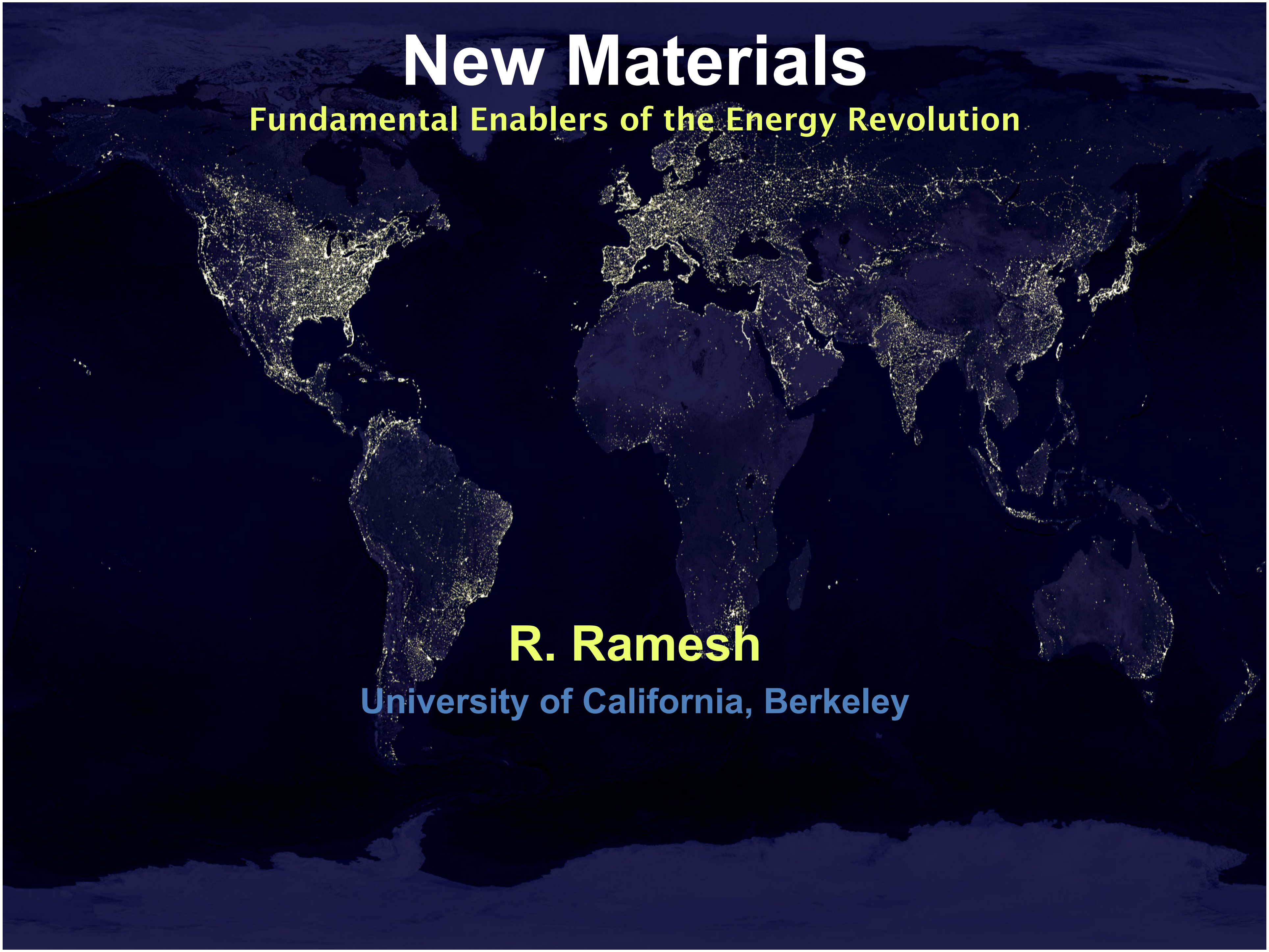


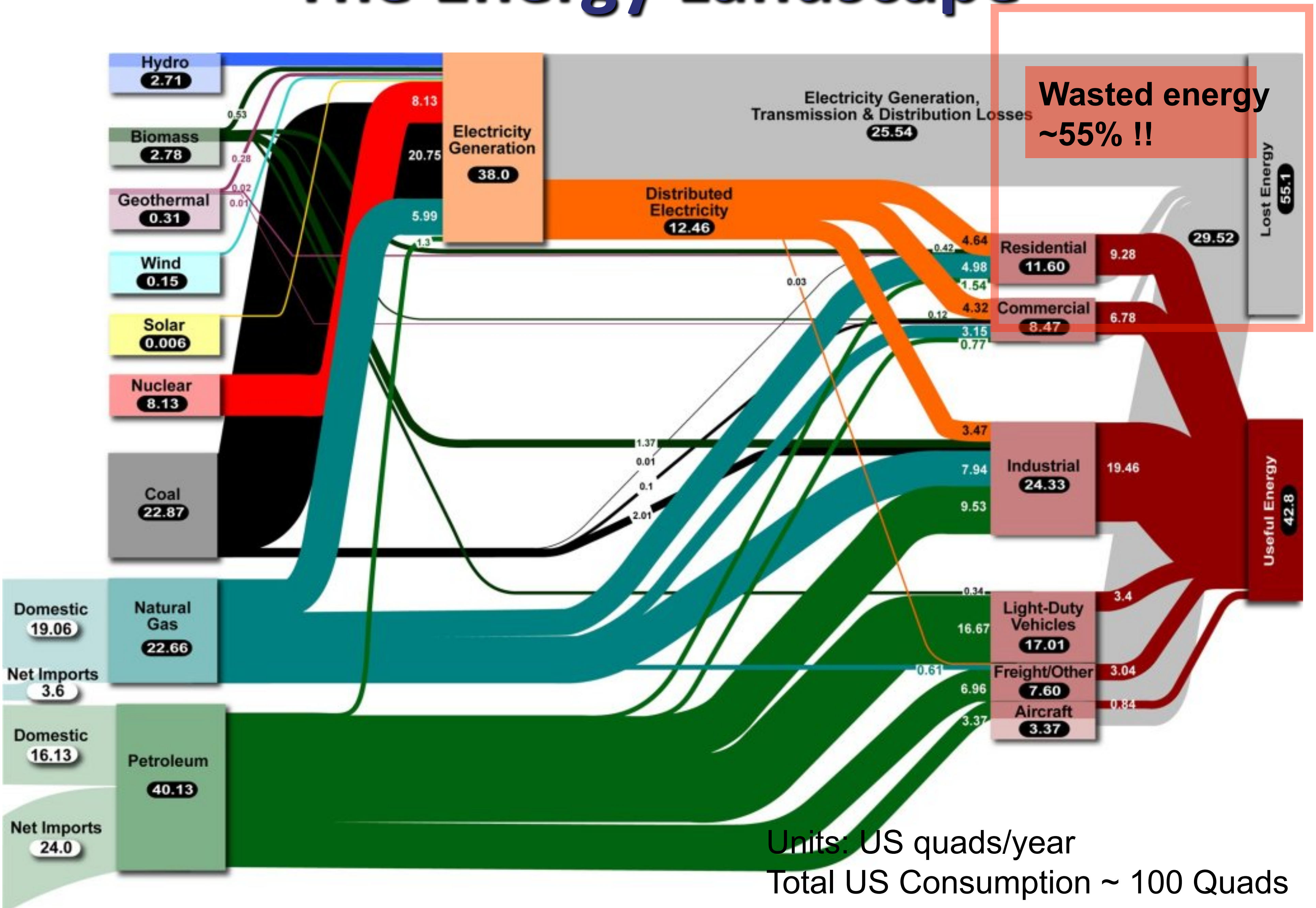
New Materials

Fundamental Enablers of the Energy Revolution

R. Ramesh

University of California, Berkeley

The Energy Landscape



