more assembly will require more in ineluctable labor, materials, and time. On top of that, most of the components of EPC do not scale with battery costs, and they certainly don't go down over time.

What about the *other* costs?

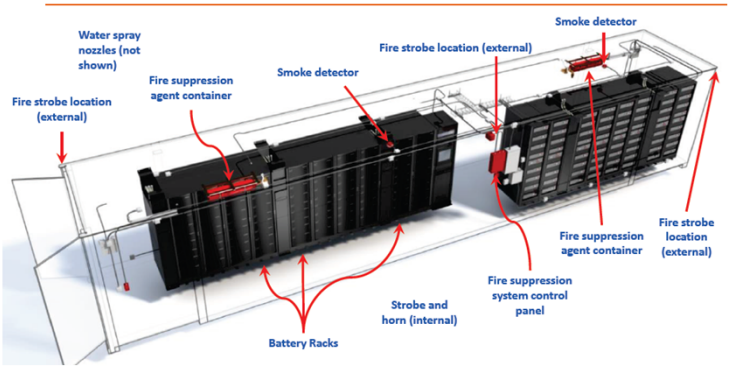
- Construction and Install
- Cooling
- Safety
- Transportation
- Service
- Warranty
- Operating

- Cooling is dependent on battery needs, environmental factors and battery efficiency
  - Typical Sizing is around 1 - 2 Tons per MWh
  - Up-front costs about $1K per ton, or $1 - $2 / kWh
  - Not a big factor in the over-all costs, but will contribute to additional service costs

Lithium-ion often gets a bad rap for its cooling costs. I don't deny its need for cooling and its complexities in design. But I just want to clarify the magnitude of its effect on the total system cost. Lithium-ion batteries are extremely efficient. So, when coupled with well-insulated enclosures, most lithium-ion batteries need about 1 to 2 tons of cooling per MWh. So, the total HVAC cost will be around $1 to $2 per kWh. This is not a big factor in the over-all system costs.

What about the *other* costs?

- Construction and Install
- Cooling
- Safety
- Transportation
- Service
- Warranty
- Operating



- Safety system costs depend on technology and its reaction to the UL 9540A test results
- Also depends on installation jurisdiction and the AHJ's requirements
- Typically can cost $2 - $4 per kWh depending on so many different factors

Safety is also another favorite target against lithium-ion technology. Let me ask you this? When was the last time you thought it was unsafe to pack your kids into an enclosed space inches away from a potential fireball from an extremely energy-dense liquid we know as gasoline? But, yet we do it every day, and even park such a hazard in our garages every night. The point is that even though the car contains a hazardous material, it design keeps the probability of such a catastrophe to an acceptably small level and we have come to trust it.

Same with lithium-ion batteries. We've learned over the years of its potential dangers and we have responded with system designs which keep its users and neighbors safe. Typically, a smart system can expect to add about $2 – 4 per kWh to maintain satisfactory safety margins under most installation conditions.

What about the *other* costs?

- Construction and Installation
- Cooling
- Safety
- Transportation
- Service
- Warranty
- Operating

- Transportation is expensive!
  - $3,000 - $5,000 to transport ONE truck-load across the U.S.
  - $7,500 - $10,000 to transport one container across the ocean
- Add in logistics, fees, dangerous-goods surcharges, tariffs, and the costs can add up to $7 - $14 per kWh
- More containers for less energy-dense technologies will cost proportionally more

Transportation is expensive for all energy storage, not just lithium ion. One truck load across the US will cost between 3 and 5 thousand dollars, and one container across an ocean will cost up to ten thousand dollars. Add in logistics, fees, dangerous goods surcharges, tariff and the costs can add up to $7 to $14 per kWh. My point is, the smaller, the denser a battery is, the less it will cost to transport.

What about the *other* costs?

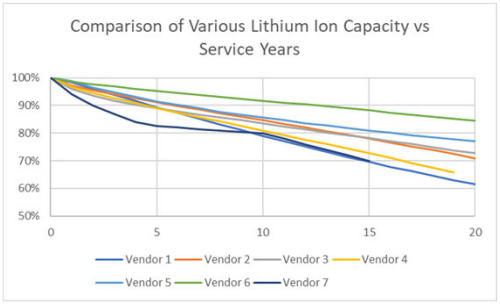
- Construction and Installation
- Cooling
- Safety
- Transportation
- **Service**
- Warranty
- Operating

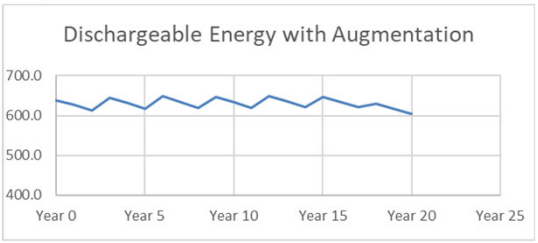
- Regular service keeps all products running in top-top shape
  - HVAC filters, coils, blowers
  - Coolant levels and flushing
  - Connection integrity
- Generally around $0.3 – 0.7 / kWh per year ➔ A small but essential factor

Just like any car, truck or vintage tractor, regular upkeep will keep any machine running in tip-top condition. The costs for essential preventative maintenance are generally less than a dollar per kWh per year.

What about the *other* costs?

