

Future of Energy Efficiency Research at Berkeley Lab



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EETD Organization

Advanced Energy Tech. (Russo) - 95 staff

- Battery Program
- Physical/Chemical tech.
- Combustion tech.

Indoor Environment (Fisk) - 63 staff

- Environmental Chemistry & Exposure
- Airflow and pollutant transport
- Commercial building & indoor env. Quality
- Energy performance & buildings

Atmospheric Sciences

(Brown) - 26 staff

- Atmospheric Processes & Air quality
- Atmosphere & global climate
- Emissions
- Aerosols

Building Technology Dept.

(Selkowitz) - 66 staff

- Windows & daylighting
- Commercial buildings systems
- Lighting systems
- Simulations
- Demand response
- Applications

Energy Analysis Dept. (McMahon)- 123 staff

- Electricity Markets & Policy
- China energy
- International Energy Studies
- Govt & Industry Programs
- Energy Efficiency Studies
- End use forecasting & market assessment
- Heat islands
- Independent research projects

2007 IPCC Nobelists from EETD

1. Mark Levine
2. Surabi Menon
3. Evan Mills
4. Lynn Price
5. Jayant Sathaye
6. Ernst Worrell
7. Maithili Iyer
8. Phil Haves
9. Stephane de la Rue du Can

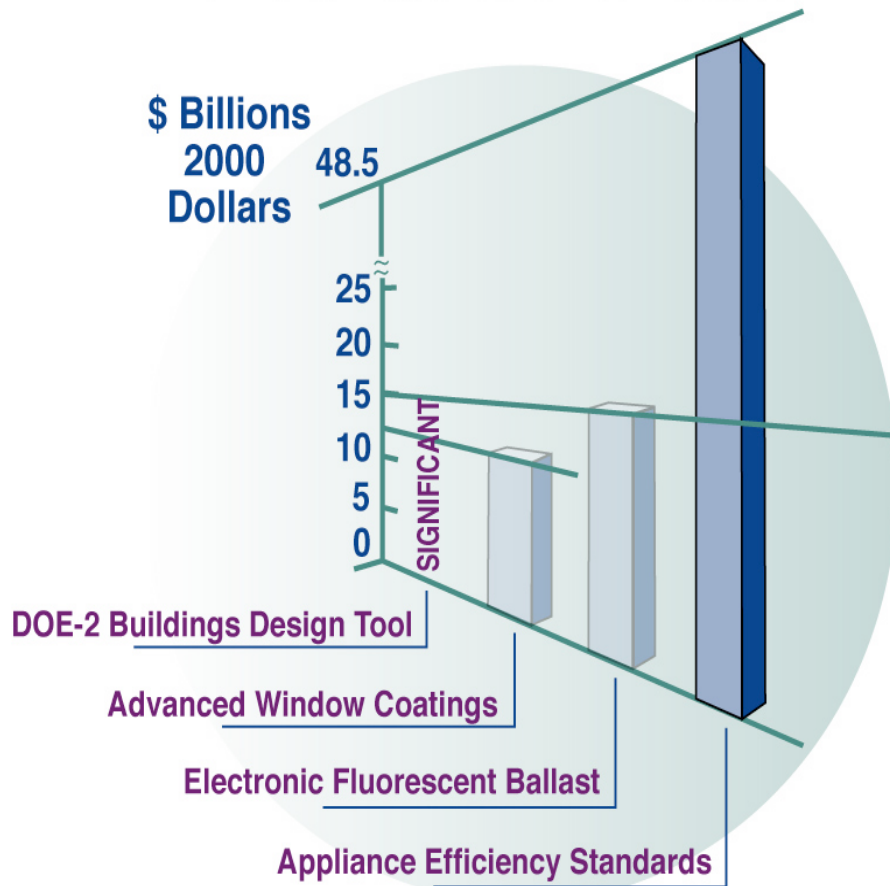


Prior Impacts of EETD's Efficiency R&D

From National Academy of Sciences Report

Estimate of Economic Benefits

Lifetime Savings (Net) for Technologies*



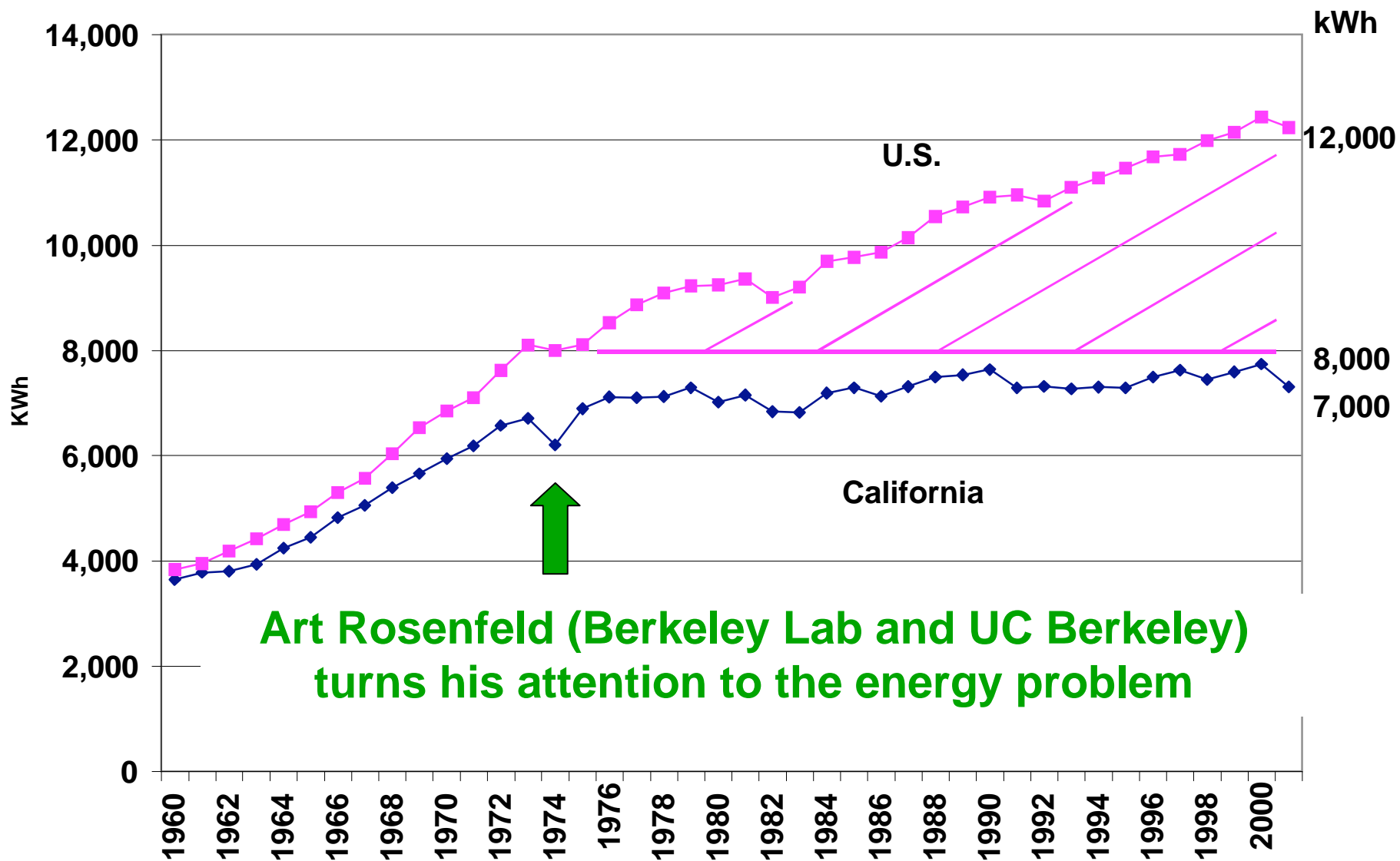
NAS estimate of economic benefits of EE R&D assigns \$23 of \$30 billion in savings to LBNL - derived technologies

Additional \$48 billion in savings from energy efficiency standards for 9 residential products

- *Primary energy savings*
= 9% of 2025 residential energy use
- *Carbon reductions in 2025*
= 132 million metric tons CO₂/year

