Washington **Clean Technology** Alliance

BATTERIES INCLUDED

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Batteries Included

Batteries 101

M. Grant Norton
Washington State University

Washington Clean Technology Alliance, December 11, 2013

Electrochemical Storage

Chemical Energy → Electrical Energy

Alessandro Volta
… the first useful professor!

The Chemistry

$Zn \rightarrow Zn^{2+} + 2e^-$

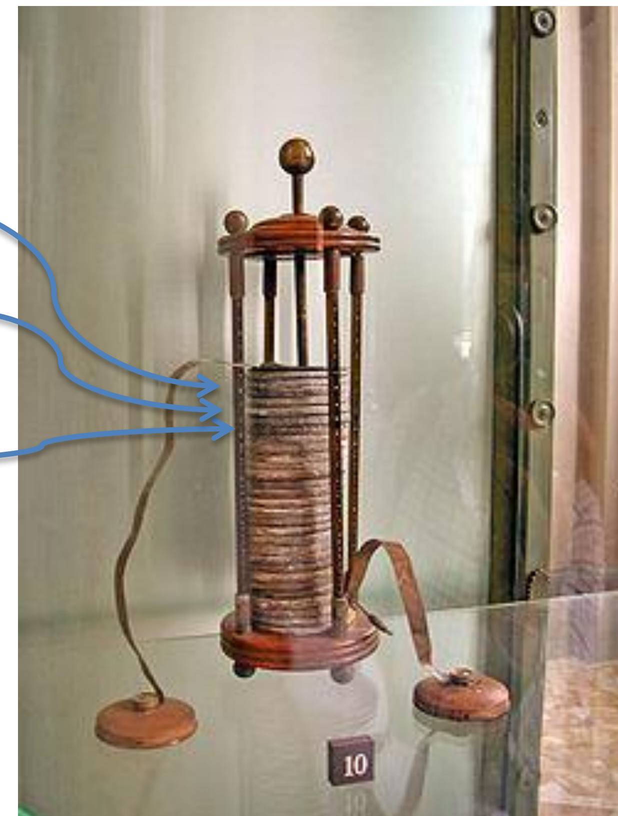
$2H^+ + 2e^- \rightarrow H_2$

Produces 0.76V

Zinc

Brine-soaked cloth

Copper



1800 First electrochemical cell (battery)

The Three Basic Parts ... this is what we can change

1. Anode – Negative electrode

2. Cathode – Positive electrode

It is not rocket science!

Ted Norton with his lemon battery

3. Electrolyte - Conducts ions but not electrons

Types of Battery

Two Types

- Primary battery – single use
- Secondary battery – multiple uses

The Chemistry

$Zn + 2OH^- \rightarrow ZnO + H_2O + 2\mathbf{e}^-$

$MnO_2 + 2H_2O + 2\mathbf{e}^- \rightarrow Mn(OH)_2 + OH^-$

Anode: Zinc
Cathode: MnO_2
Electrolyte: KOH

Produces 1.5 V

$Cd + 2OH^- \rightarrow Cd(OH)_2 + 2e^-$

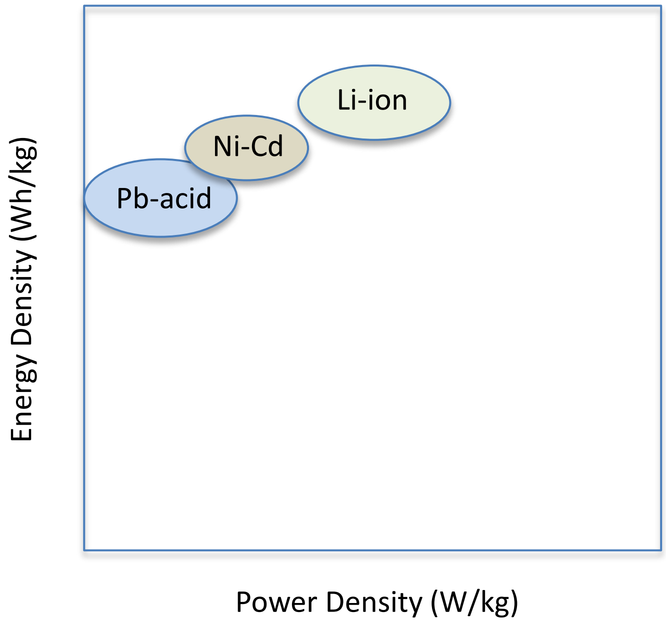
$2NiO(OH) + 2H_2O + 2e^- \rightarrow Ni(OH)_2 + 2OH$

Anode: Cadmium
Cathode: NiO(OH)
Electrolyte: KOH

Produces 1.4 V

Comparing Batteries

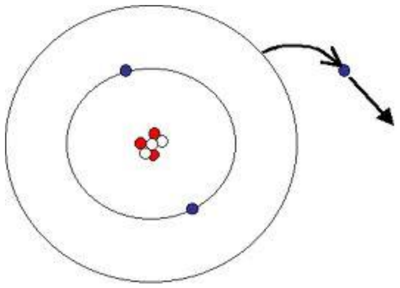
- Electrical energy can do work
- It is proportional to the cell voltage
- The cell voltage is determined by the difference in electrical potential between the electrodes
- So the electrodes (or the difference between them) is what is really important



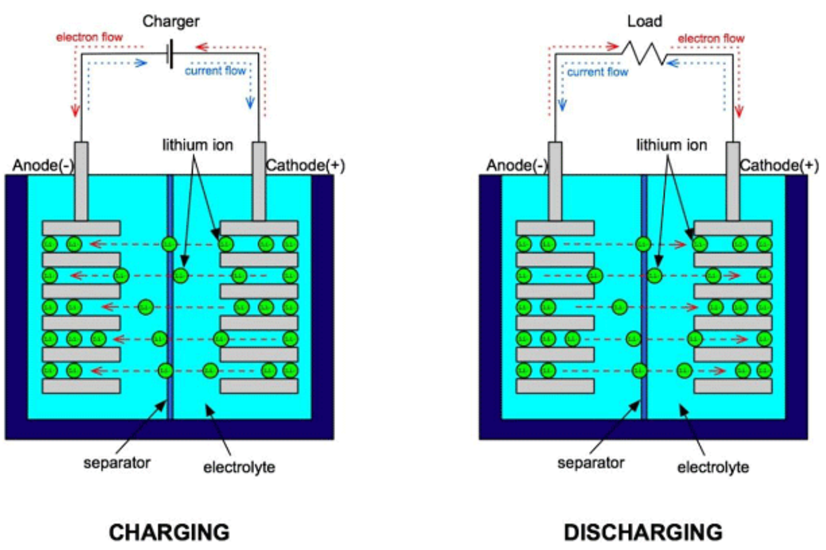
The Ragone plot

Important Fact

Lithium is the most easily oxidized metal (i.e., it likes to lose electrons) – good for batteries!



Lithium-ion Battery



$$C_6Li \rightarrow C_6 + Li^+ + e^-$$

$$Mn_2O_4 + Li^+ + e^- \rightarrow LiMn_2O_4$$

Reaction 1 = 3.05 V
Reaction 2 = 0.59 V
Total = 3.6 V

Anode: Graphite
Cathode: Layered nanoparticle oxide e.g., $LiMn_2O_4$
Electrolyte: Organic carbonates with $LiPF_6$

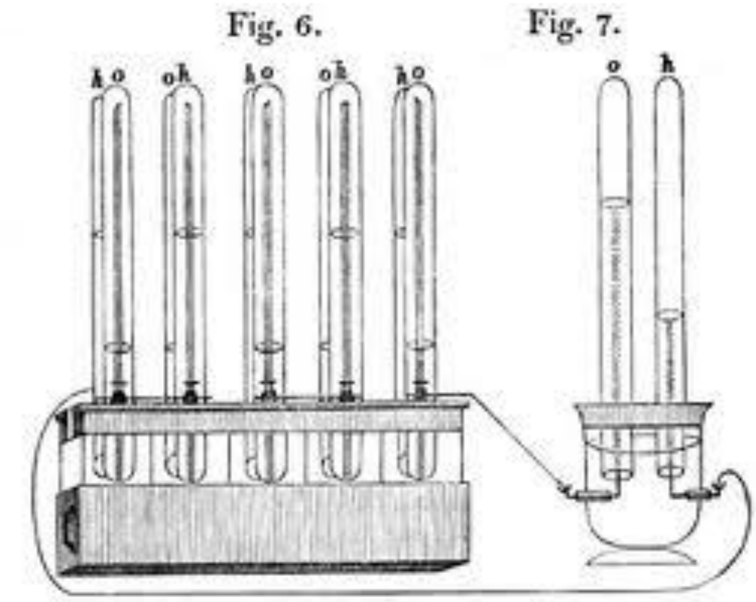
Produces 3.6 V

Applications

Fuel Cells

An electrochemical cell with a separate fuel source – a **flow** battery

Sir William Grove
… a useful lawyer!