- Construction and Installation
- Cooling
- Safety
- Transportation
- Service
- **Warranty**
  - Break Fix
  - Performance
  - Capacity
- Operating





- ALL lithium-ion batteries degrade over time and use
  - Some more than others
  - Requires either up-front oversizing, or continual augmentation*
- Generally around $2 – 3 / kWh per year ➔ amounts to $20 - $30 / kWh (NPV) over 20 years

* Preparation for future augmentation adds up-front costs ➔ $15 - $25 / kWh extra CAPEX

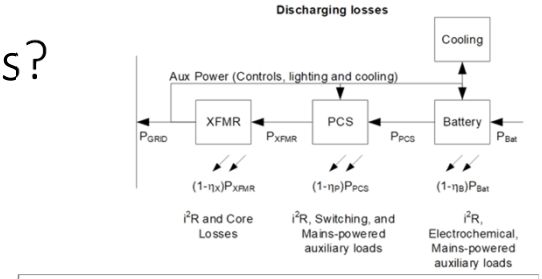
The most common warranties are break-fix warranties. Increasingly though, customers are asking to have certain performances guaranteed, such as availability, reliability, efficiency, and others. In batteries, one such performance metric is capacity. Since the capacity of all lithium-ion batteries degrade with use and time, customers ask the battery vendors to provide a warranty to guarantee a certain level of energy.

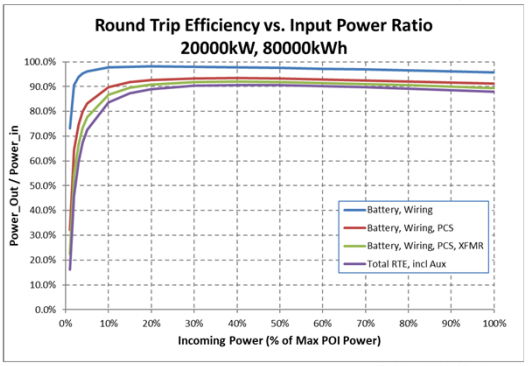
To meet their warranty obligations, vendors can either over-size the battery at the beginning, or over time deliver more supplemental energy storage to the site. Augmenting a battery over a 20-year service life can add up 20 to 30 dollars per kWh in NPV costs and an up-front $15 to $25 / kWh in supporting infrastructure.

What about the *other* costs?

- EPC
- Cooling
- Safety
- Transportation
- Service
- Warranty
- Operating

- Lithium-ion batteries are super efficient, especially at low rates ➔ 0.95 – 0.98% RTE
  - The Balance of Plant will add another 8 – 9% RTE losses though
- Total RTE 85% to 91% for a complete system
- @ $0.05 / kWh electricity costs, this amounts to $1 - $2 per kWh per year = $10 - $20 per (NPV) for 20 years





Operating costs include that required to charge the batteries every day. Fortunately, lithium-ion batteries are extremely efficient, and the power conversion and transformers are becoming more and more efficient every year. Typically, a lithium-ion based energy storage system will lose about 10 to 15% of its energy while cycling, resulting in about $10 – 20 per kWh NPV costs over 20 years.

Let's not underestimate the importance of efficiency…

100% RTE battery

50% RTE battery

Let's talk about efficiency for a moment. If the entire world is an island, with one load, one right-sized solar panel, and a 100% efficient battery, the solar energy will charge the battery and the battery will power the load; no energy lost. If, however, the battery is less than 100% efficient, you'll need proportionally more solar panels to provide for the same load.

On a planetary level, if we are 100% reliant on renewable energy sources, but have low-efficiency energy storage, we will need to cut down more trees, occupy more farmlands, shade more of the Sahara, and use more resources to power the same global demand in energy, than we would have with a more efficient energy storage technology.

Other Costs Comparisons

	Lithium-ion Costs / per kWh		Compared to other technologies	Notes
	CAPEX	OPEX		
Construction and Installation	$25 - $125		Generally Lower	
Cooling (of batteries)	$1 - $2		Generally Higher	
Safety systems	$2 - $4		Higher	
Transportation to site	$7 - $14		Lower	
Service (Preventative Maint.)		$3 – $7	Lower	NPV over 20 yrs
Warranty (Capacity and Break-fix)	$15 - $25	$10 - $20	Depends on technologies	NPV over 20 yrs
Operating (Charging costs)		$10 - $20	Lower	Assuming $0.05 / kWh, NPV over 20 yrs
Total *other* costs	$50 - $170	$23 - $47	Typically lower	

Summary Slide

This table summarizes the upfront and operating expenses I mentioned. I show you these as examples of how a seemingly minor factor can contribute a significant life-cycle cost.

Remember, consider every cost associated with *purchasing*, *installing* and *operating* an energy storage system.

"If you are not careful, the cheapest part of your next energy storage project will be its price."

Thank you

C. Michael Hoff, Energy Storage Specialist
@ HoffPower LLC
www.hoffpower.com

Remember, consider every cost associated with *purchasing*, *installing* and *operating* an energy storage system.

"If you are not careful, the cheapest part of your next energy storage project may be its price."

Thank you.

Credits

- Scooter picture:
  - https://www.prweb.com/releases/2007/10/prweb561533.htm
- Silicon Anode:
  - ACS Nano 2010, 4, 9, 5366–5372
  - Publication Date:August 13, 2010
  - https://doi.org/10.1021/nn100963j
  - Copyright © 2010 American Chemical Society
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  - https://www.pgecurrents.com/2020/07/29/pge-tesla-break-ground-on-landmark-battery-energy-storage-system/