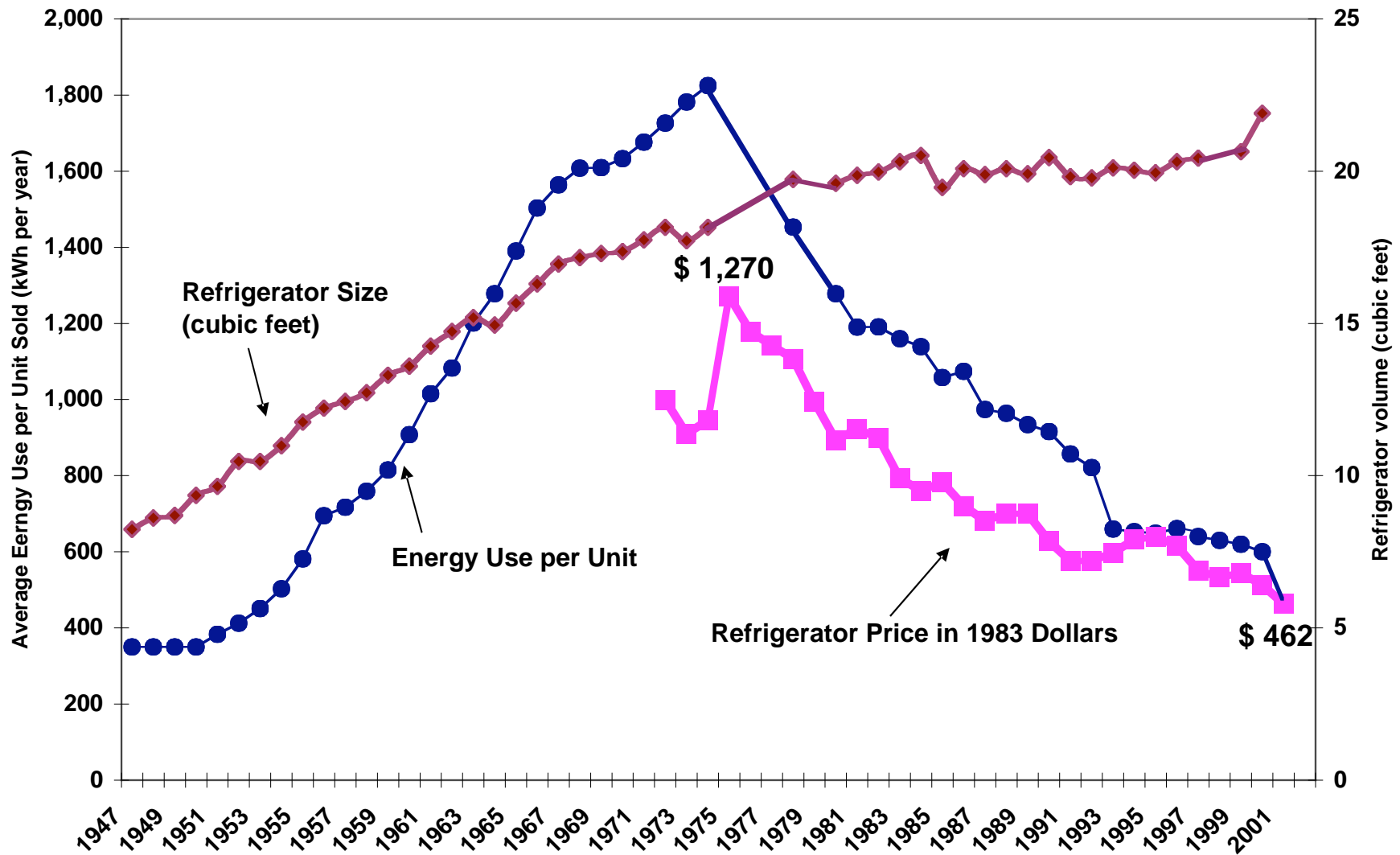
Per Capita Electricity in the U.S. and California (1960-2001)

(Karin)



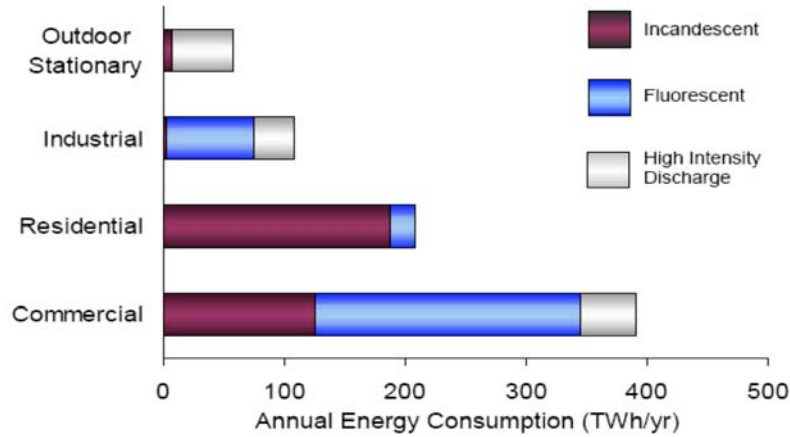
U.S. Refrigerator Energy Use

United States Refrigerator Use v. Time

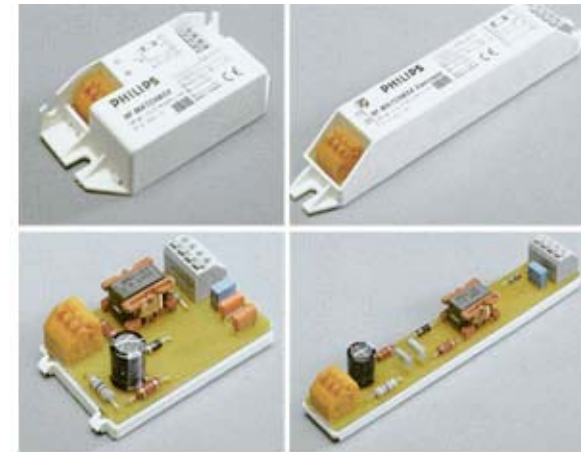
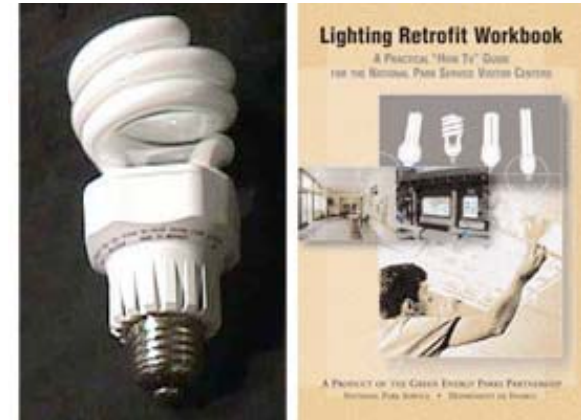
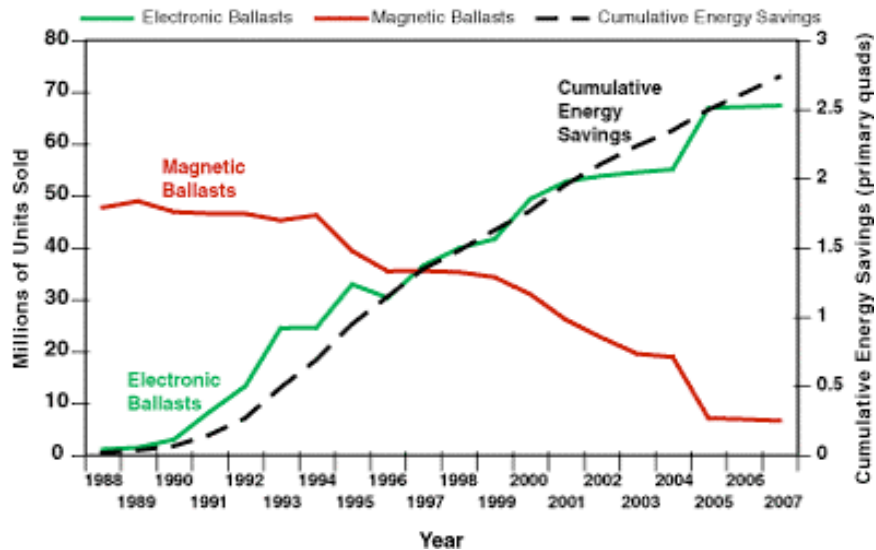