1842 First fuel cell

The Chemistry

$2H_2 \rightarrow 2H^+ + 2e^-$

$O_2 + 2H^+ + 2e^- \rightarrow H_2O$

Produces 1.2 V

The Three Basic Parts ... this is what we can change

1. The Anode

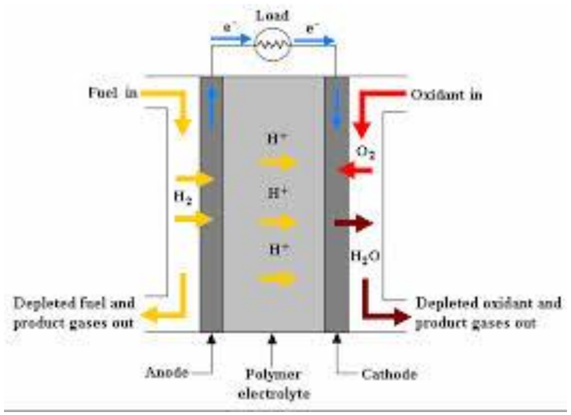
2. The Cathode

3. The Electrolyte ... Conducts ions but not electrons

Types of Fuel Cell

Proton Exchange Membrane (PEM)

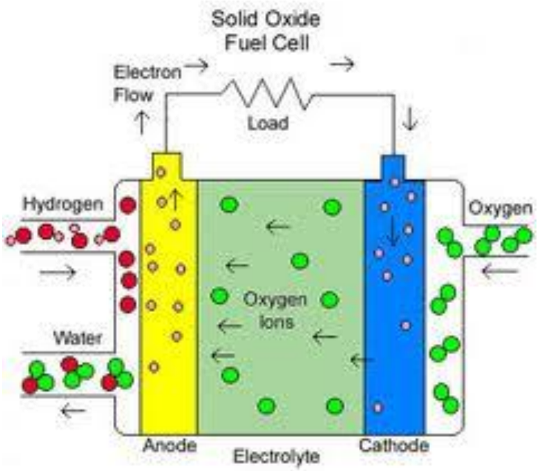
Anode: Platinum on carbon support
Cathode: Platinum on carbon support
Electrolyte: Proton conducting polymer membrane - Nafion



Operates below 80°C

Solid Oxide Fuel Cell (SOFC)

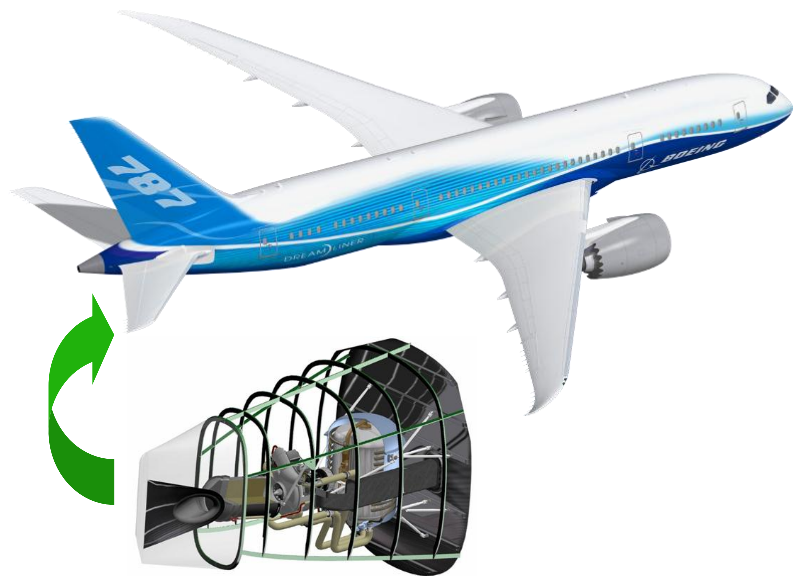
Anode: Nickel with YSZ
Cathode: Lanthanum strontium manganite (LSM)
Electrolyte: Oxygen ion conducting ceramic yttria-stabilized zirconia (YSZ)



Operates above 500°C

Applications

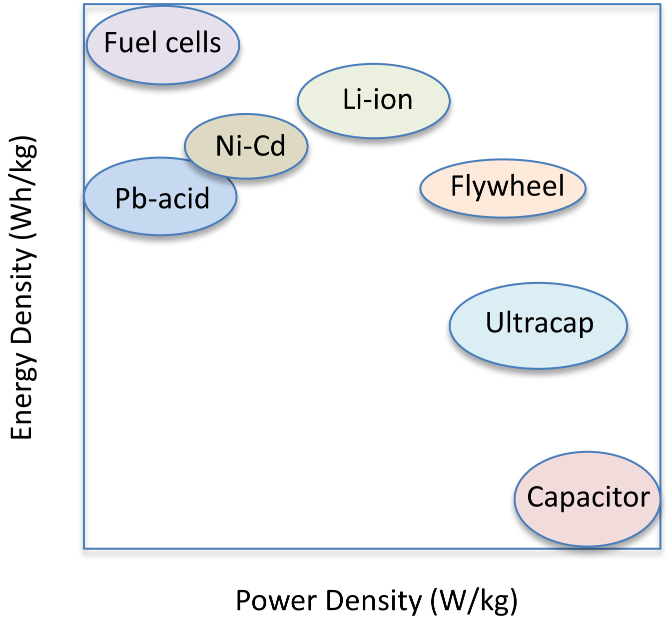
TEKION

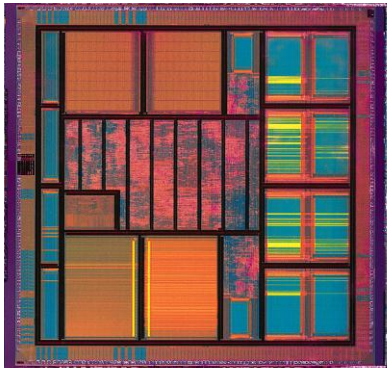


Fuel Cells – vs – Batteries

Both electrochemical cells

- A fuel cell requires an external source of chemical energy
- A battery has an internal source of chemical energy





We have known about the science for 200 years
Semiconductors we have only known science for 50 years

Washington Clean Technology Alliance
"*Batteries Included*"

Craig W. Collar
Snohomish Public Utility District

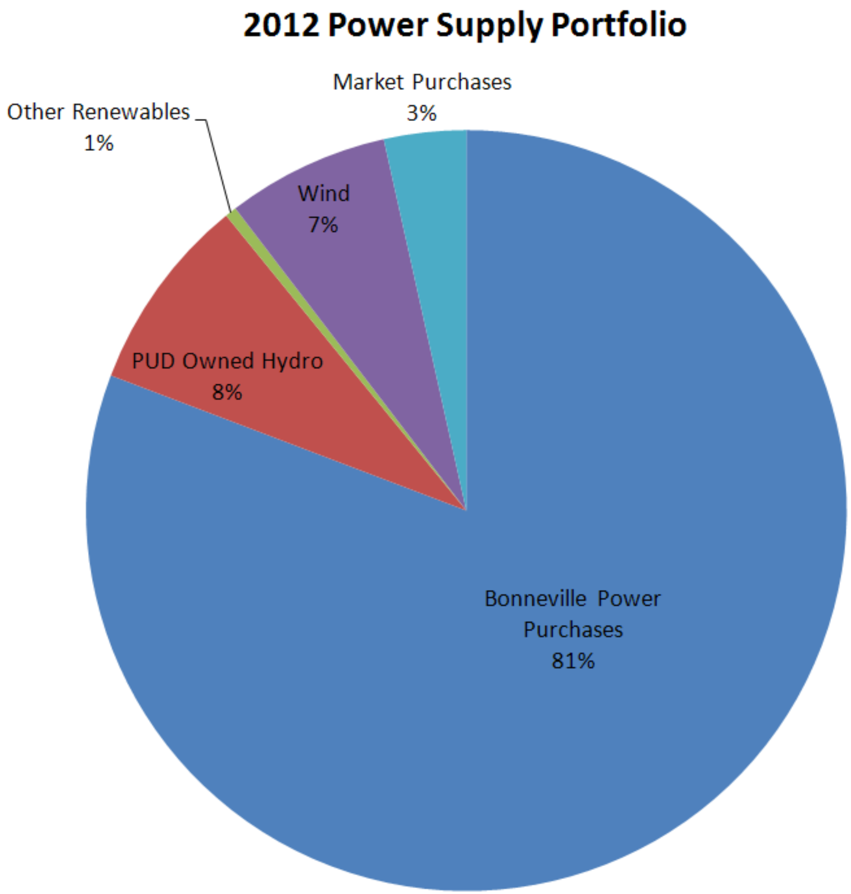
December 11, 2013

SNOHOMISH COUNTY
PUD
PUBLIC UTILITY DISTRICT NO. 1

Summary

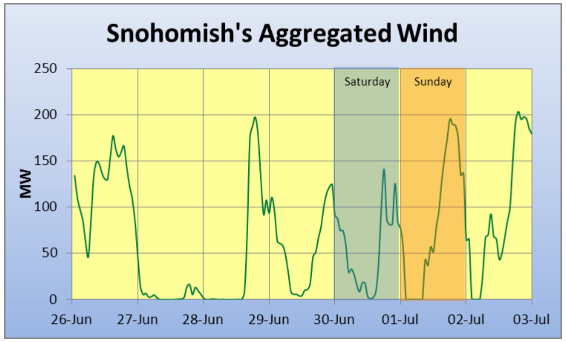
- Energy storage from utility's perspective
  - Tremendous potential: integrate renewables, smart grid
  - Significant challenges: supply chain too costly, no standards
- Opportunity for software/IT expertise in WA
  - Transform the energy storage market through **development of software/IT standards**
  - Become **industry center of gravity** for energy storage
- Example: Snohomish PUD MESA project
  - Software by 1Energy Systems (Seattle) & Alstom (Redmond)

