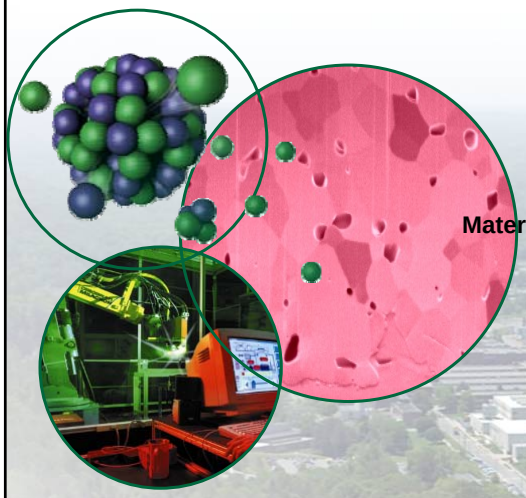
The United States need new batteries
An investment potential in research and future technology



Claus Daniel

Materials Science and Technology Division
Oak Ridge National Laboratory

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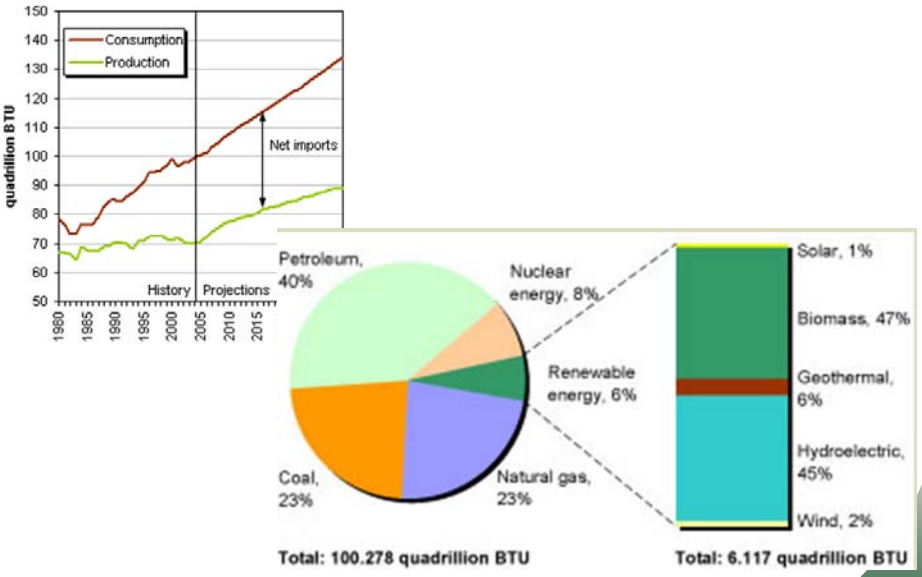
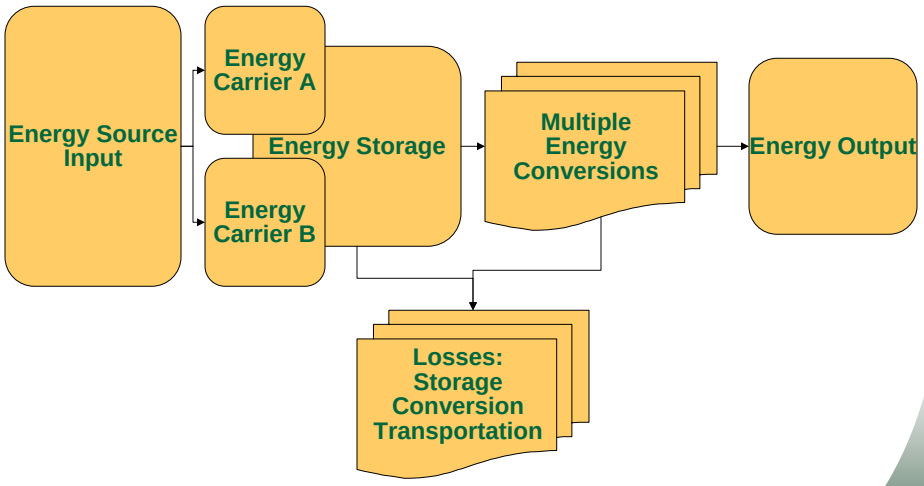
Our today's energy supply