Fluorescent Lighting

390 Billion kWh used for lighting in all commercial buildings in 2001

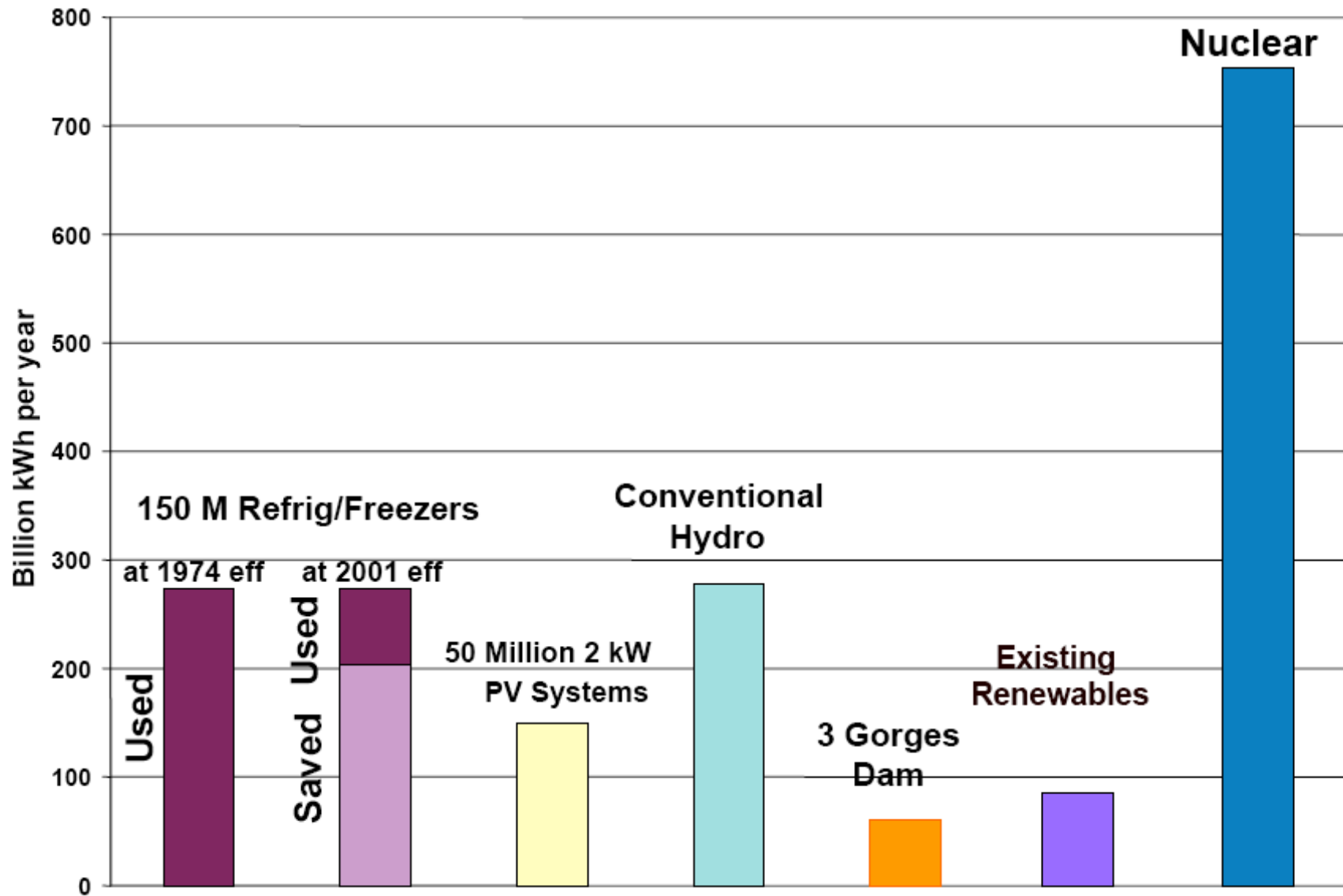


Ballast Sales and Energy Savings

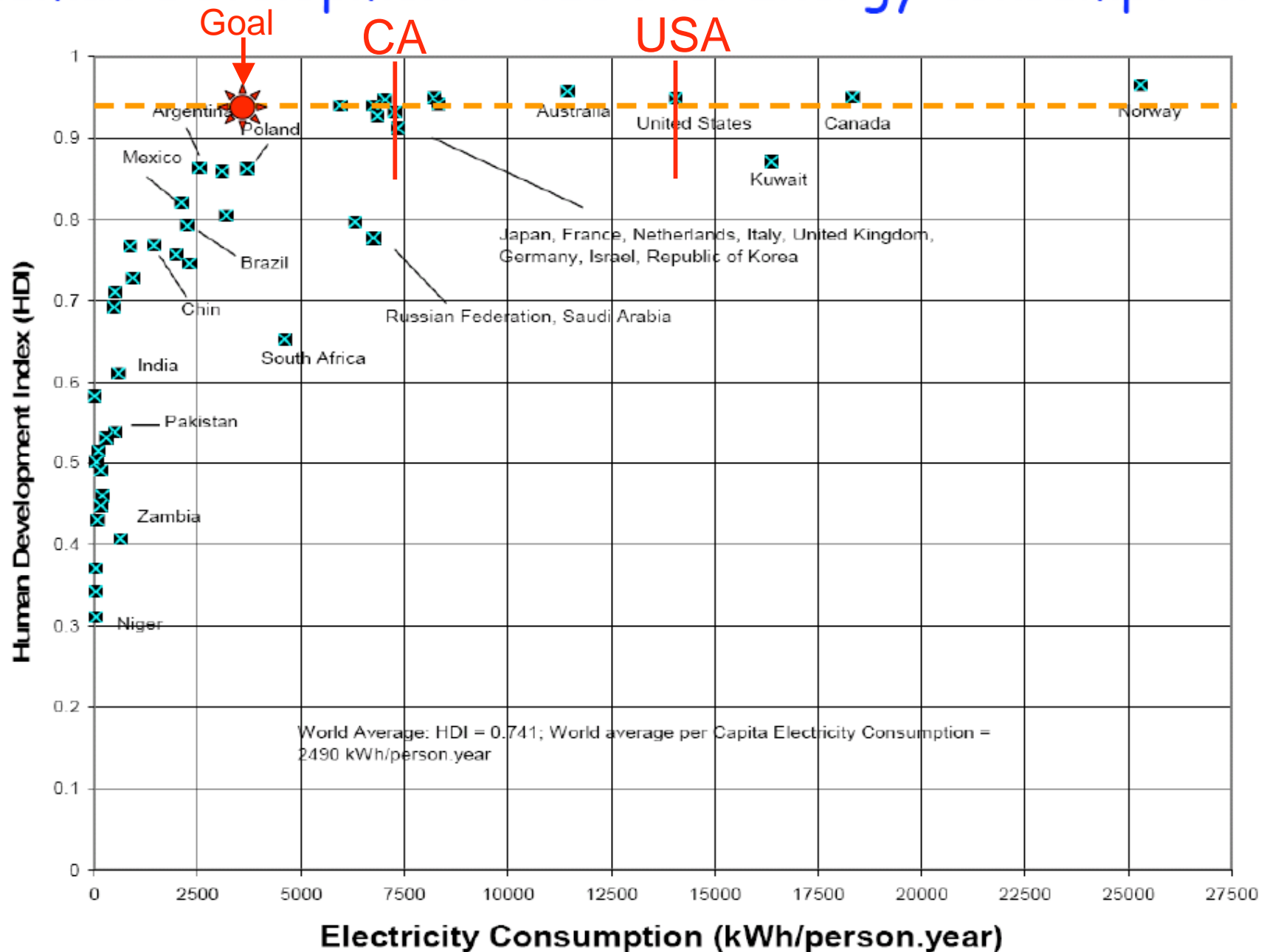


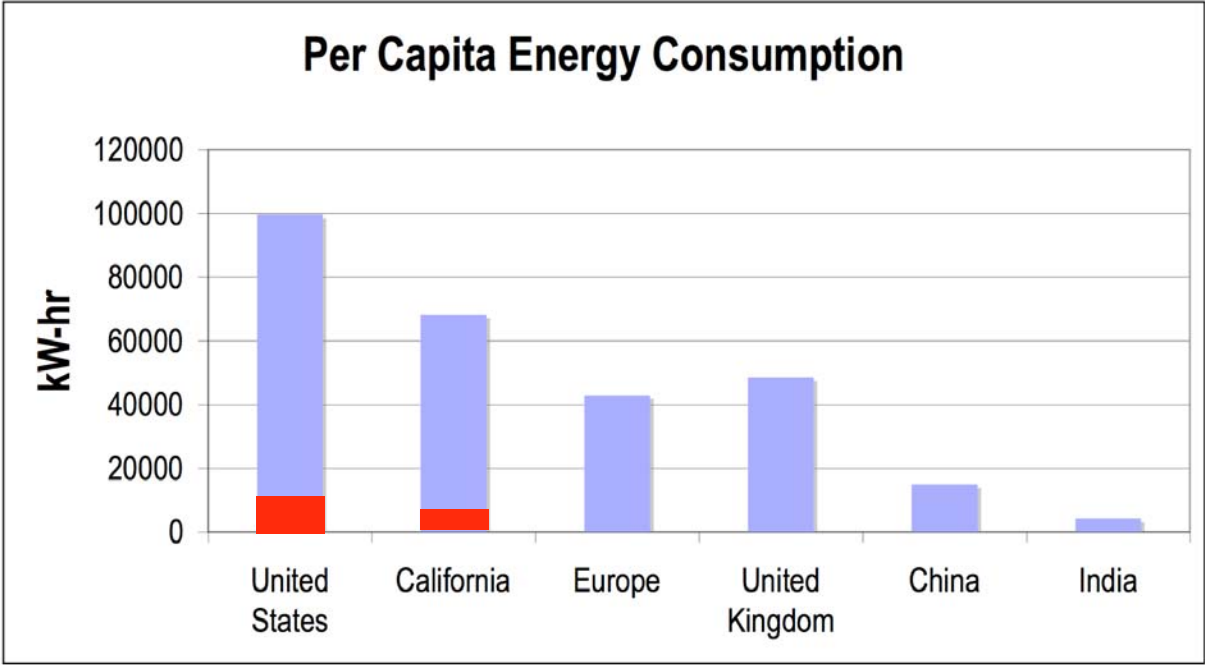
1 quad = 300 billion kW-hr

US Electricity Use of Refrigerators and Freezers compared to sources of electricity