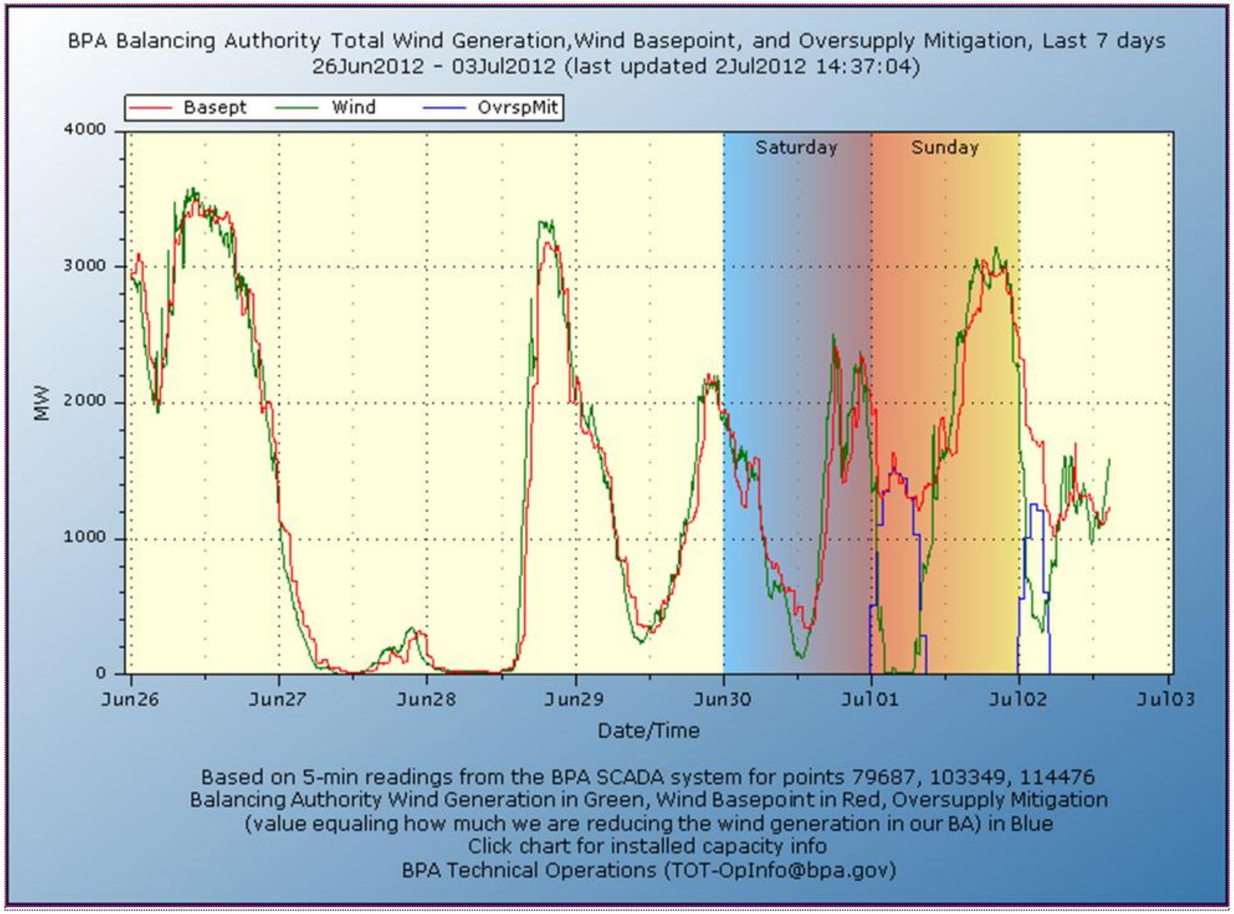
PUD Resource Portfolio



Challenge:
Meet load growth and renewable portfolio standard requirements without the use of fossil fuels.

Wind Variability





Grid Energy Storage

- Storage potentially has many energy and power uses:
  - Variable energy resource integration
  - Peak shaving
  - Voltage support
  - Infrastructure upgrade deferral
  - Frequency regulation
- Large scale hydro and pumped hydro storage facilities have dominated the storage landscape
  - Limited options geographically and environmentally
- Batteries are beginning to enable smaller and more modular/scalable energy storage systems

Current State

- Current battery-based grid energy storage offerings
  - Expensive
  - Lack modularity
  - Lack interoperability
  - Lack scalability
  - Lack standardization
  - Monolithic; vendors operate beyond core expertise
- Large gap between battery manufacturers and utilities
  - Core suppliers cannot easily serve core customers

Opportunity

- Implications:
  - Utility market for significant-scale battery based storage is very small and slow growing
  - Projects to-date are either highly optimized one-off niche projects, or small learning/demonstration projects
  - Decreasing battery prices alone are unlikely to stimulate utility energy storage market growth significantly
  - EPRI, battery manufactures, and others see the same landscape, but there is little apparent activity to facilitate change

- Opportunity: focus on architecture and standardization
  - Develop and deploy "Modular Energy Storage Architecture" (MESA)

Genesis of MESA

CES

- 25 kWh Li-ion battery
- ~$100k

One-off Projects

Nissan Leaf

- 24 kWh Li-ion battery
- $35k
- Plus a car

Engineered for Scale

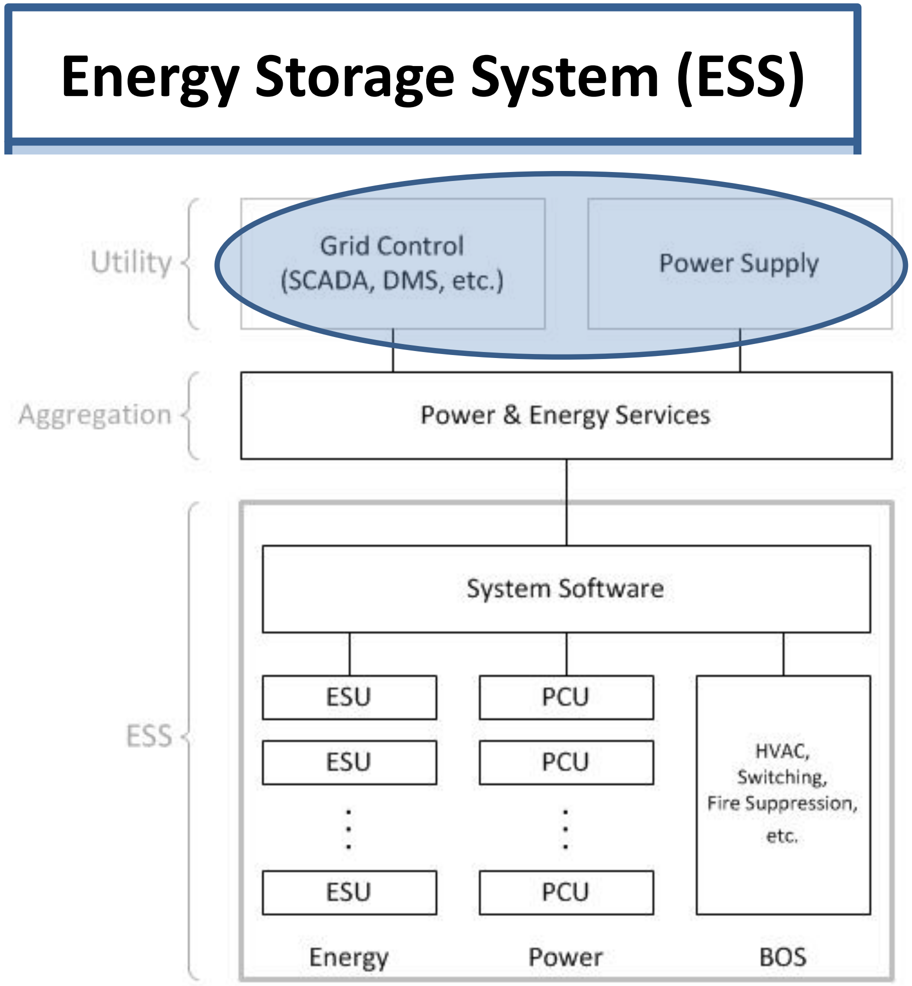
MESA Project

Technology Transforming the Energy Storage Market

Taxonomy

ESS Components

- Energy (battery)
  - Many chemistries, families
  - Active innovation
- Power (PCS)
  - Incremental improvement
- Control (software, comms)
  - Opportunity