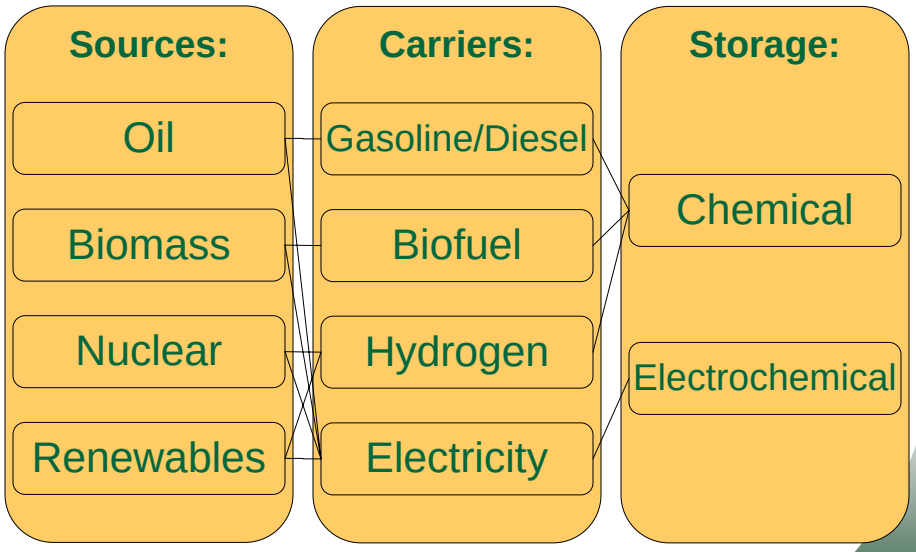


Source: Energy Information Administration

Energy conversion

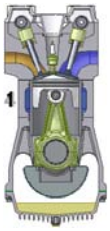


Energy classifications



Energy efficiency
Example Transportation

Internal Combustion Engine



Total chemical energy 100%

Cooling 36%

Exhaust 38%

Friction 6%

Mechanically used 20%

Waste 80%

Electric Engine

Including power plant losses e.g. 10% hydro, 51% coal
Results in 39%-71% net efficiency for small electric engine

Battery 5%

Induction/Heat 10%

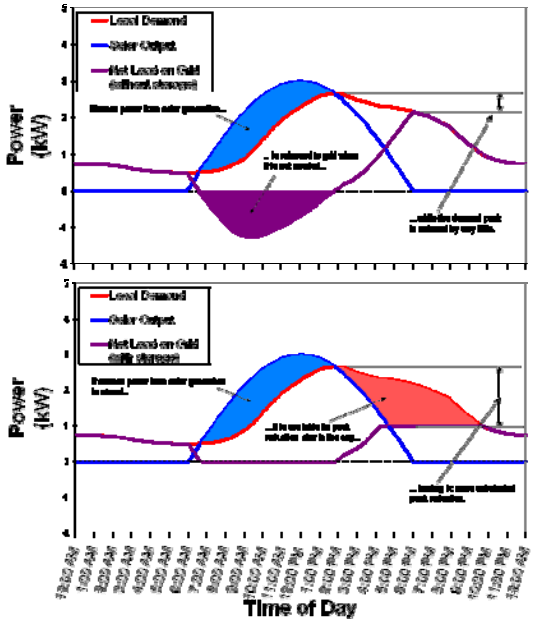
Friction 6%

Waste 21%

5 Managed by UT-Battelle
for the Department of Energy

MSTD/CD-Apr-08

Stationary Storage Motivation



Source: EPRI

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MSTD/CD-Apr-08

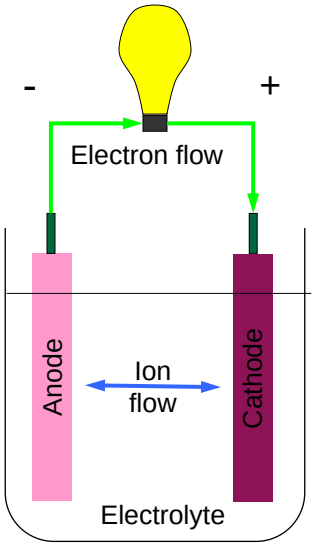
Energy Storage Technologies

- **Electrochemical (batteries and electrochemical capacitors)**
  - **Long series strings of batteries are considered troublesome.**
- **Physical (flywheels, pumped hydro, compressed air)**
  - **long life, generally only large scale, flywheels are expensive**
- **Magnetic (superconducting magnetic storage=SMES)**
  - **expensive, large scale**
- **Chemical (H_2 generation, electrolysis + fuel cell)**
  - **generally energy conversion rather than storage to/from electrical**
- **Thermal (adiabatic compression/expansion, heat exchange, phase transition)**

T. Armstrong et al.

What is a battery?