Units: US quads/year

Total US Consumption ~ 100 Quads

Materials Impacting the Energy Landscape

Efficiency
Thermoelectrics

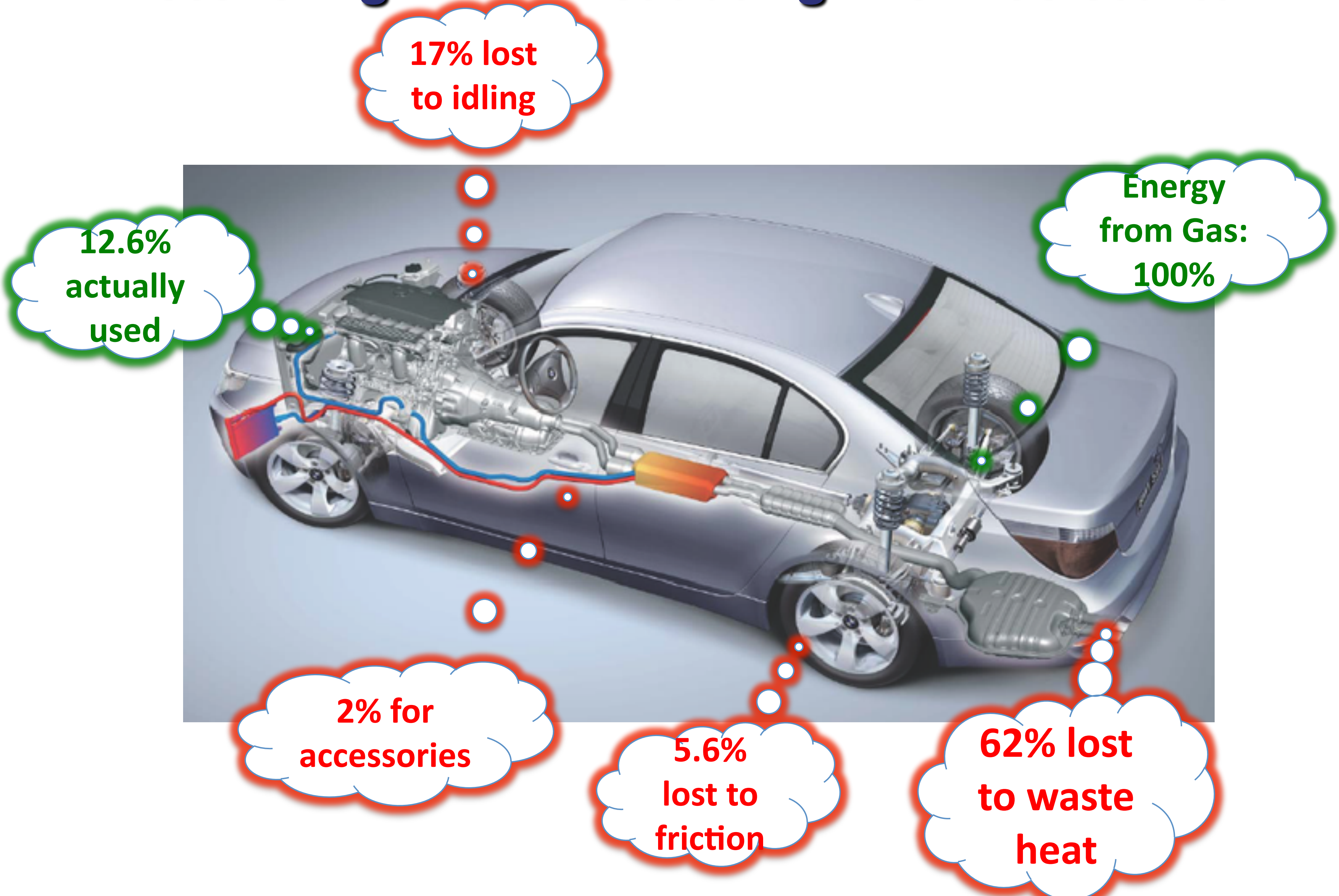
Efficiency
Smart Buildings, Transportation