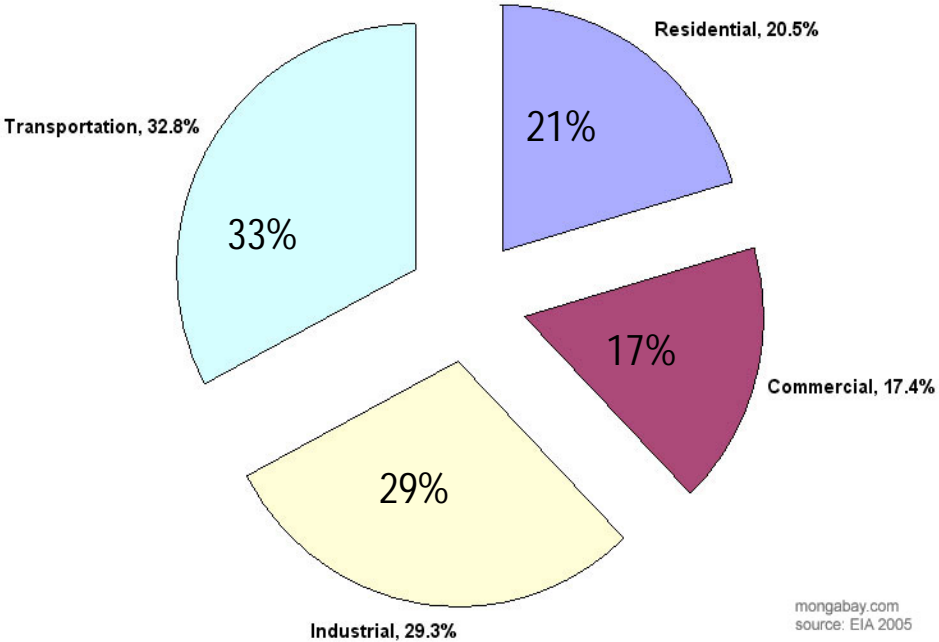


Human Development Index vs. Energy consumption

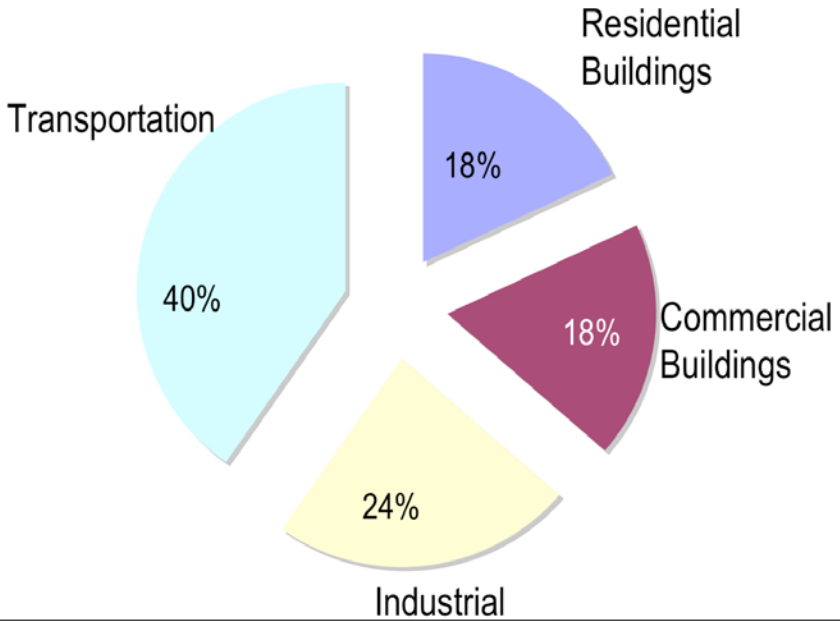




US Energy Consumption



California Energy Consumption



Helios Project - Supply Side

Demand Side

EBI & JBEI

SERC

Lawrence Berkeley National Laboratory



Physical Biosciences Division

Materials Sciences Division

Environmental Energy Technology Division

Biofuels

Photovoltaics
Photoelectrochemical
Devices

University of California, Berkeley



Biological Sciences

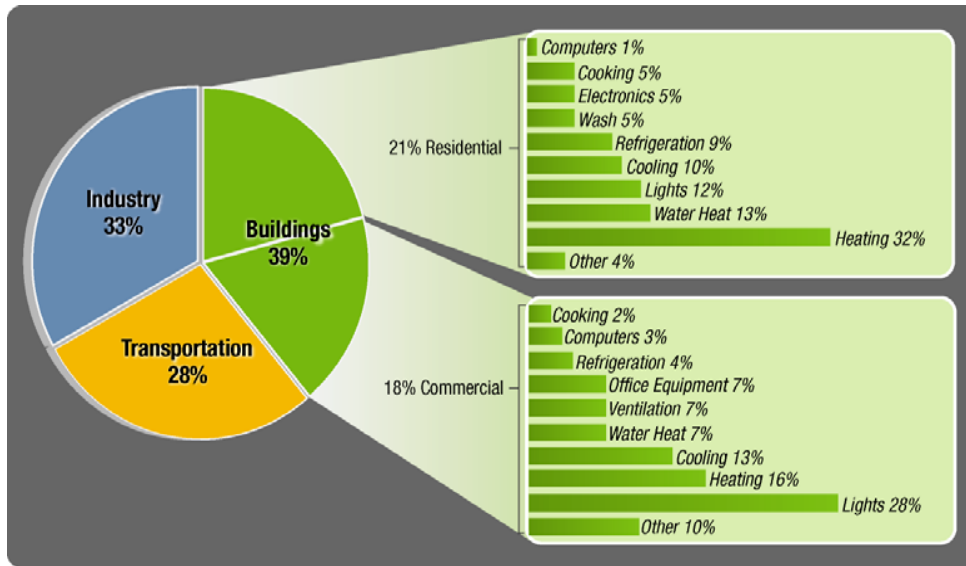
Physical Sciences

Architecture/Planning

College of Chemistry

College of Engineering

Demand Side



U.S. Buildings consume

- 39% of total U.S. energy
- 71% of U.S. electricity
- 54% of U.S. natural gas

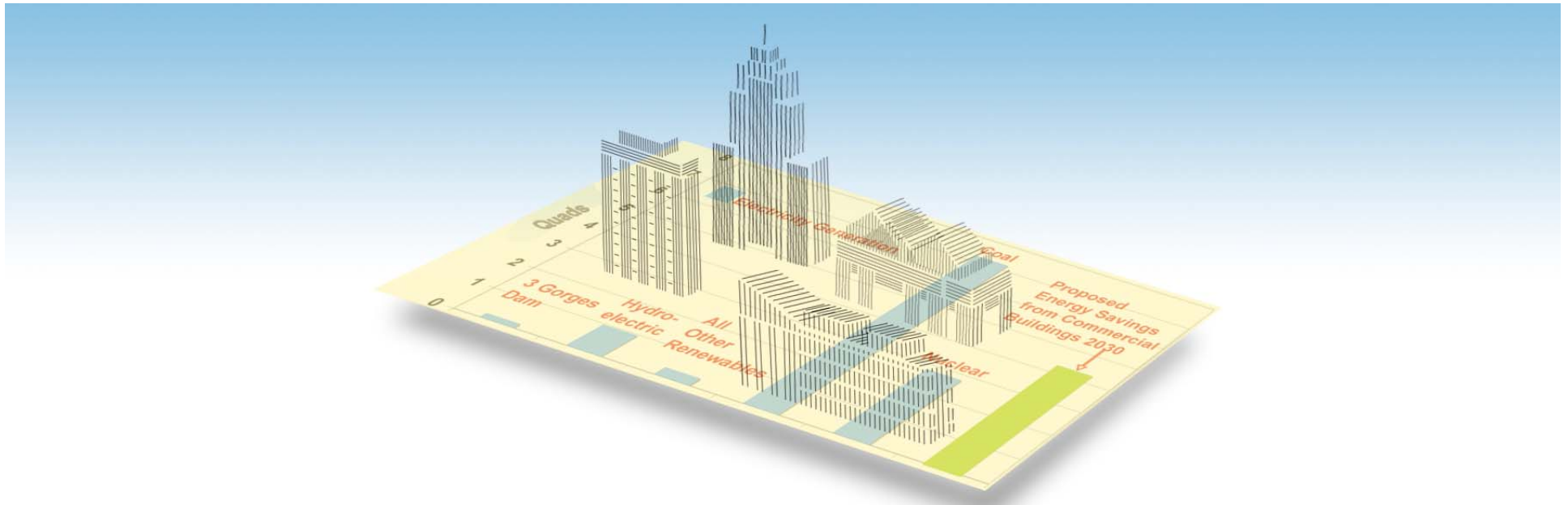
U. S. Buildings produce 48% of Carbon emissions

U.S. Commercial Buildings annual energy bill: \$120 billion (2004)

Commercial Building Energy Intensities are increasing

- Electrical Energy consumption *doubled* in last 18 years
- 25% growth projection through 2030

High Performance Buildings Research & Implementation Center (HiPerBRIC)