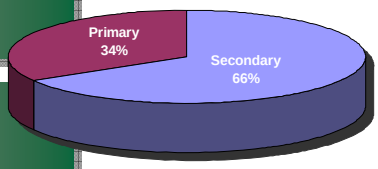
- **A device that stores chemical energy in its active materials and converts it, on demand, into electrical energy by means of an *electrochemical reaction***
  - ***Electrochemical reaction* is a chemical reaction involving the transfer of electrons**
- **Batteries are made up of one or more basic electrochemical units called *cells.***
  - ***Cells* are usually connected in series to increase the voltage.**



Sentech

Types of batteries

- ***Primary batteries*** **are used once and thrown away, like the alkaline batteries used in portable CD players**
  - **Electrochemical reactions are not reversible and active materials cannot be restored to their original state.**



- ***Secondary (or rechargeable) batteries*** **can be used many times, like the battery in cell phones and laptop computers**
  - **The electrochemical reactions are reversible, and the active materials can be restored to their original chemical composition.**

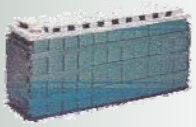
Widely used rechargeable batteries

Market share

- **Lead acid**
  - **Over 100 years old, and still the most widely used rechargeable battery in the world.**

51%

- **Nickel metal hydride**
  - **A high power battery chemistry similar to nickel cadmium, introduced in the 1980s. It is environmentally friendly, contains no toxic cadmium, and is replacing NiCd in many applications.**



8%

- **Lithium ion**
  - **The newest and fastest growing rechargeable battery technology.**

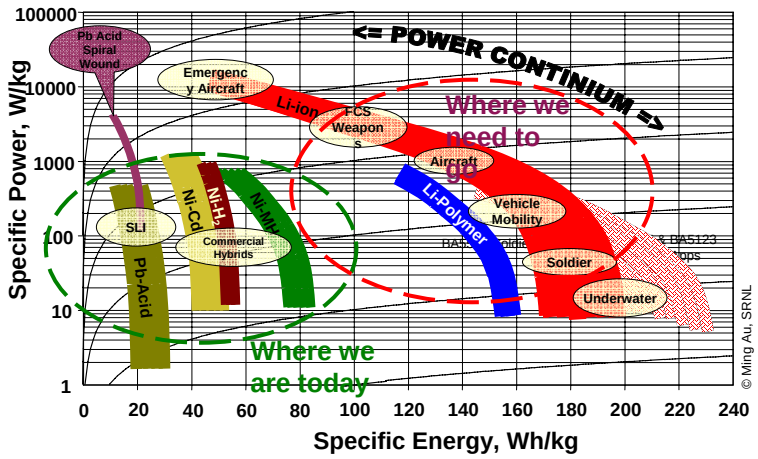
31%

Others

10%

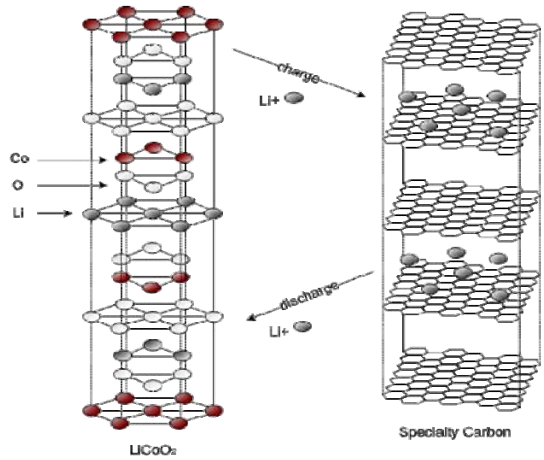
Main concerns: large volumes, liquid technology, leakage, and toxicity

Actual technology and materials



Lithium ion, lithium polymer

Lithium ion battery principle



Discharge reaction: $Li^+ + e^- + MeO2 \rightarrow LiMeO2$ $\quad LiC6 \rightarrow Li^+ + e^- + C_6$

Lithium ion battery problems

- **Cost**
  - **raw materials**
  - **materials processing**
  - **cell and module packaging**
  - **manufacturing**
- **Performance**
  - **discharge pulse power limitations at low temperatures**
  - **capacity and power fading**
- **Abuse Tolerance / Safety**
  - **short circuits**
  - **overcharge**
  - **over-discharge**
  - **crush**
  - **fire or high temperatures**
  - **thermal runaway**
- **Life**
  - **calendar life**