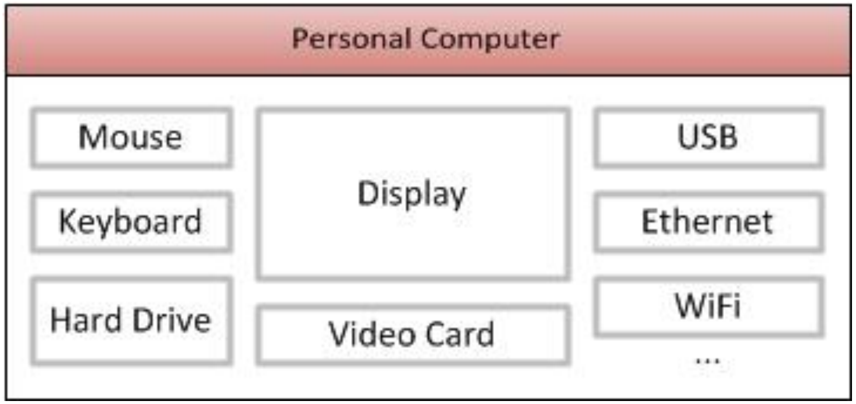
Vision

ESS ←→ {battery, PCS, …}

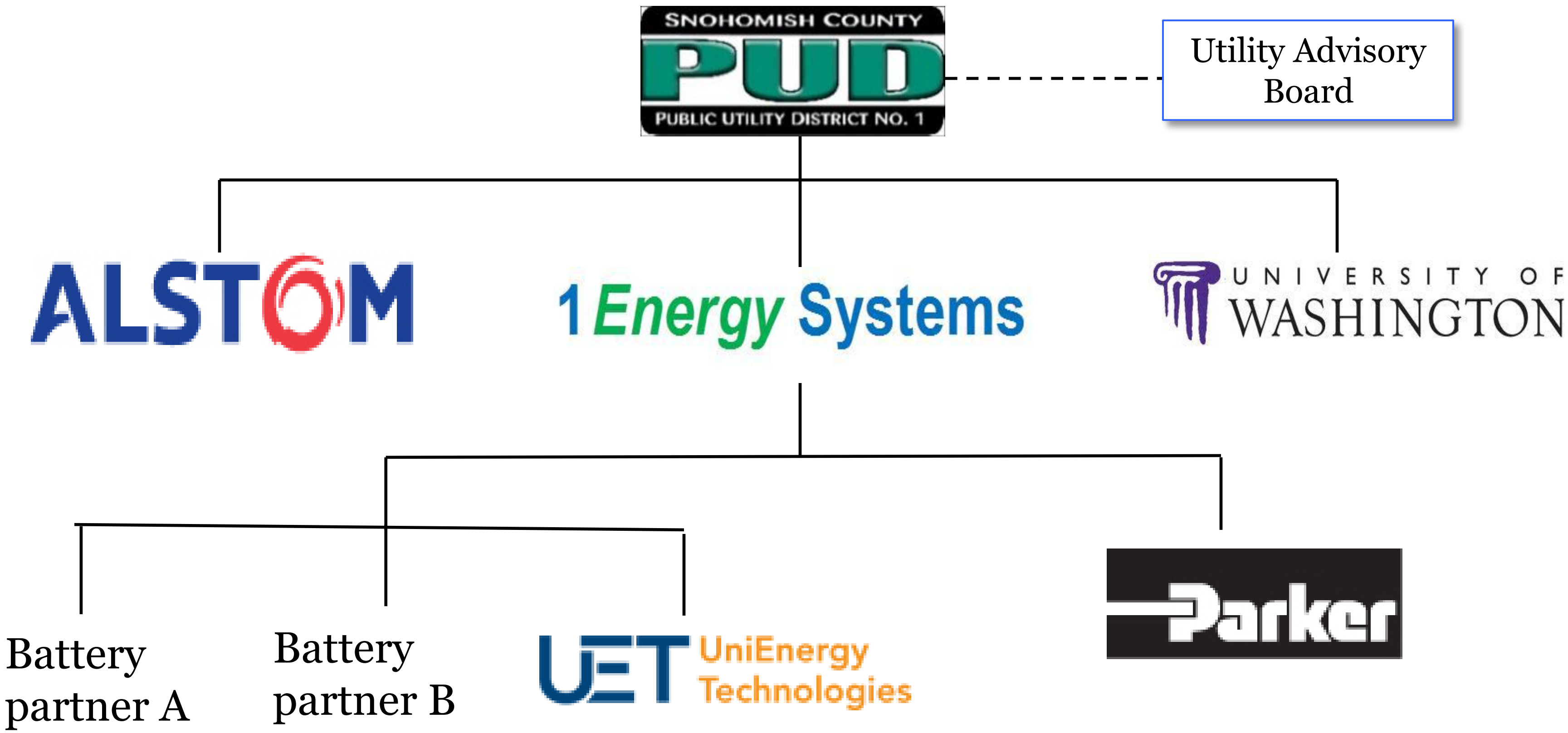
- Utilities want:
  - Standard components
  - Install, operate, maintain, upgrade, expand, …
  - Functional, cost-effective supply chain

- Standards must cover:
  - Physical
  - Electrical
  - Communications
  - Think USB, Ethernet, etc.

Analogy: PC Industry



Project Organization



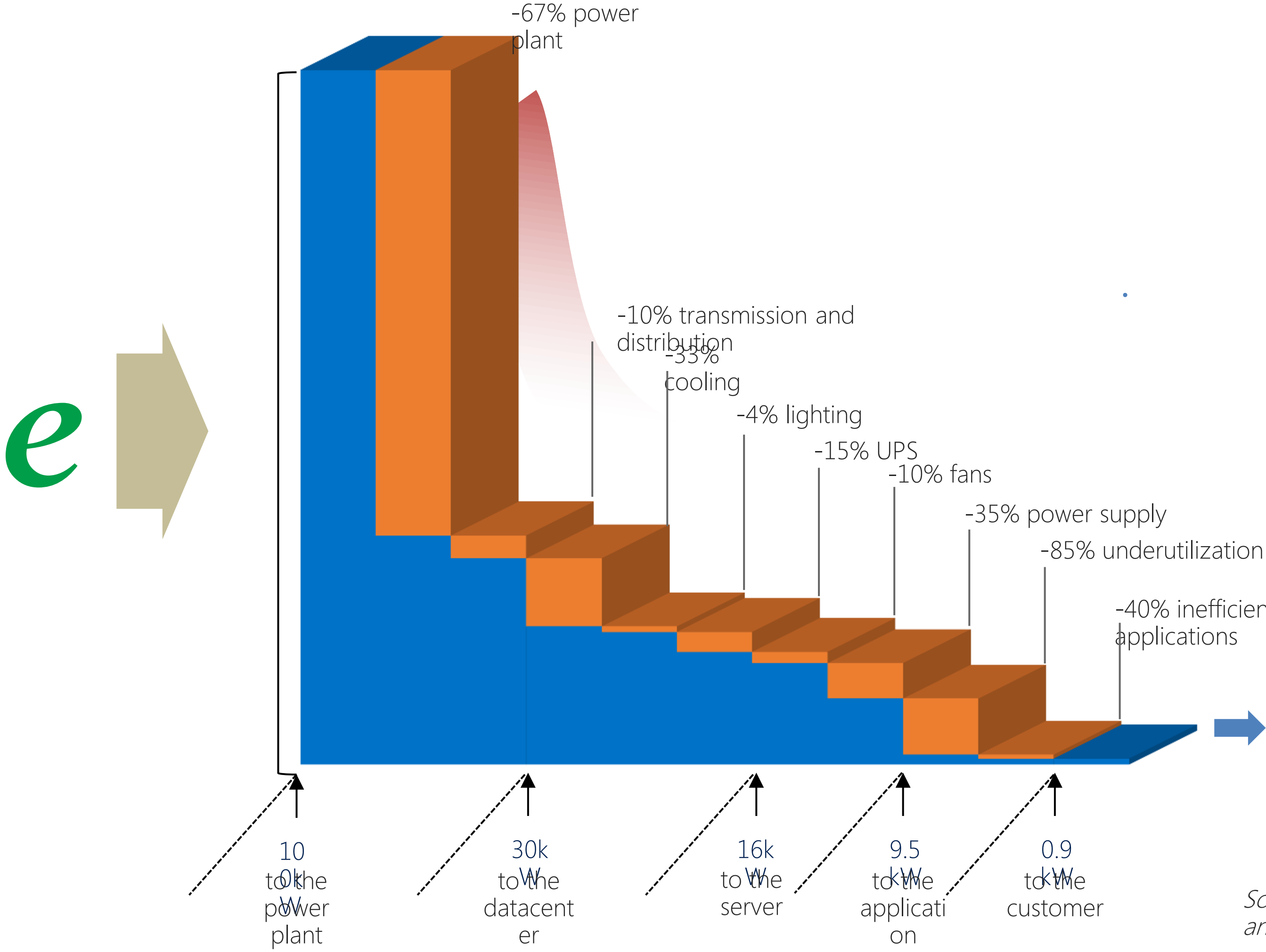
MESA Goals

- **Standardize components and interfaces**
  - Scalable, modular ESS from standard batteries, PCS, s/w
- **Give utilities real, long-term flexibility**
  - Avoid rigid, proprietary solutions
  - Enable true, large-scale **ES infrastructure**: scalable, manageable
- **Give suppliers more reach**
  - Core competencies, lower cost → more customers, profit
- **Transform the energy storage market**
  - Standard components, more customers, lower risk for all