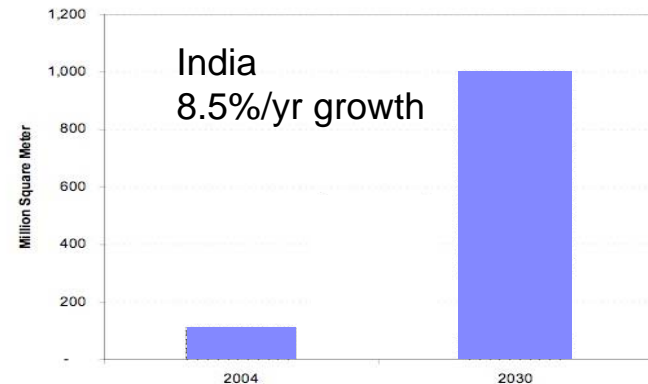
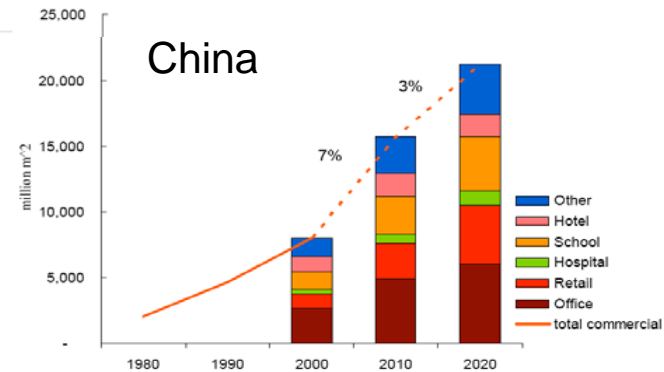
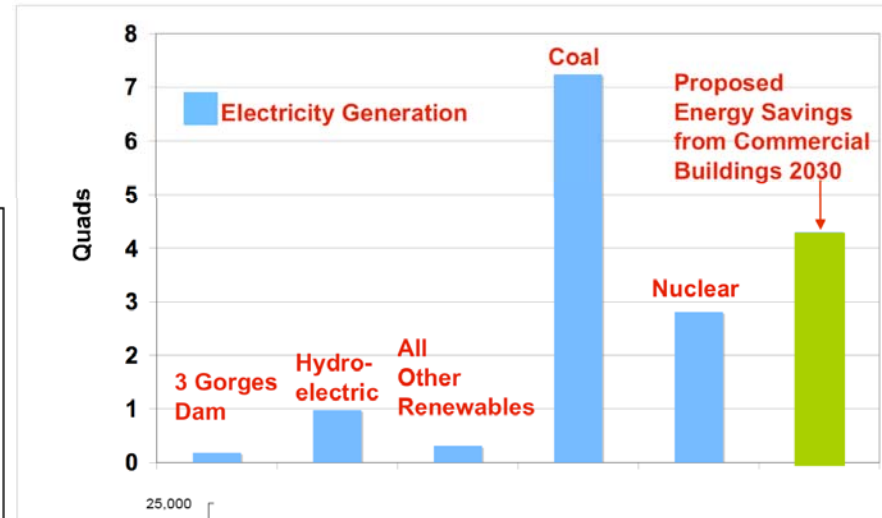
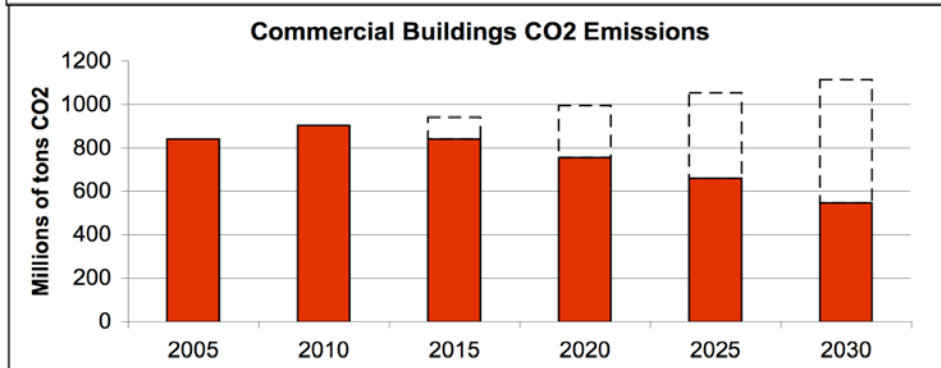
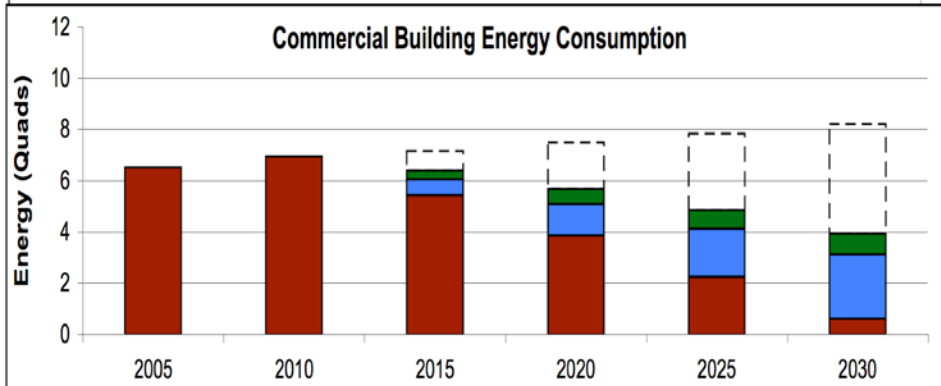
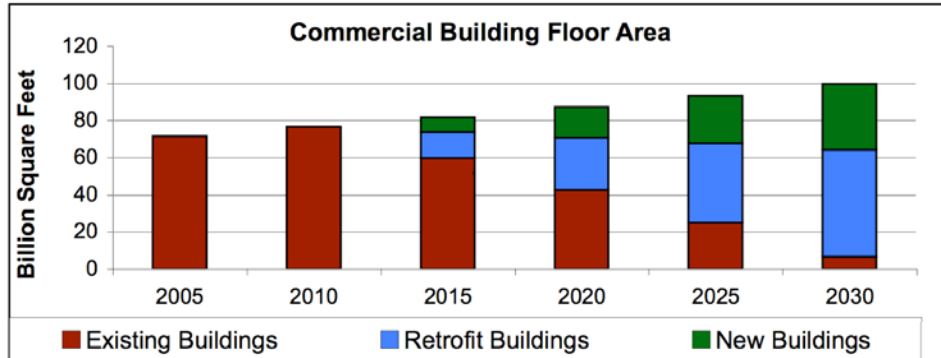
National Lab-Industry-University Partnership

Arun Majumdar
Director, Environmental Energy Technologies Division

Transforming Commercial Buildings Energy Management

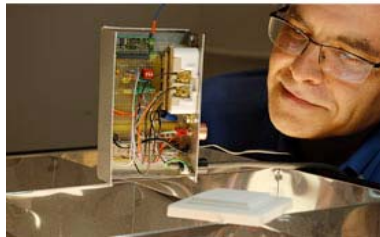
By 2030

- 90% reduction in new buildings
- 50% reduction in retrofitted old buildings



Zero Energy Building

Creating a New Generation of Net-Zero Energy, Carbon-Neutral Buildings



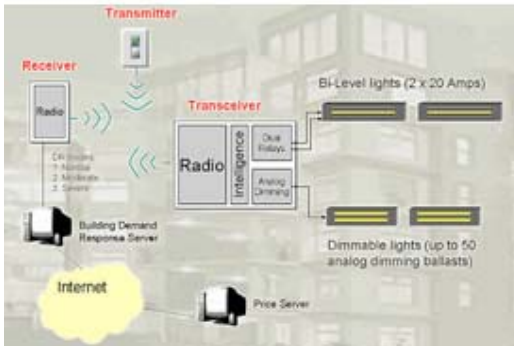
Automation

- Energy sensors & actuators
- Wireless communication
- Feedback control systems

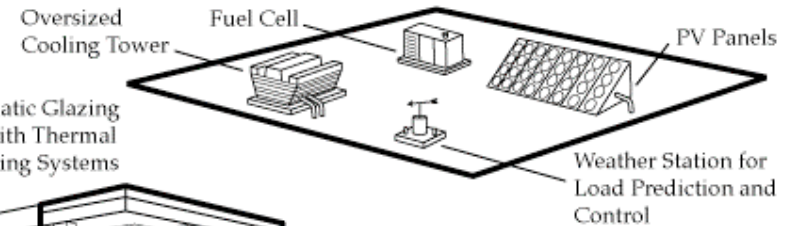
Functional Building Materials

- Thermal
- Structural

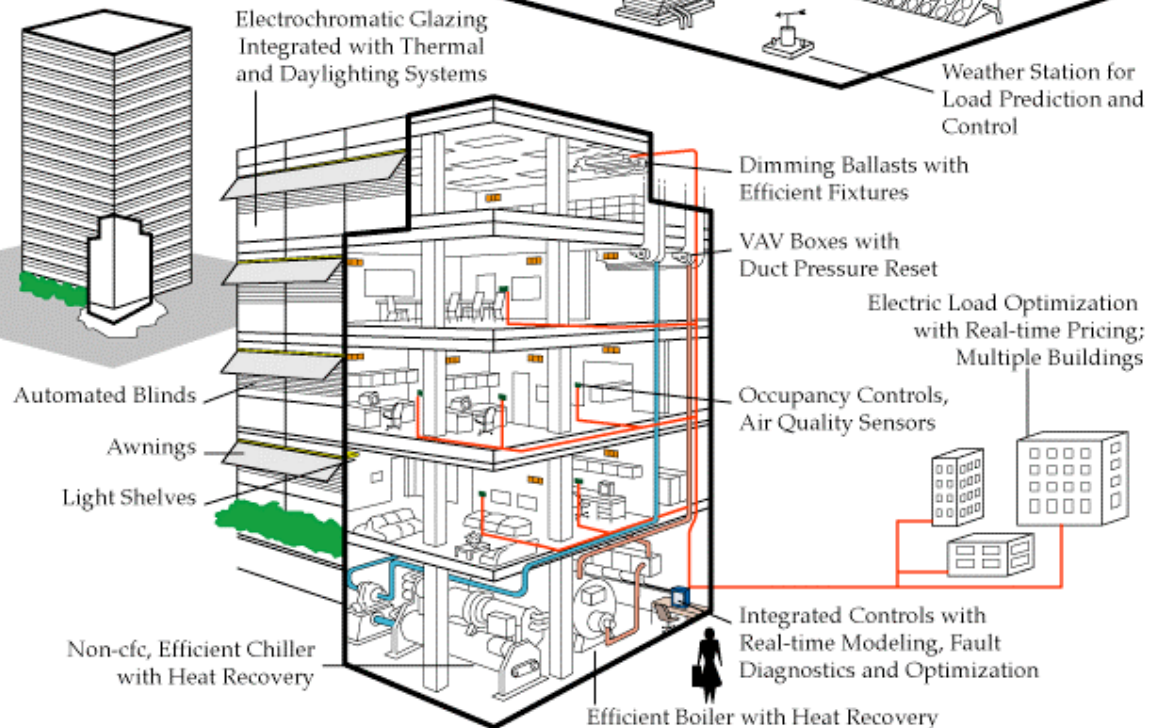
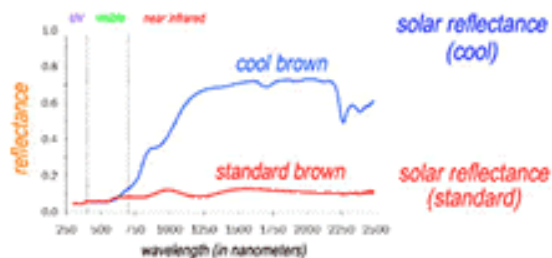
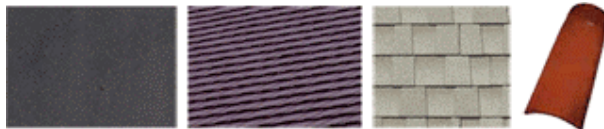
Tunable Windows