DOE Energy storage targets

Characteristics	Minimum value	Maximum value
Pulse discharge power (kW)	25 (for 10 seconds)	40 (for 10 seconds)
Maximum regenerating pulse (10 s; kW)	20 (50 Wh pulse)	35 (97 Wh pulse)
Total available energy (kWh)	0.3	0.5
Round trip efficiency (%)	>90, 25 Wh cycle	>90, 50 Wh cycle
Cycle life (cycles)	300k 25-Wh cycle (7.5 MWh)	300k 50-Wh cycle (15 MWh)
Cold-cranking power at −30°C (three 2-sec pulses, 10-s rests between; kW)	5	7
Calendar life (years)	15	15
Maximum weight (kg)	40	60
Maximum volume (liters)	32	45
Production price @ 100k units/year ($)	500	800
Maximum operating voltage (Vdc)	<400 maximum	<400 maximum
Minimum operating voltage (Vdc)		
Maximum self-discharge (Wh/d)		
Operating temperature (°C)		
Survival temperature (°C)		

HEV

PHEV

Characteristics at EOL (End of Life)		High Power/Energy Ratio Battery	High Energy/Power Ratio Battery
Reference Equivalent Electric Range	miles	10	40
Peak Pulse Discharge Power (2 sec/10 sec)	kW	50/45	46/38
Peak Regen Pulse Power (10 sec)	kW	30	25
Available Energy for CD (Charge Depleting) Mode, 10 kW Rate	kWh	3.4	11.6
Available Energy in CS (Charge Sustaining) Mode	kWh	0.5	0.5
CD Life / Discharge Throughput	Cycles/ MWh	5,000 / 17	5,000 / 58
CS HEV Cycle Life, 50 Wh Profile	Cycles	300,000	300,000
Calendar Life, 35°C	year	15	15
Maximum System Weight	kg	60	120
Maximum System Volume	Liter	40	80
System Recharge Rate at 30°C	kW	1.4 (120V/15A)	1.4 (120V/15A)
Unassisted Operating & Charging Temperature	°C	-30 to +52	-30 to +52
Survival Temperature Range	°C	-46 to +66	-46 to +66
Maximum System Production Price @ 100k units/yr	$	$1,700	$3,400

Battery production prize for vehicles

Targets*

- **HEV (0.3-0.5kWh)**
  - **$1.6 – 1.7/Wh**
- **PHEV (3.4-11.6kWh)**
  - **$0.3 – 0.5/Wh (charge depleting mode)**

State of the art

- **HEV (0.3-0.5 kWh)**
  - **High quality materials: $1.28-1.33/Wh**
  - **Max. processing and manufacturing: $0.32-0.37/Wh**
  - **State of the art low cost materials can potentially save 25%.**

*based on 100k units per year

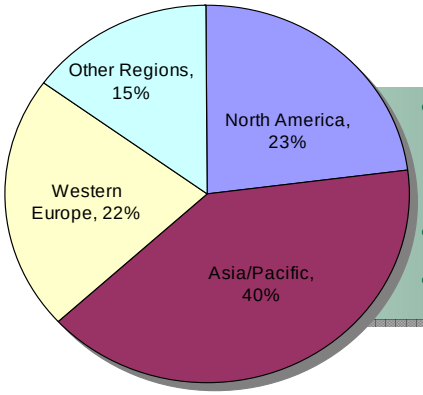
Processing and Manufacturing together between $0.32 and $0.64 per Wh!
That's just $100-190 for a 25kW unit!

DOE, Energy Storage Research and Development Annual Progress Report 2008
G.L. Henriksen et al., Materials Cost Evaluation Report for High power Li-ion HEV Batteries, ANL

Research need for materials and processing for batteries

- **New design**
  - **replacing actual sheet-rolling design**
- **barrier coatings**
  - **preventing oxidation, decomposition, gas formation, electrolyte intercalation**
- **film deposition**
  - **preventing inactive electrode areas due to no physical contact to gel electrolyte**
- **thermal processing of electrodes without affecting polymers or temperature sensitive substrates**
  - **photonic processing for annealing, sintering, solidification of surfaces**
- **3D-electrode/battery design**
  - **battery foam materials, flexible chemically bonded layer structure**
- **electrode inter-connection**
  - **periodic structuring of electrodes and nano-fiber arrays**