Datacenter energy R&D

Sean James
Sr Research Program Manager
Microsoft Corporation

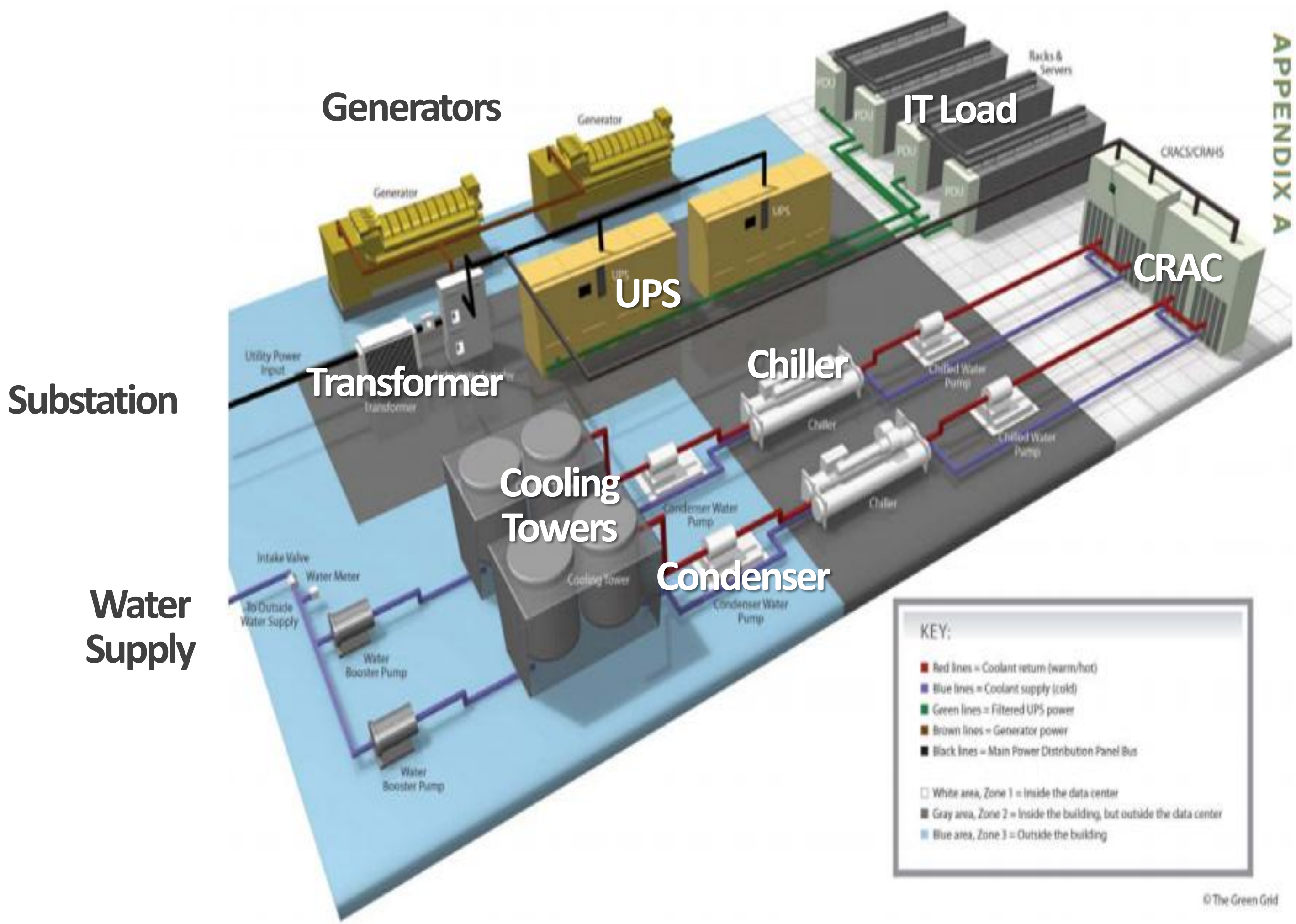
Typical datacenter energy system efficiency



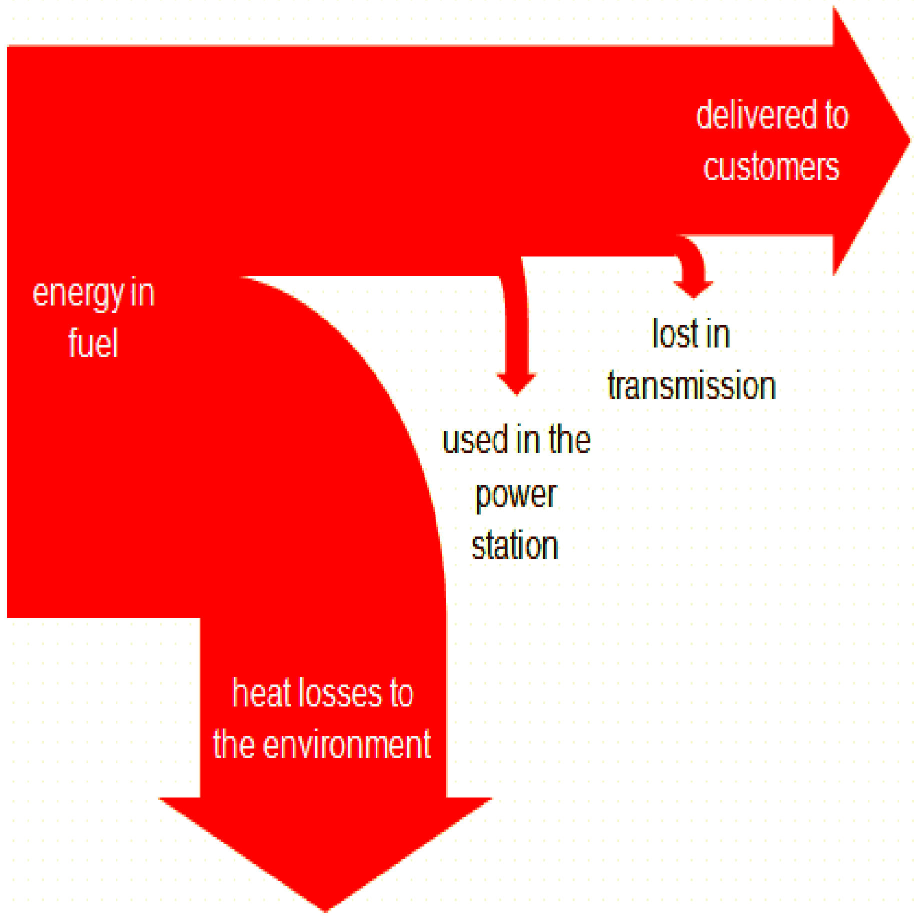
>99% of initial energy lost in conversion

Source: Reinventing Fire (Lovins and RMI)

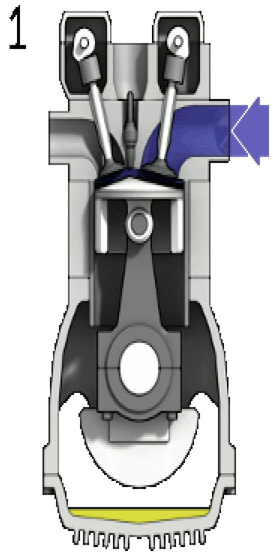
Conventional Datacenter



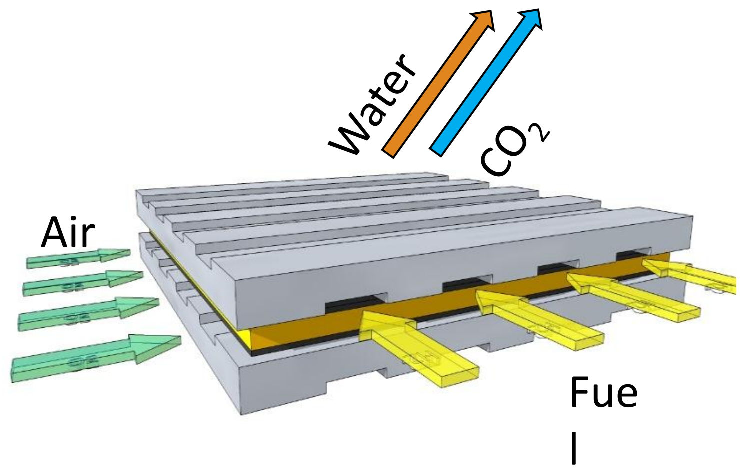
Plant losses



Power generation



Reciprocating



Electrochemical

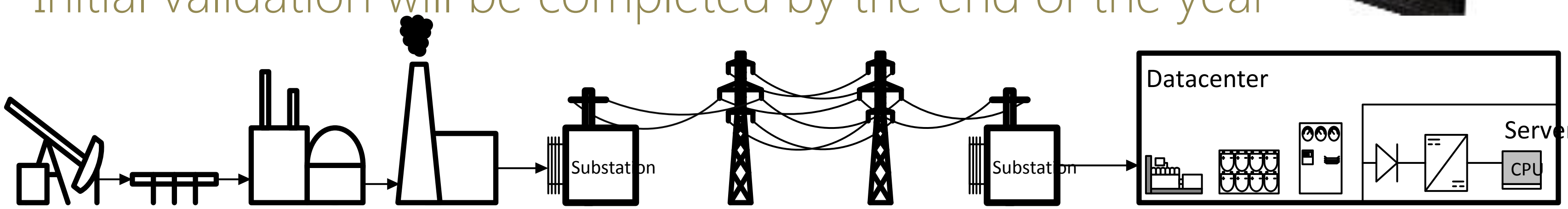
Redesigning datacenters towards hyper-efficiency