Supply and Demand
- Conversion
- Efficiency
- Storage
- Transport

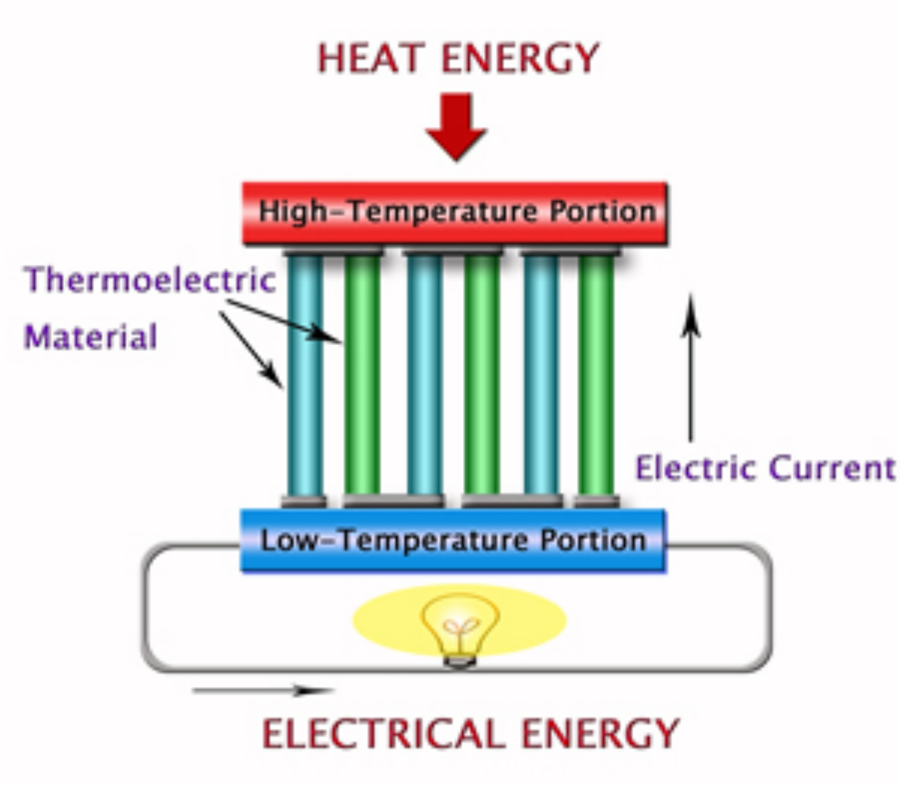
Conversion
Solar Energy to Electricity or Fuel

Storage and Transport
Batteries, Thermal Science

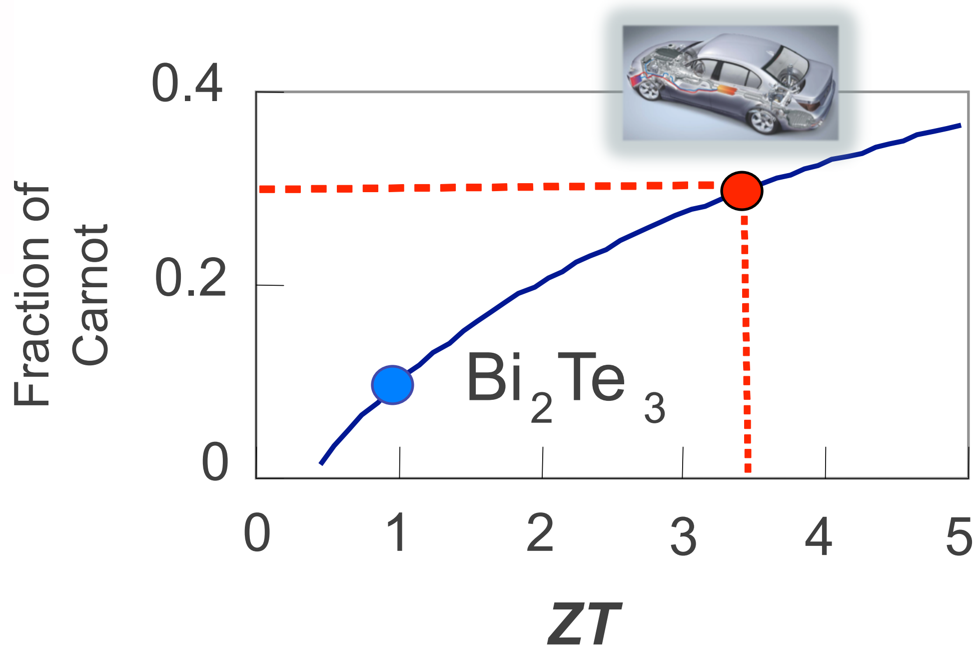
Recovering Waste Heat using Thermoelectrics