Commercial Building with Integrated System Design and Operations

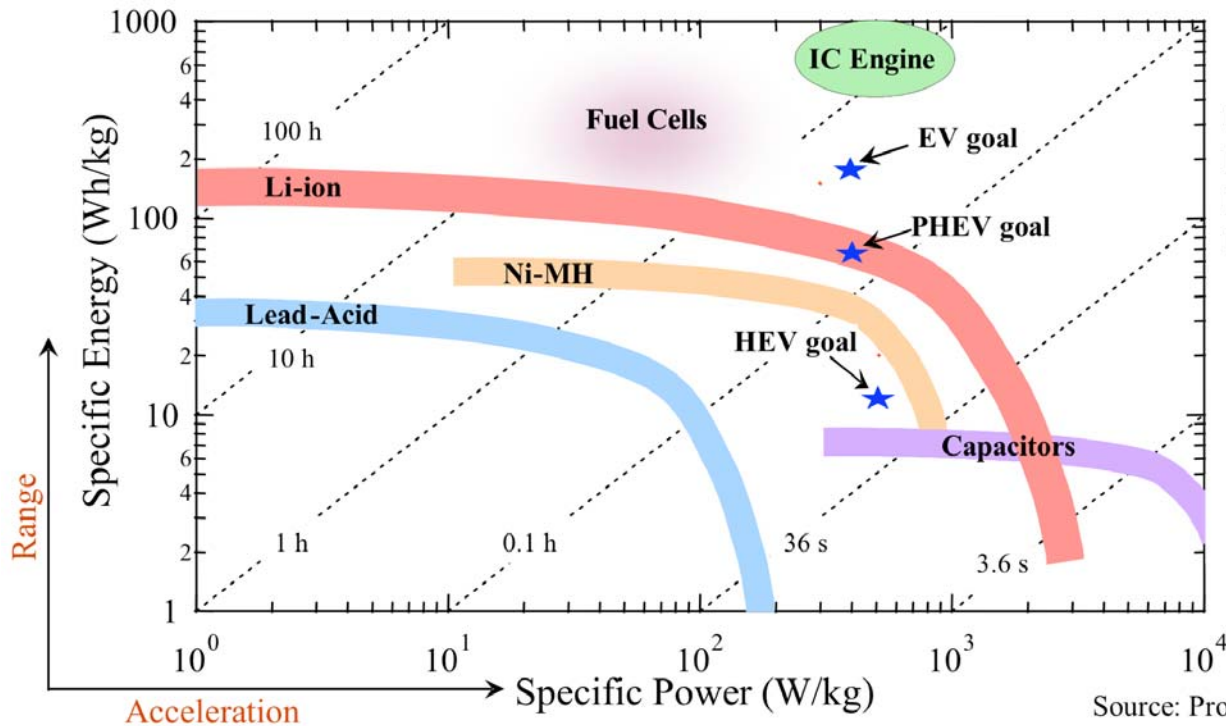
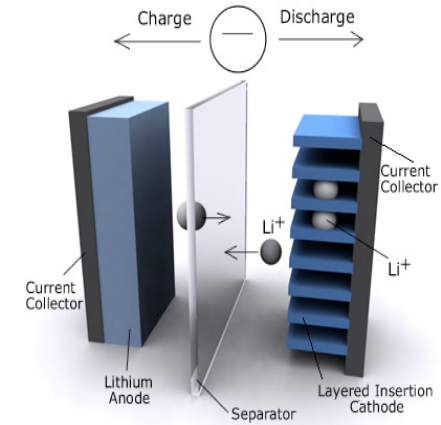


Cool Stuff



Transportation

Batteries

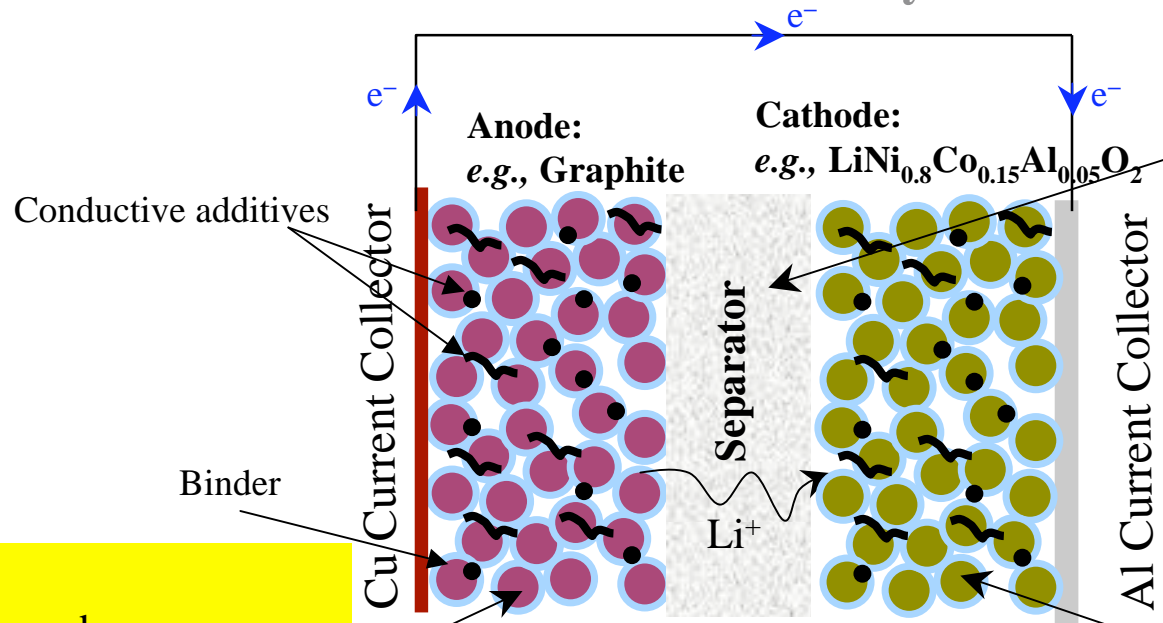


EV – Electric Vehicle
PHEV– Plug-in Hybrid-Electric Vehicle
HEV – Hybrid-Electric Vehicle

Source: Product data sheets

Li Ion Batteries

Lithium-ion battery



Electrolyte:

- Liquid organic solvents
- Gel
- Polymers
- Ionic liquids

Cathode:

- Layered transition-metal oxides
- Spinel-based compositions
- Olivine-based compositions

Anode:

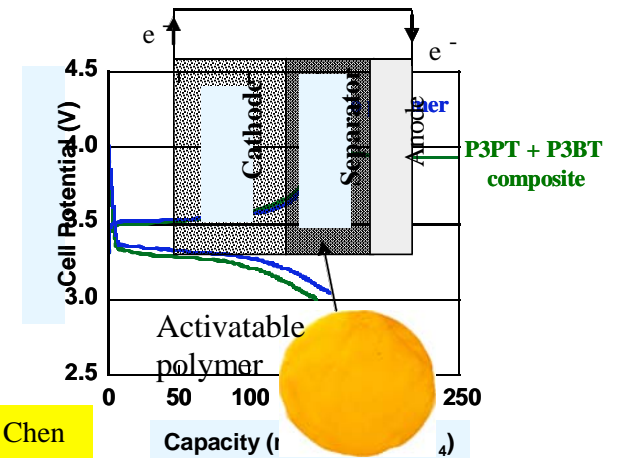
- Carbon-based
- Alloys and intermetallics
- Oxides
- Lithium-metal

- A lithium-ion battery is not a single chemistry (unlike a lead-acid battery)
- Presently three classes of **cathodes**, four classes of **anodes**, and four classes of **electrolytes** under consideration for Li-ion cells

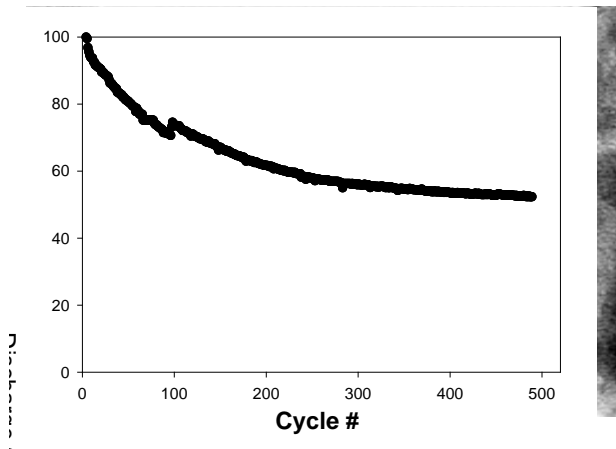
Recent Successes

Polymer for Overcharge Protection:

Developed an activatable-polymer separator that becomes electronically conductive at high voltages. This prevents voltage excursions above the operating range.



T. Richardson and G. Chen



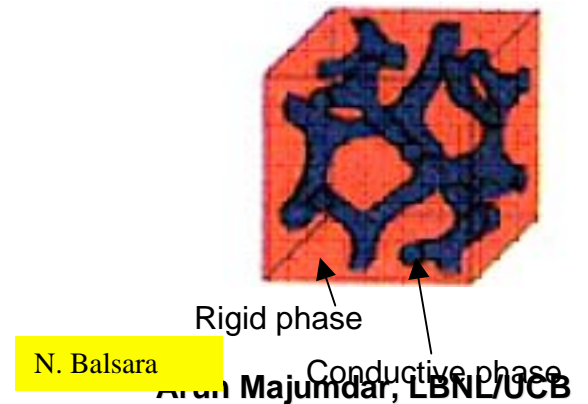
Composite alloy anodes:

Developed a microwave-based technique to deposit nanosized tin particles in a carbon matrix. Carbon matrix allows the accommodation of the large volume changes during cycling, thereby increasing battery life.