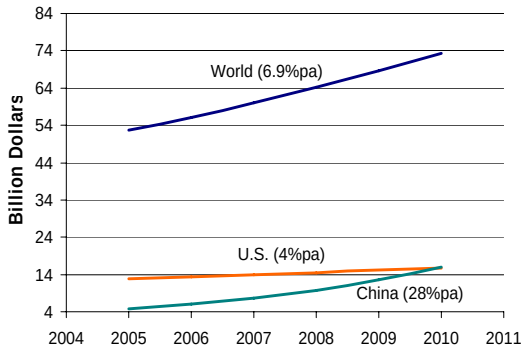
North America is with 23% of the world demand the largest single country battery market today



Source Freedonia

- **$52.6 Billion world demand today**
- **U.S.: $12 Billion**
- **China: $4.7 Billion**

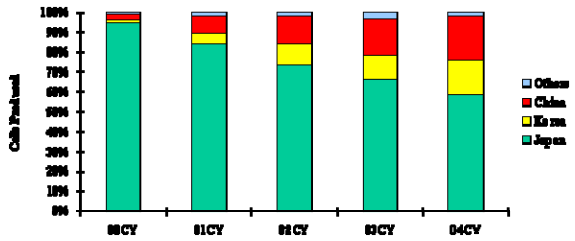
China's battery demand is growing 7 times faster than the U.S. and will surpass the U.S. in 2010



- **Worldwide battery demand projected to grow by $21 Billion until 2010.**
- **China's market will rise by 28% annually while the U.S. will rise only by 4%.**
- **By 2010, China will surpass the U.S.**

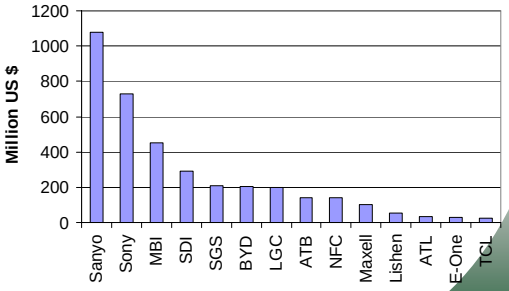
Calculations based on Freedonia predictions

Batteries are manufactured in Japan



U.S. world share in manufacturing is insignificant and included in "others"

U.S. needs to break into batteries with breakthrough technology and new design.



U.S. needs investment in high-end battery research

President Bush's State of the Union Address

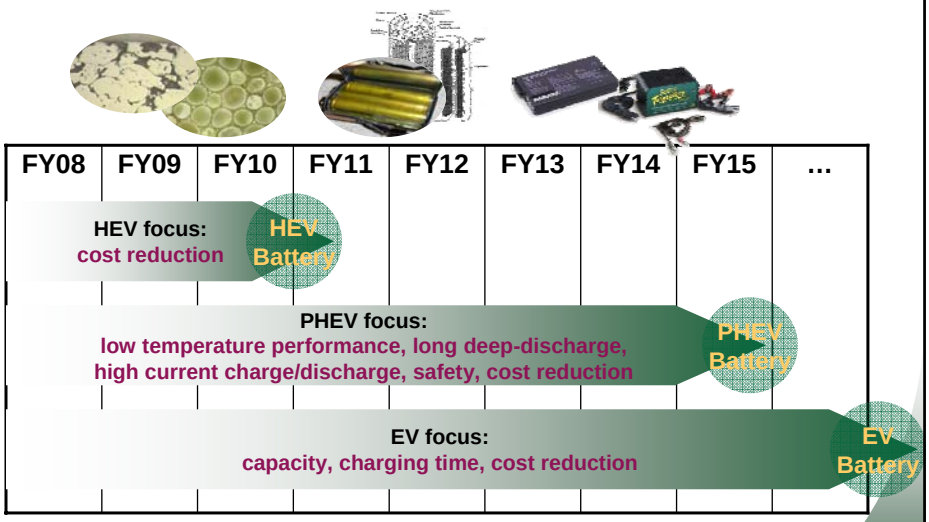
"Let us continue **investing in advanced battery technology** and renewable fuels to power the cars and trucks of the future. […]"
2008

"It's in our vital interest to diversify America's energy supply -- the way forward is through technology. […] **We need to press on with battery research** […]."
2007

Keeping America competitive requires affordable energy. […] We must also change how we power our automobiles. **We will increase our research in better batteries** […]
2006

- **Japanese manufacturer hold 80% market share**
- **Low-tech manufacturing shifted to China because of production cost drop of 10-50%.**
- **U.S. needs to invest in battery research for high-tech products**

And we need it fast…



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