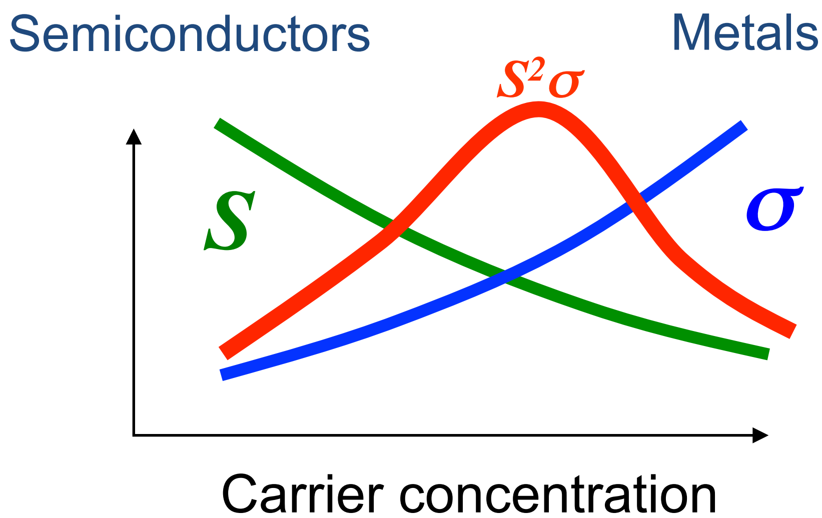
Thermoelectric Energy Conversion

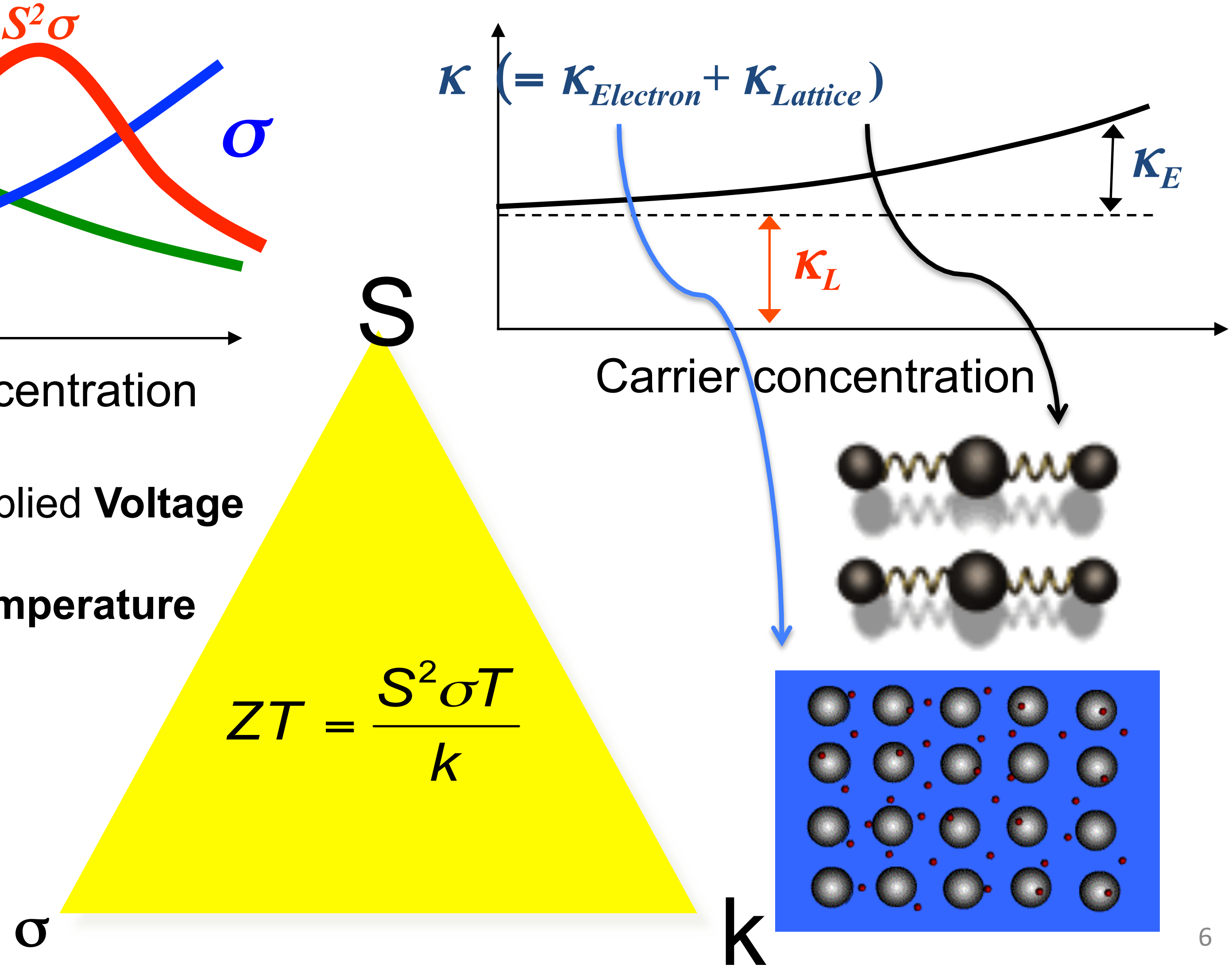


$$ZT = \frac{S^2 \sigma T}{k}$$



Mission Impossible ??
Dealing with Contra-indicating Phenomena



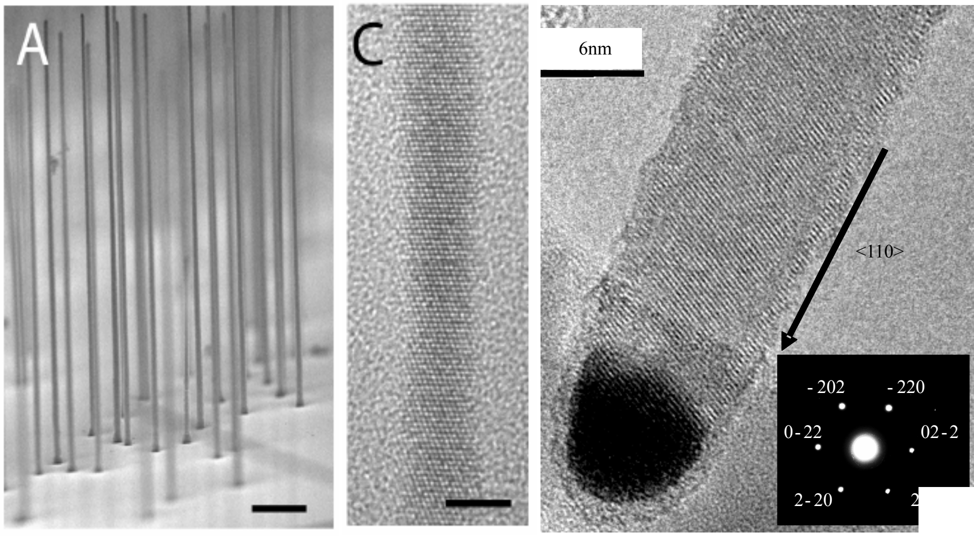