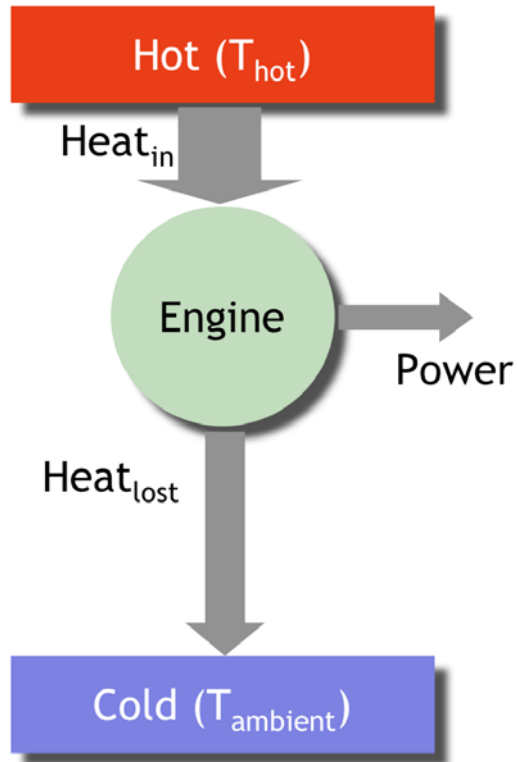
R. Kostecki

Block Copolymers for Li-metal Batteries:

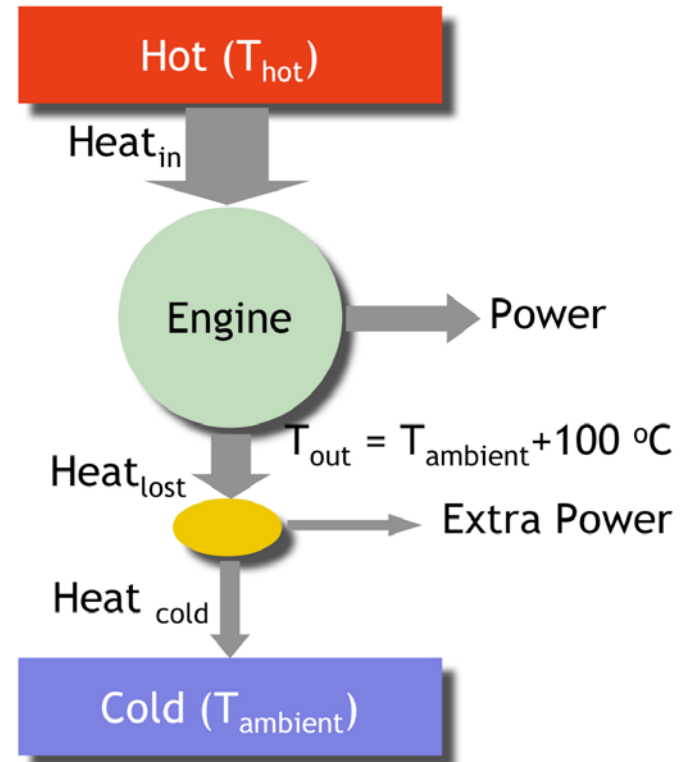
Developed a block co-polymer separator with one phase with high mechanical strength and second phase with high ionic conductivity. When placed against Li-metal the separator prevents growth of dendrites.



Energy Conversion



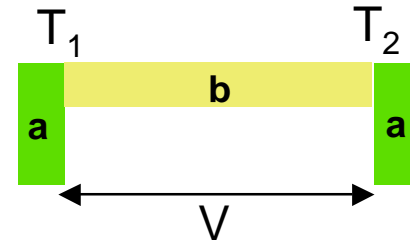
Power = 10 TrillionWatts
Efficiency = Power/Heat_{in} ~ 40%
Heat_{in} = 25 TW
Heat_{lost} = 15 TW



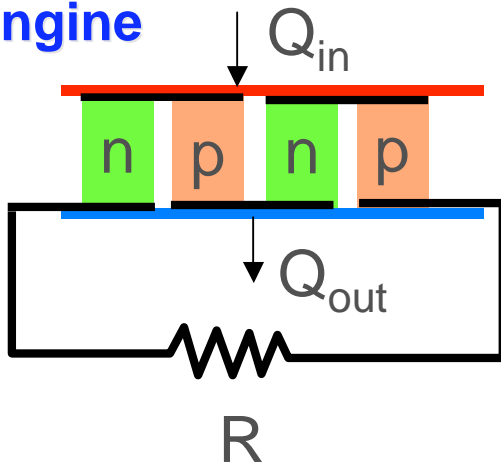
Efficiency ~ 3 %
Extra Power = 0.45 TW
US Electrical Capacity = 1 TW (2005)

Thermoelectricity & Energy Conversion

Seebeck Coefficient, $S = V/\Delta T$

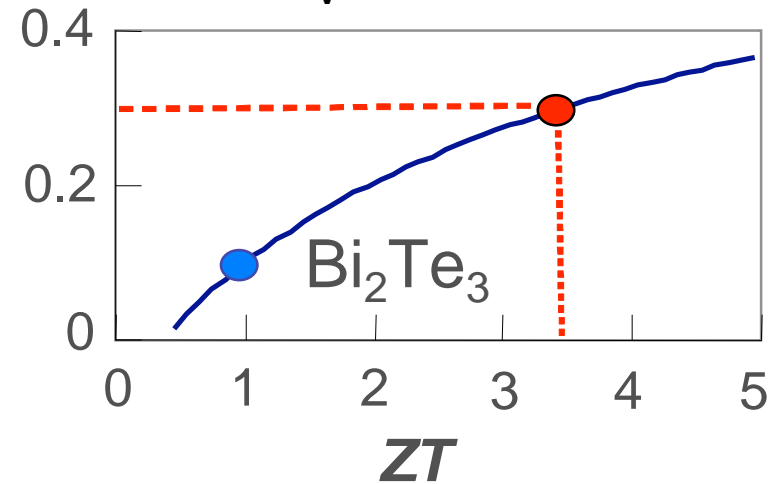


Engine

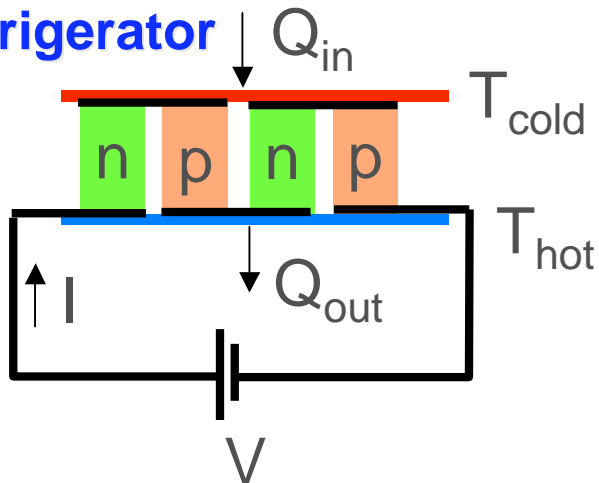


$$ZT = \frac{S^2 \sigma T}{k}$$

Fraction of Carnot

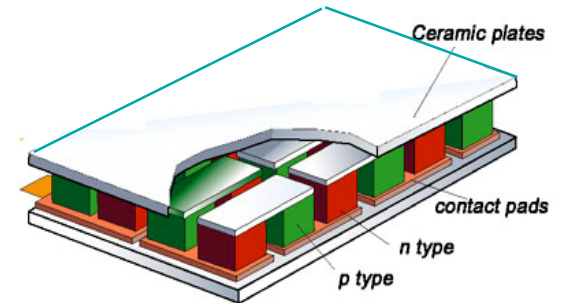


Refrigerator



Bismuth Telluride

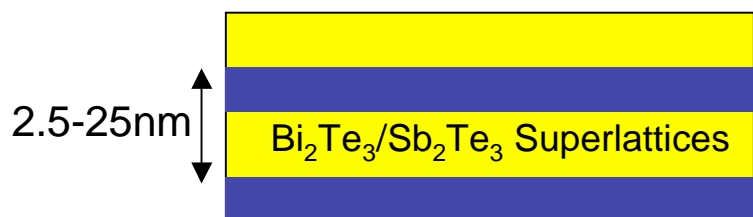
(low efficiency, expensive)



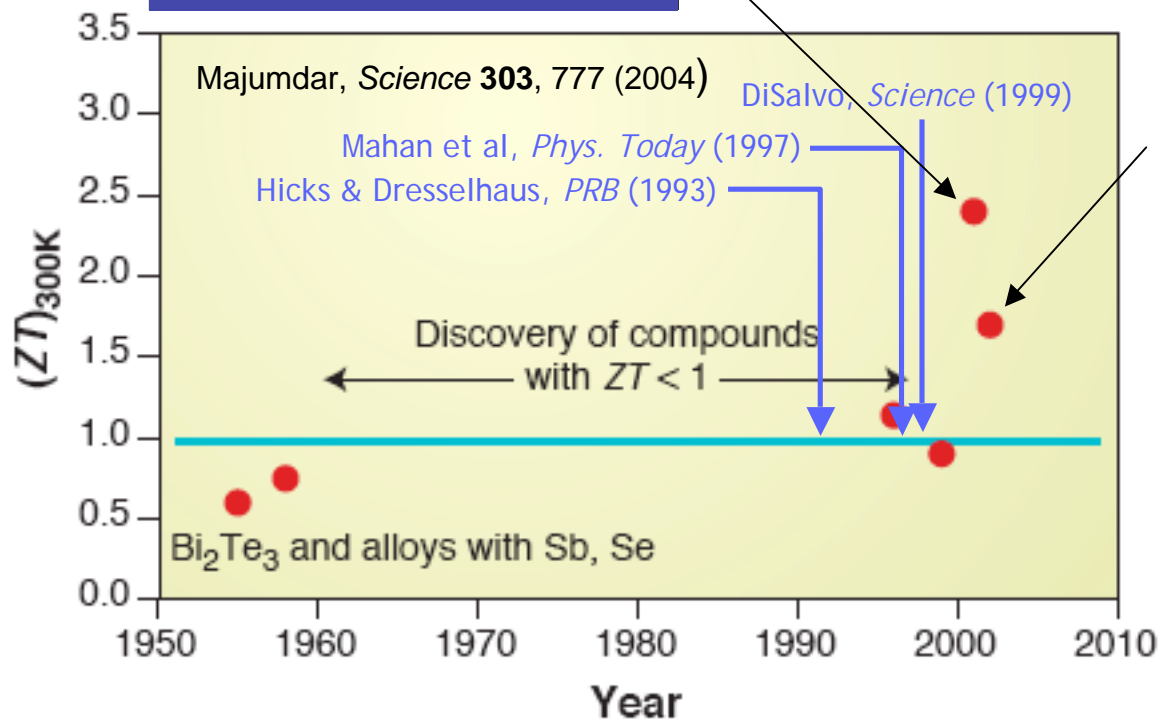
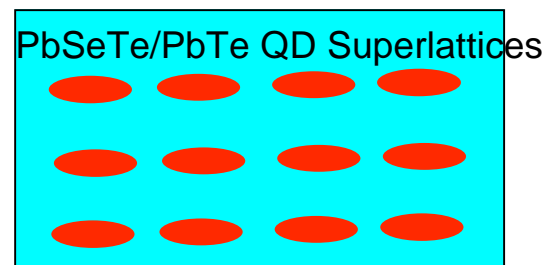
Arun Majumdar, LBNL/UCB