Data Plant: Integrating power generation and data production

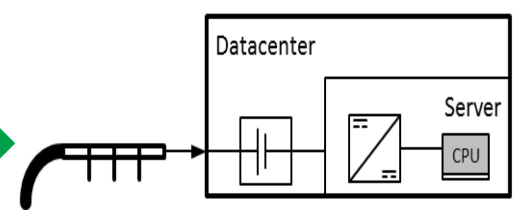
- Simplifies the supply chain and deliver greater efficiency
- Reduces losses, infrastructure costs and emissions

What, when and how?

- In-rack fuel cells deliver DC power directly to the server
- 2x the total system efficiency from power plant to chip
- Initial validation will be completed by the end of the year



Radically simplified supply chain delivers more data with less resources



Microsoft Datacenter Resources

Microsoft Datacenter Team Web Site & Blogs

www.microsoft.com/datacenters

Microsoft Environmental Sustainability Web site

www.microsoft.com/environment

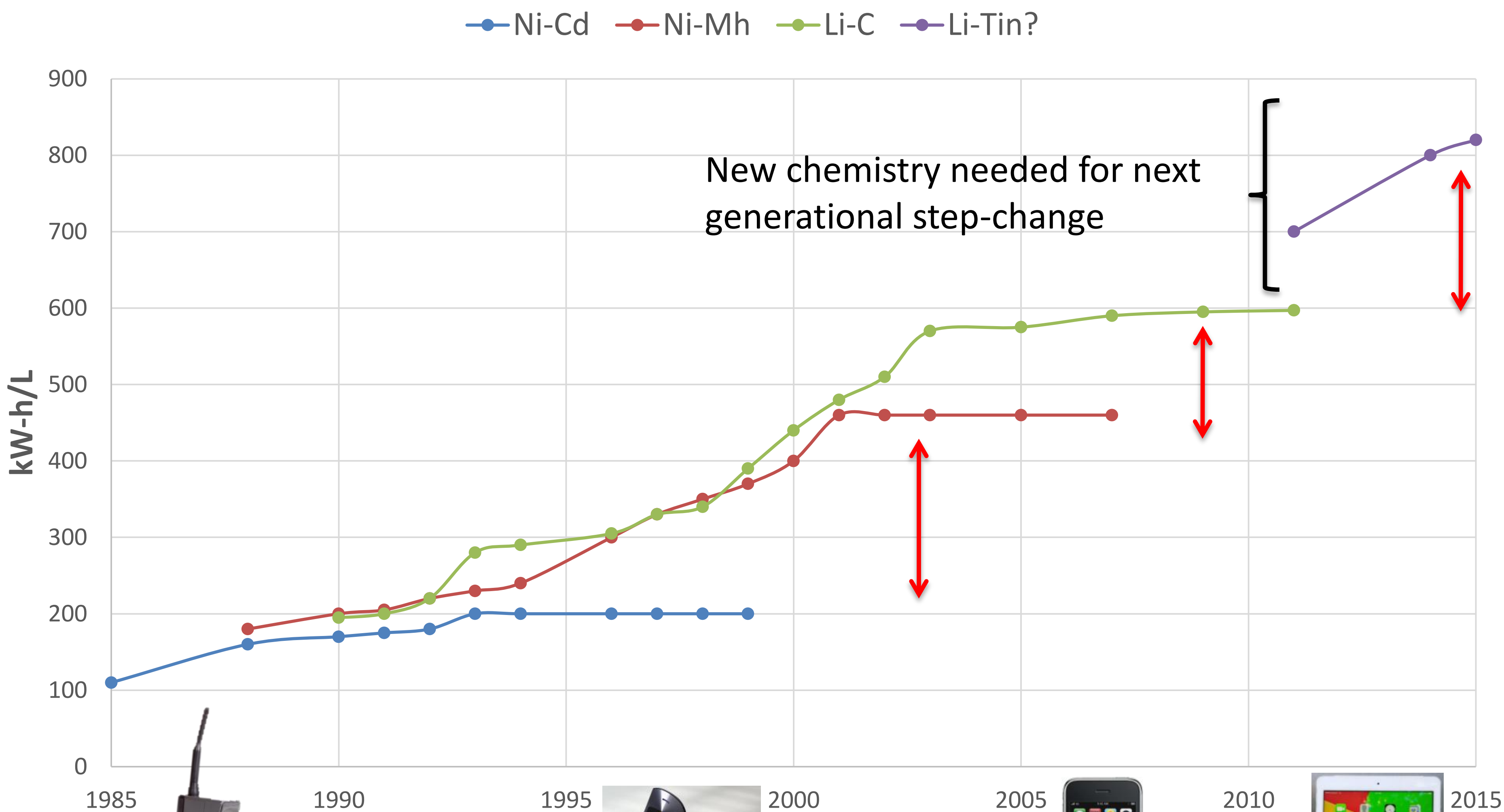
Tell Me What You Want, What You Really, Really Want

Battery Technology for Mobile Applications

The Consumer Wish List:

- Bright, hi-res screen
- Fast processor/graphics
- GPS
- Camera
- Lots of apps
- Fast internet, multiple wireless radios
- Always-on data for rich apps
- Predictive computing features
- No worry about battery life

Increased Capacity Enables Innovation



2 AA alkaline
4-6 h

Ni-Cd rechargeable
2-4 h

primary or secondary
12 h use

Li rechargeable
1-2 days use

1 Li rechargeable
6-8 h

Li rechargeable - 1 day use

Candidate Next-Gen Battery Chemistries

New materials to improve lithium-ion batteries
An Example: the anode
Improves: energy, power, safety, cycle life

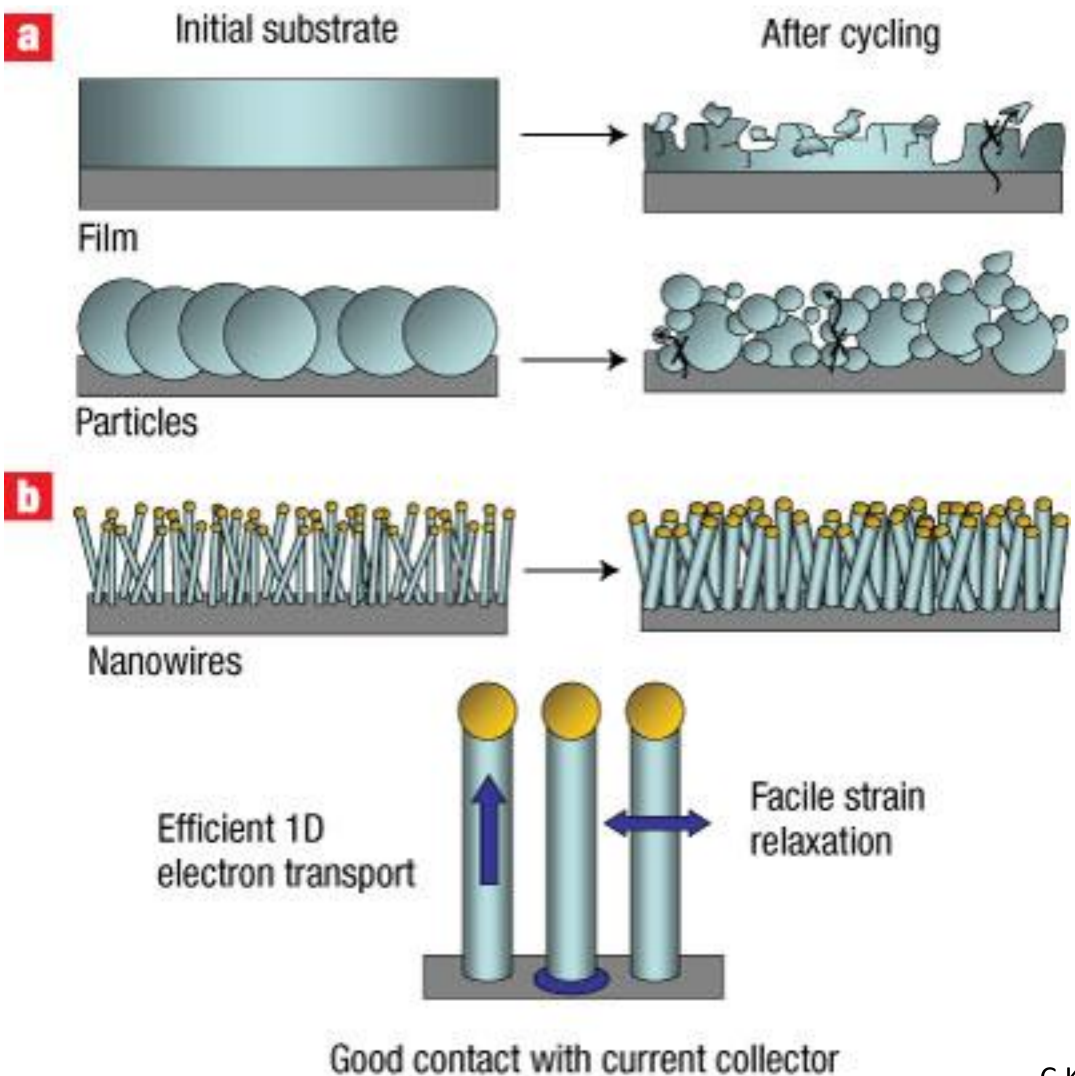
Metal	Li	Si	Al	Ge	Sn (WSU)	Al	Graphite
M_xLi_y	Li	$Li_{22}Si_5$	Al_4Li_9	$Li_{22}Ge_5$	$Li_{22}Sn_5$	AlLi	LiC_6
Max. capacity (mAh/g)	>3800	>3000	2234	1600	994	993	372
Volume change	Dendritic	323	-	370	300	97	9