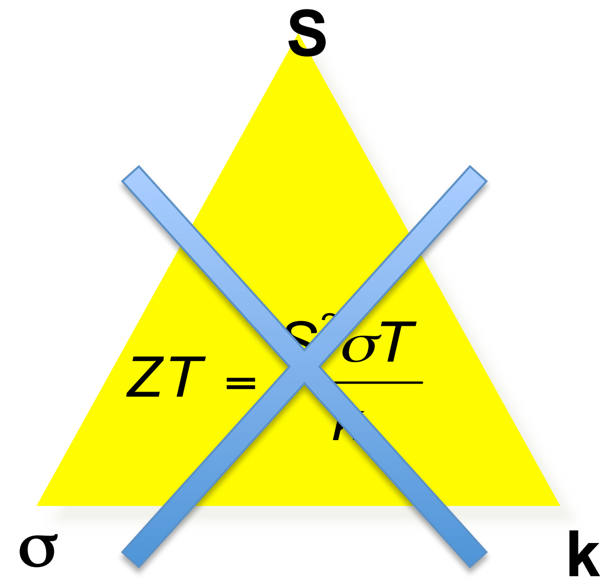
σ **Current** due to applied **Voltage**

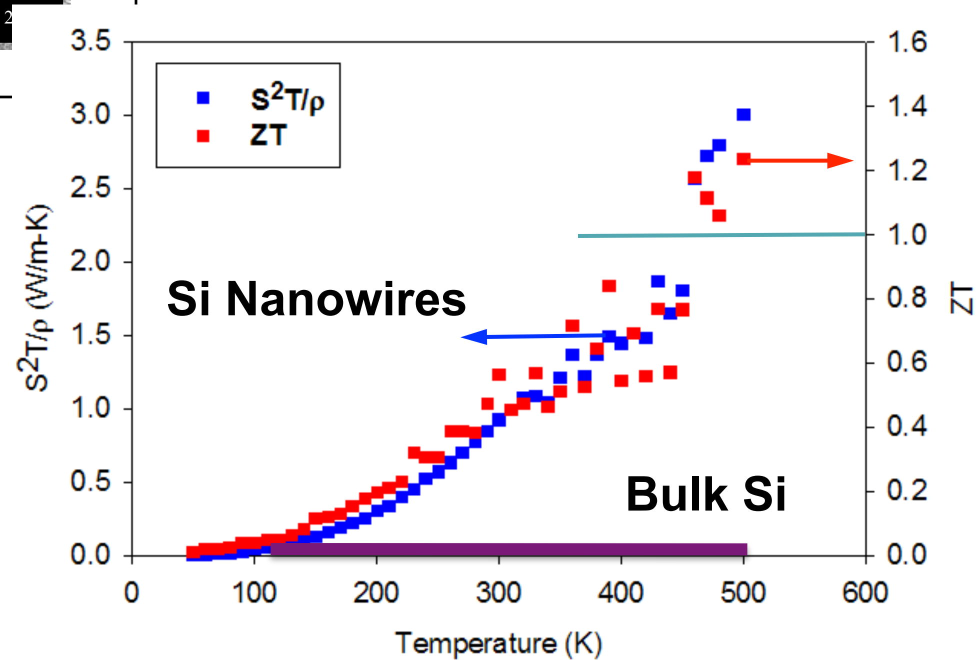
S **Voltage** due to **Temperature** difference

Nano : Accomplishing the "Impossible"

Si nanowires do the trick!!