History

Venkatasubramanian et al. *Nature* **413**, 597 (2001)

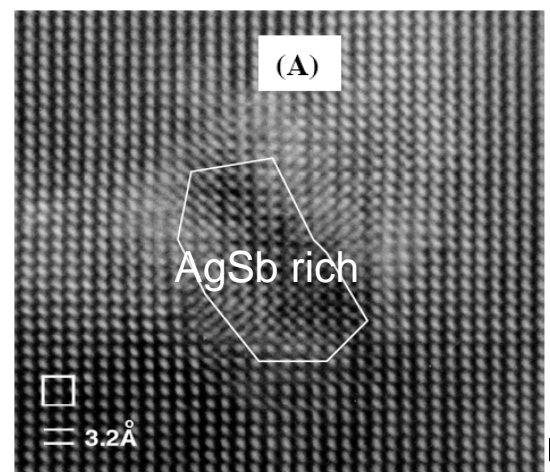


Harman et al., *Science* **297**, 2229 (2002)



$$ZT = \frac{S^2 \sigma T}{k\downarrow}$$

Hsu et al., *Science* **303**, 818 (2004)



$\text{AgPb}_{18}\text{SbTe}_{20}$
 $ZT = 2 @ 800K$

Heat Conduction

Silicon
 $k = 150 \text{ W/m-K}$
 $ZT = 0.01$

hydrogen 1 H 1.0079																			helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122													boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305													aluminum 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.971	bromine 35 Br 79.904	krypton 36 Kr 83.80		
rubidium 37 Rb 85.468	strontium 38 Sr 87.62													antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29		
cesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.967	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	wolfram 74 W 183.84	reynoldsium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]	
francium 87 Fr [223]	radium 88 Ra [226]	89-102 **	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [263]	bohrium 107 Bh [264]	hassium 108 Hs [265]	meitnerium 109 Mt [266]	unnilium 110 Uun [271]	ununium 111 Uuu [272]	unbinium 112 Uub [277]	ununquadium 114 Uuq [289]						

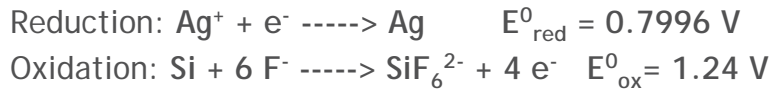
$K = 1.5 \text{ W/m-K}$
 $ZT \sim 1$

* Lanthanide series
 ** Actinide series

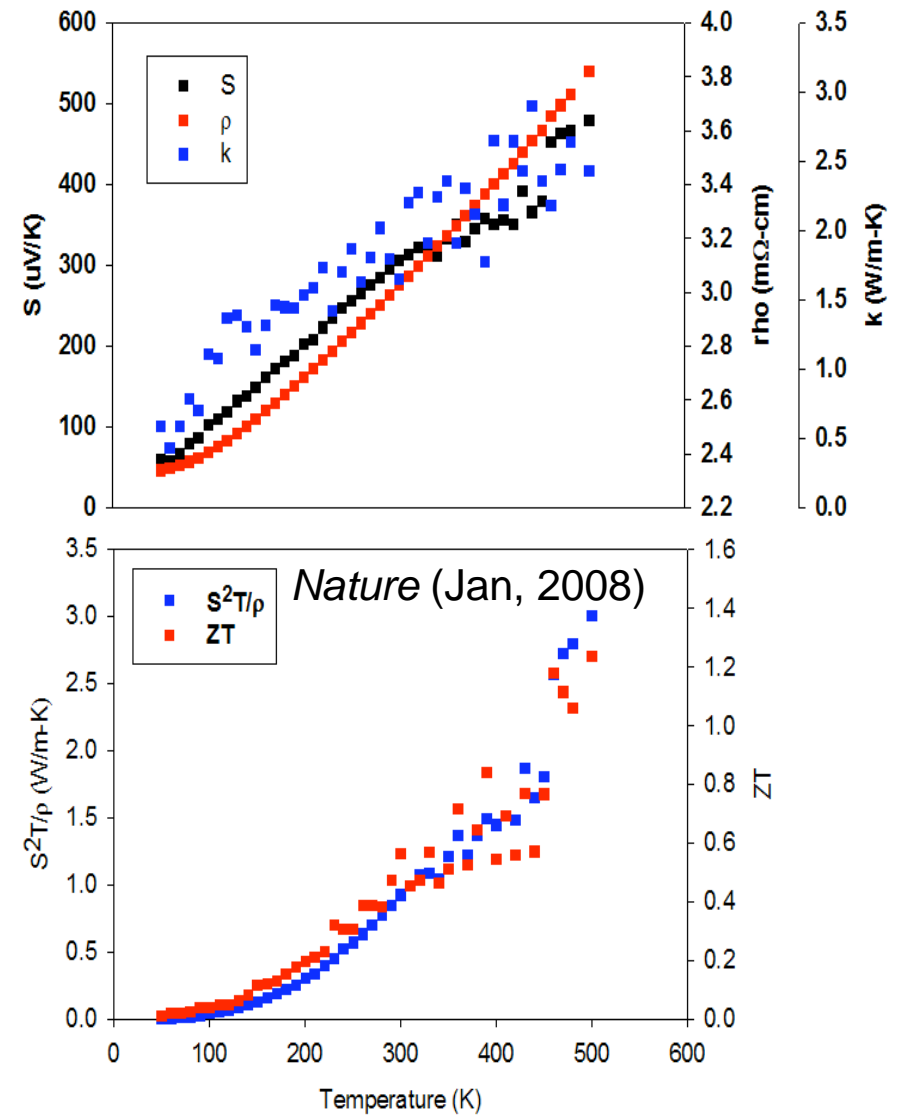
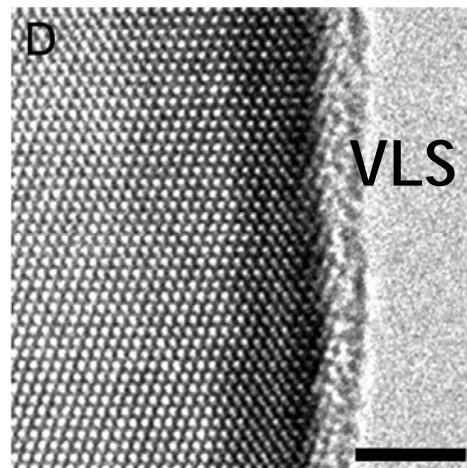
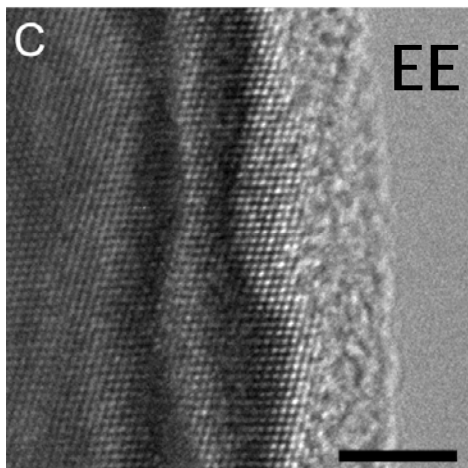
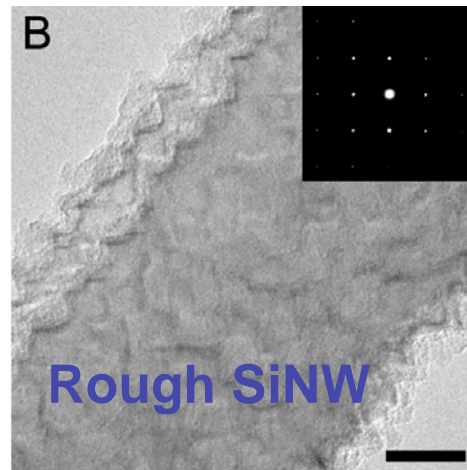
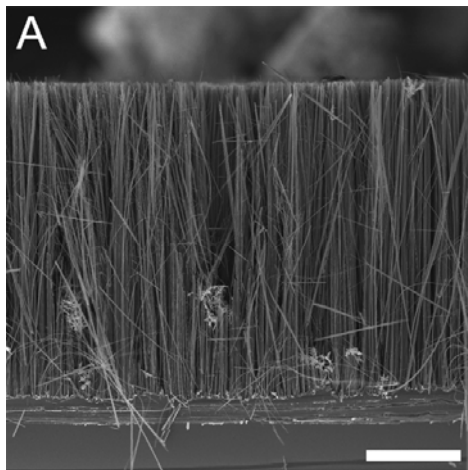
lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

Electroless Etched Si Nanowires

Wafer-Scale Wet Etching Process



Etching of Si at 50 °C in 5M HF, 0.02M AgNO₃ for 1h



Peidong Yang (LBNL/UCB)

Arun Majumdar, LBNL/UCB

Demand Side

Buildings consume 39% of total U.S. energy

- 71% of electricity and 54% of natural gas