Current State of the Art

Highest possible is Li-F battery
3,053 Wh/kg

Increasing capacity

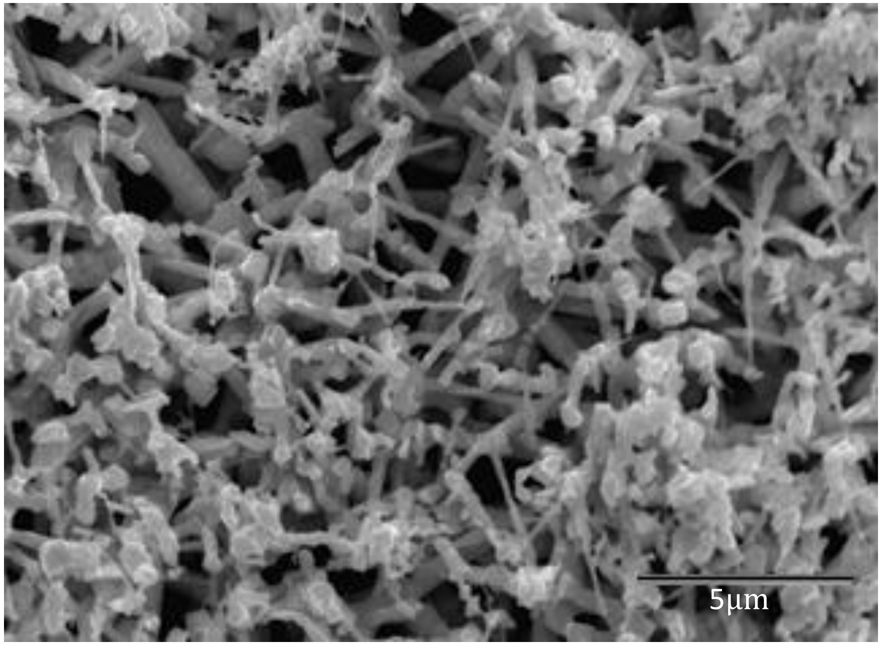
Importance of Nanostructures for Long Life



- When you incorporate large amounts of lithium your anode swells
- You can an overcome this with nanotechnology

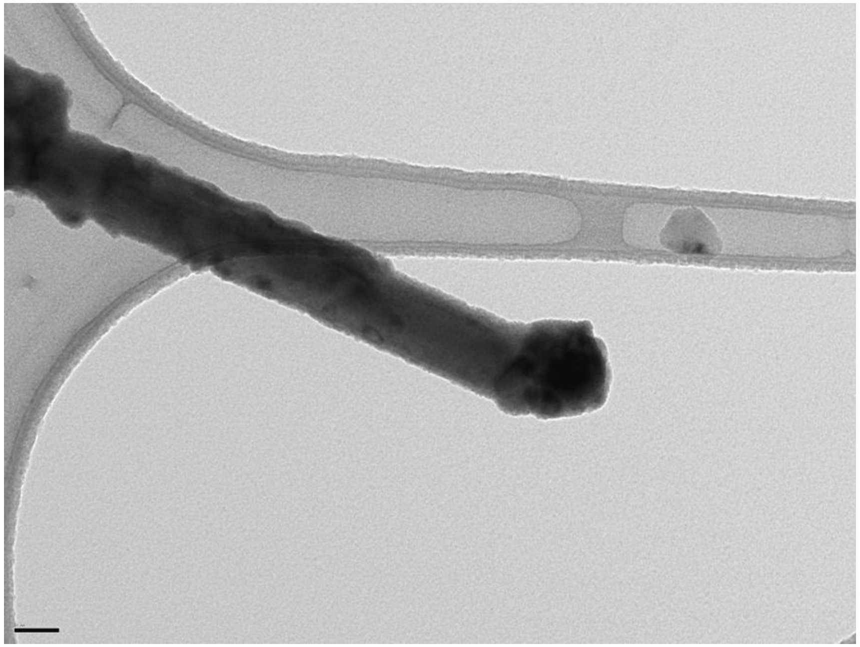
C.K. Chan, *Nature Nanotechnology* ***3, 31 - 35 (2008)***

Tin Nanoneedles a Washington State University Technology



SEM image

Densely arrayed nanoneedles directly on copper current carrier

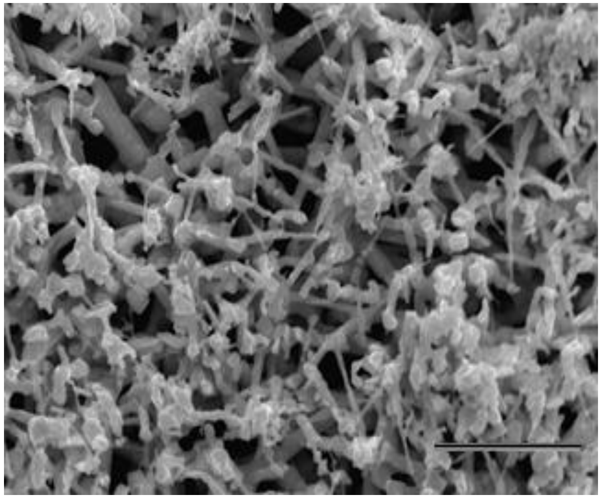


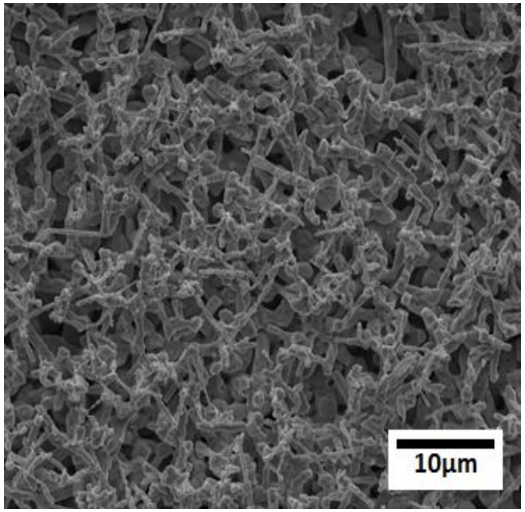
TEM image

Needle diameter ~ 50nm

Scalable Nanomanufacturing

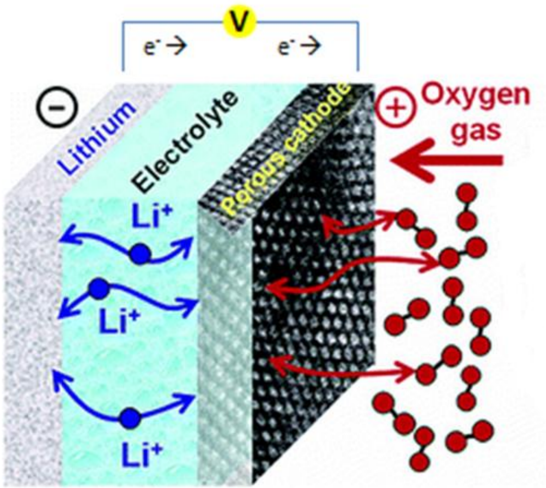
1cm x 1cm → 6cm x 2cm → 65cm x 7cm



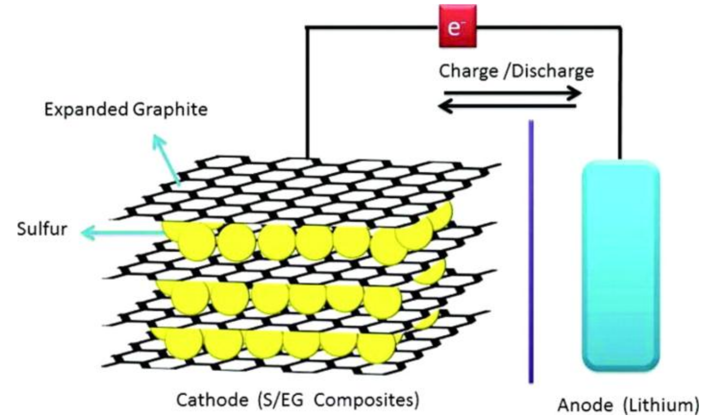


This is important – process must be low cost and industry scalable
Anode is 14% of materials cost