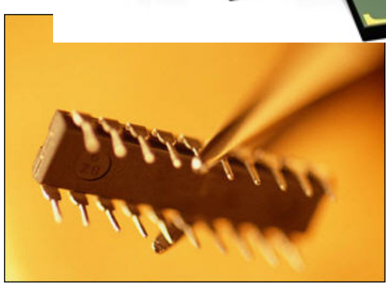


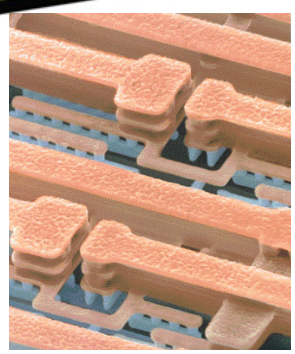


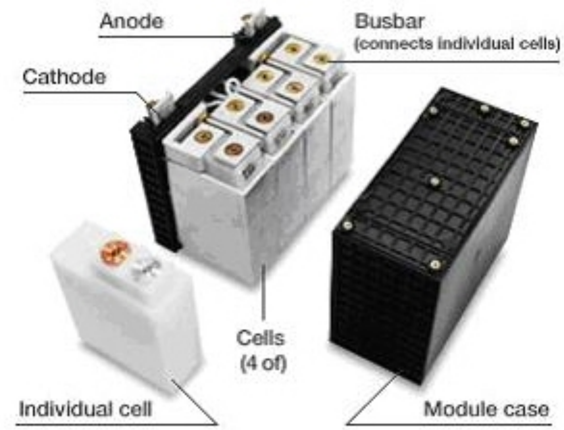
alphabet energy

Peidong Yang
Matt Scullin (Berkeley)

Energy and Information Storage



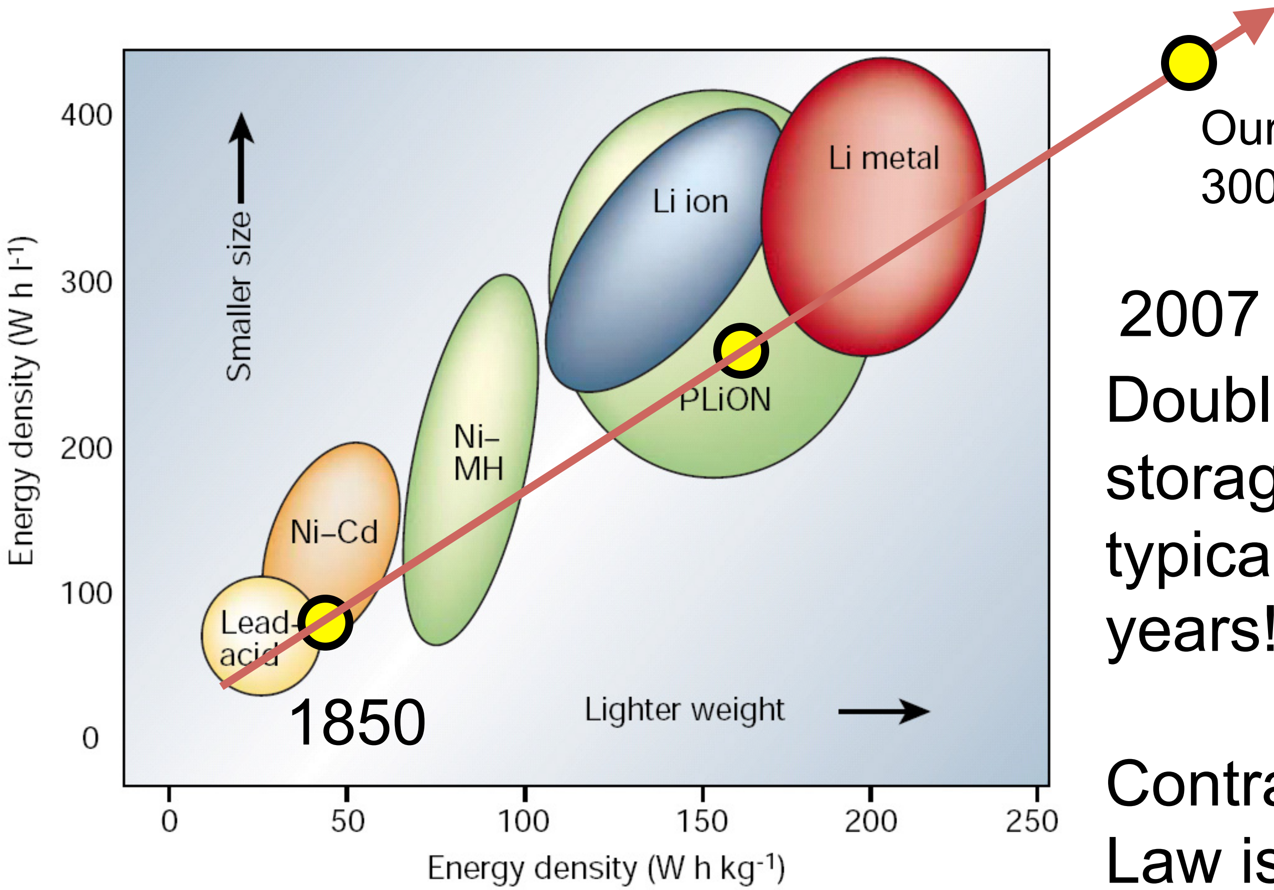




DRAMs : Solid State Memories
Very reliable!!

Batteries
Can they be recharged infinitely??
Can they last for ever??

Energy Storage : Batteries and Beyond



Our objective:
300 Wh/kg (2009)

2007

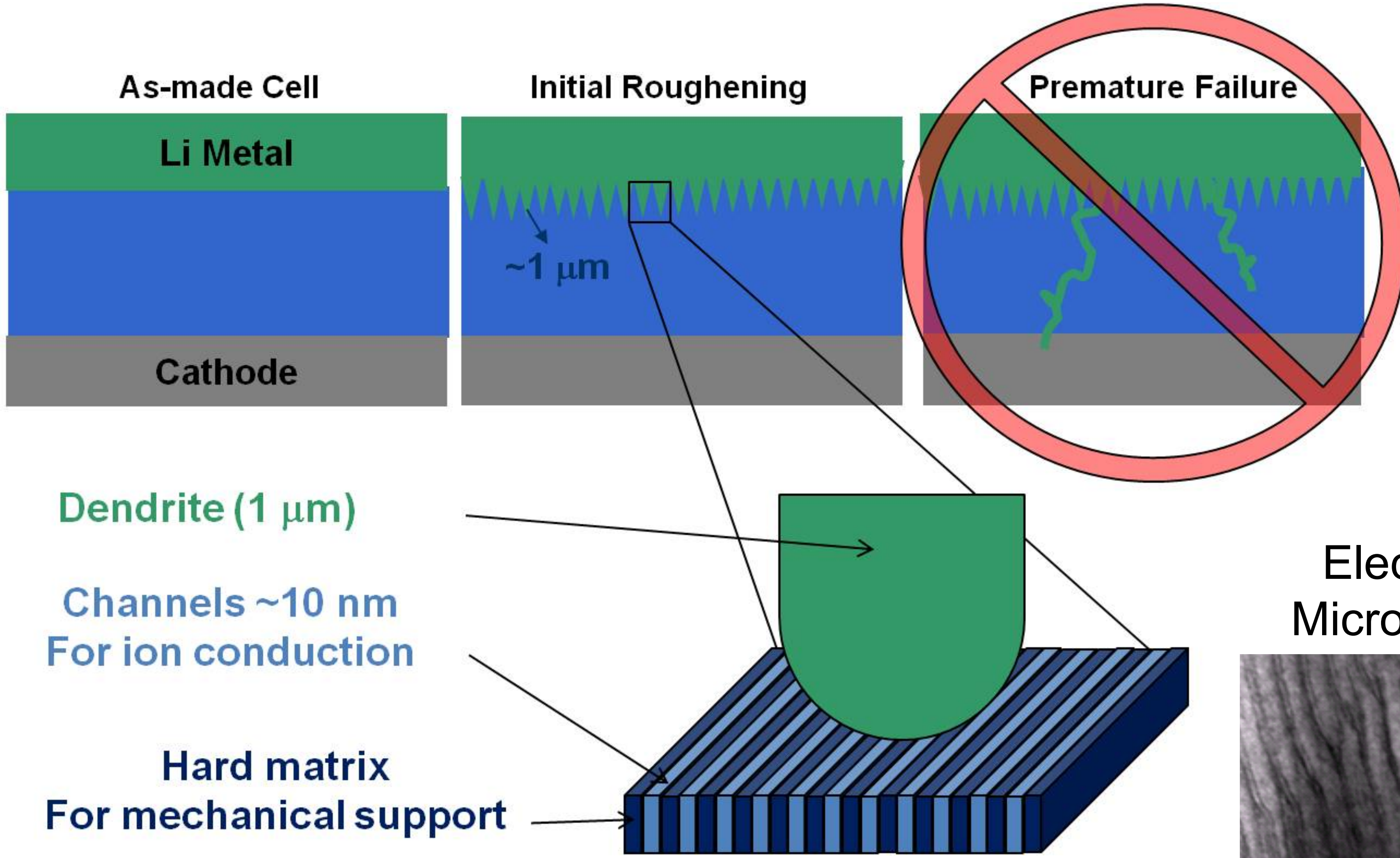
Doubling energy storage capacity typically takes 60 years!

Contrast to Moore's Law is dramatic!!