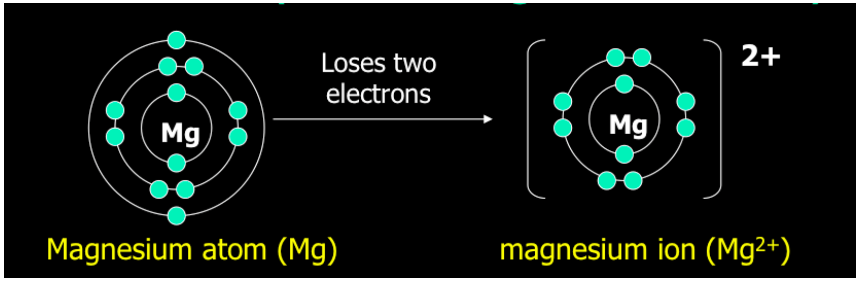
Next Decade +



Lithium-air

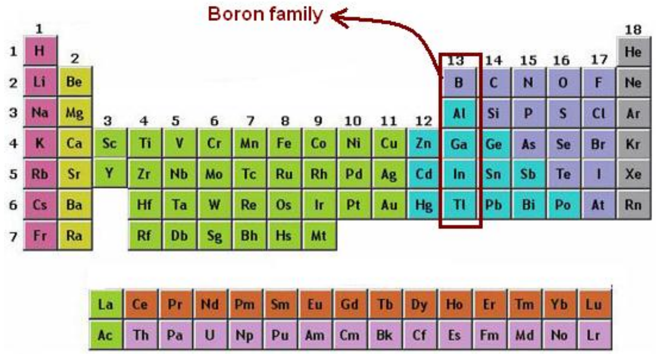


Lithium-sulfur



Magnesium

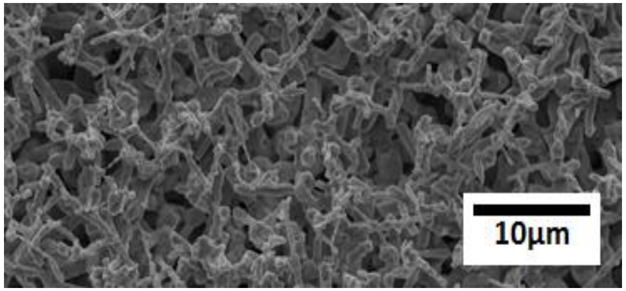
Beyond lithium



Aluminum

Mega Opportunities

Nanomanufactured Materials



Battery components that maximize energy per weight/volume with long life will require nano-structured designs

Flexibility

Consumers are expecting wearable, flexible electronics – materials that fit this need will be chosen first

Sustainable/Recyclable

Current battery materials highly toxic
Battery chemistries that incorporate easily recyclable or biologically-based materials will make the most impact

Mega Barriers

Safety

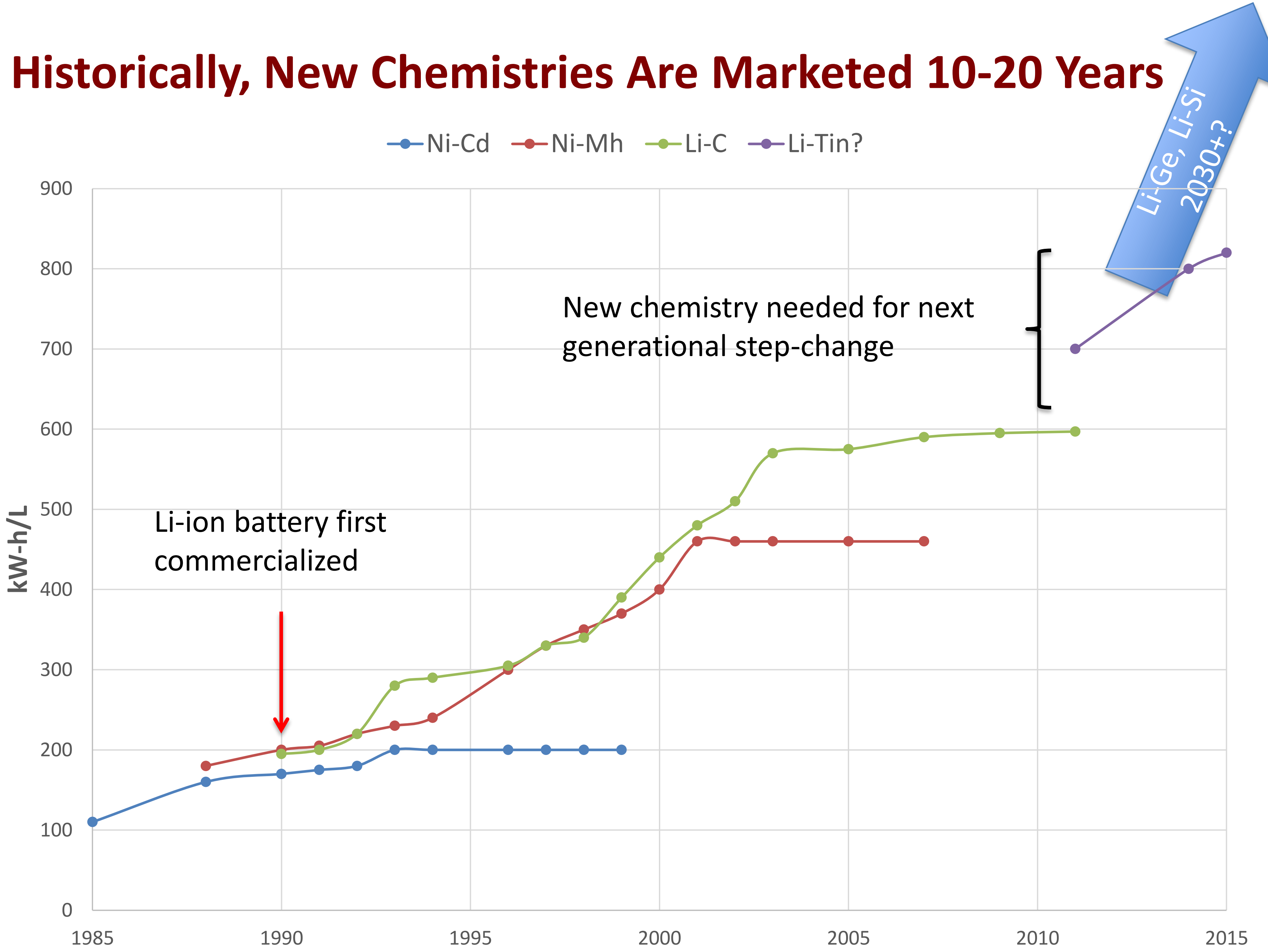
To go mainstream, any new chemistry must be proven safe. Look at all that energy density!

M_xLi_y	Li	$Li_{22}Si_5$	Al_4Li_9	$Li_{22}Ge_5$	$Li_{22}Sn_5$	LiC_6
Max cap	>3800	>3000	2234	1600	994	372

Industry Buy-in

For significant industry adoption, an entire supply chain around battery component materials and major capital investment is needed

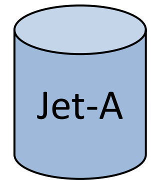
Historically, New Chemistries Are Marketed 10-20 Years

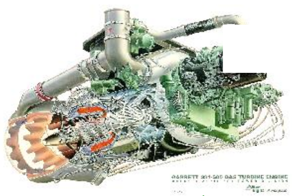


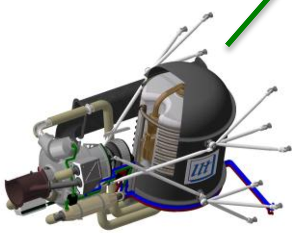
Over the Horizon

Typical turbine-powered APU

15% efficient = 1 liter

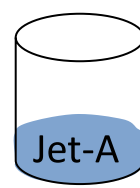






Future SOFC APU

60% efficient = 0.25 liter



75% less fuel used

Why Fuel Cells

- Non polluting
- High efficiency – 75% of fuel's bond energy into electricity (coal fired power plant 35%; internal combustion engine 25%)
- Fuel flexible – Transportation/Stationary: Jet-A, gasoline, biodiesel - Mobile : methanol, formic acid

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