Tarascon, J.-M.; Armand, M. *Nature* **2001**, *414*, 359

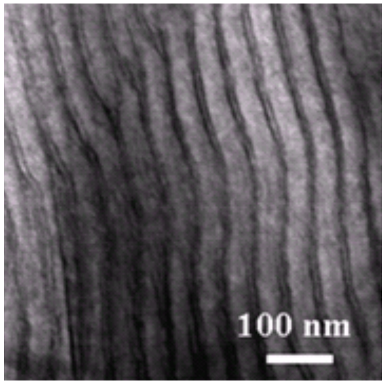
Courtesy: Nitash Balsara, UCB/LBL

Solving Fundamental Limitations with Nanoscience



Nanostructured Electrolyte

Electron Micrograph



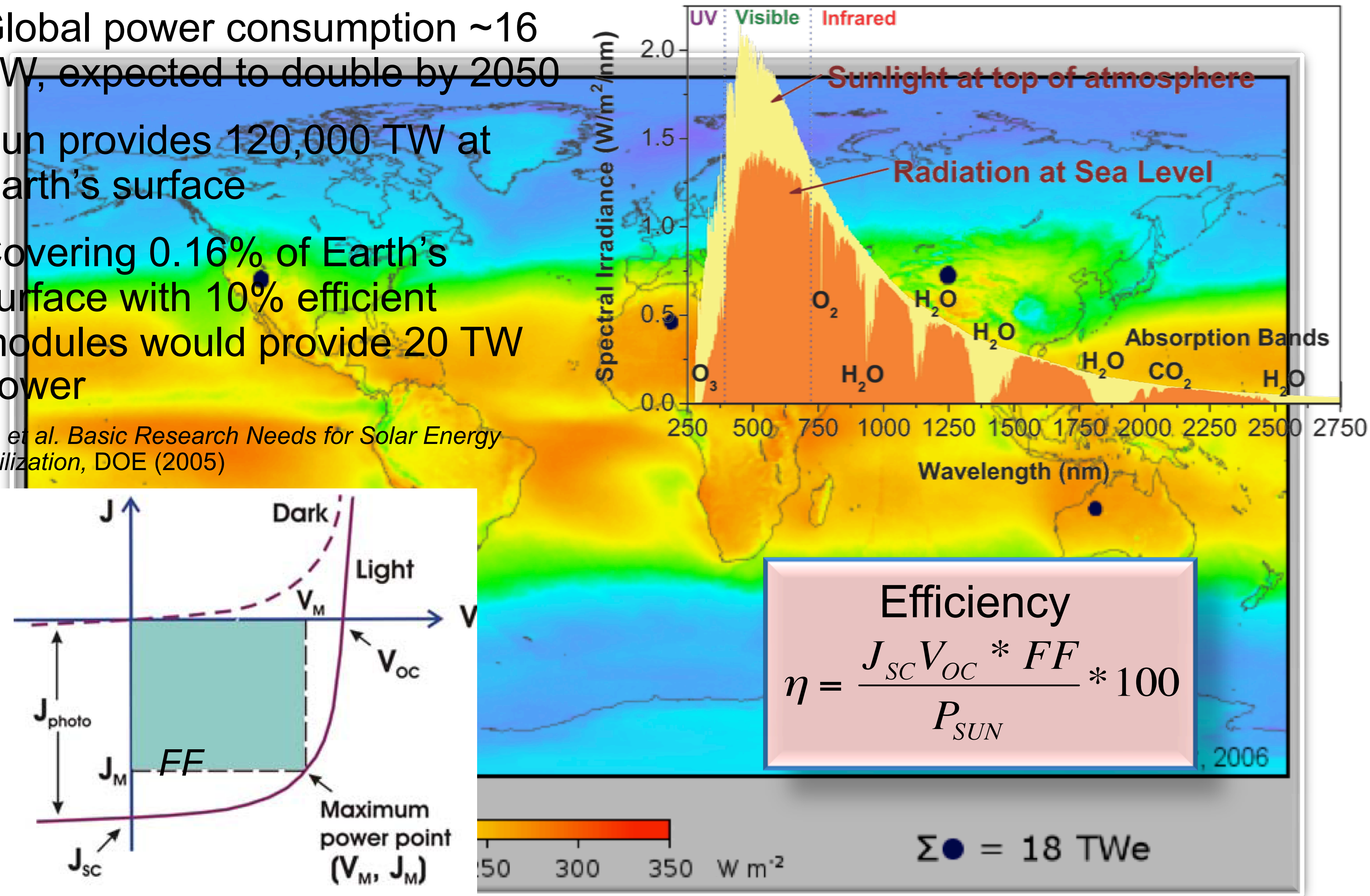
Batteries based on this invention are being taken to market by Seeo, Inc.

Courtesy: Nitash Balsara, UCB/LBL

Capturing the power of the sun

- Global power consumption ~16 TW, expected to double by 2050
- Sun provides 120,000 TW at Earth's surface
- Covering 0.16% of Earth's surface with 10% efficient modules would provide 20 TW power

Lewis *et al. Basic Research Needs for Solar Energy Utilization*, DOE (2005)



Efficiency

$$\eta = \frac{J_{SC}V_{OC} * FF}{P_{SUN}} * 100$$

Can Solar Energy be "dirt cheap"??

Twenty Most Abundant Elements in the Earth's Upper Crust

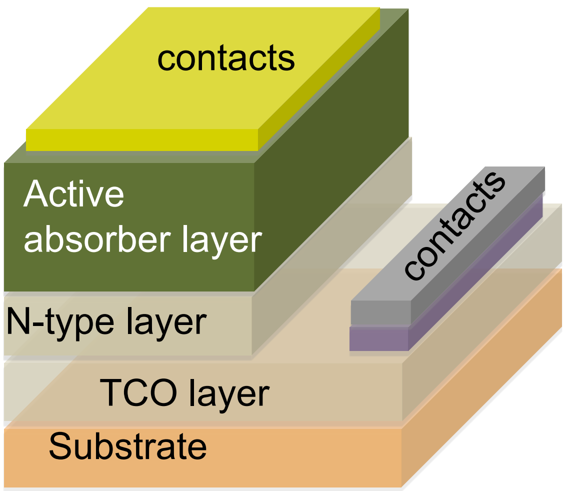
Element	Abundance	Annual Production (Tons)	Element	Abundance	Annual Production (Tons)
1) O	46.6%	10^8	11) P	0.11	1.53×10^8
2) Si	27.7%	3.88×10^6 (5000)	12) Mn	0.098	6.22×10^6
3) Al	8.17%	1.5×10^7	13) C	0.074	8.6×10^9
4) Fe	5.22%	7.16×10^8	14)F	0.059	
5) Ca	4.11%	1.12×10^8 (CaO)	15)Ba	0.044	6×10^6
6) Na	2.51%	2×10^5	16) S	0.041	5.4×10^7
7) Mg	2.34	3.5×10^5	17) Sr	0.037	1.37×10^5
8) K	2.17	200	18) Zr	0.018	7×10^3
9) Ti	0.57%	9.9×10^4	19) W	0.016	4.51×10^4
10) H	0.14%		20) V	0.014	7×10^3

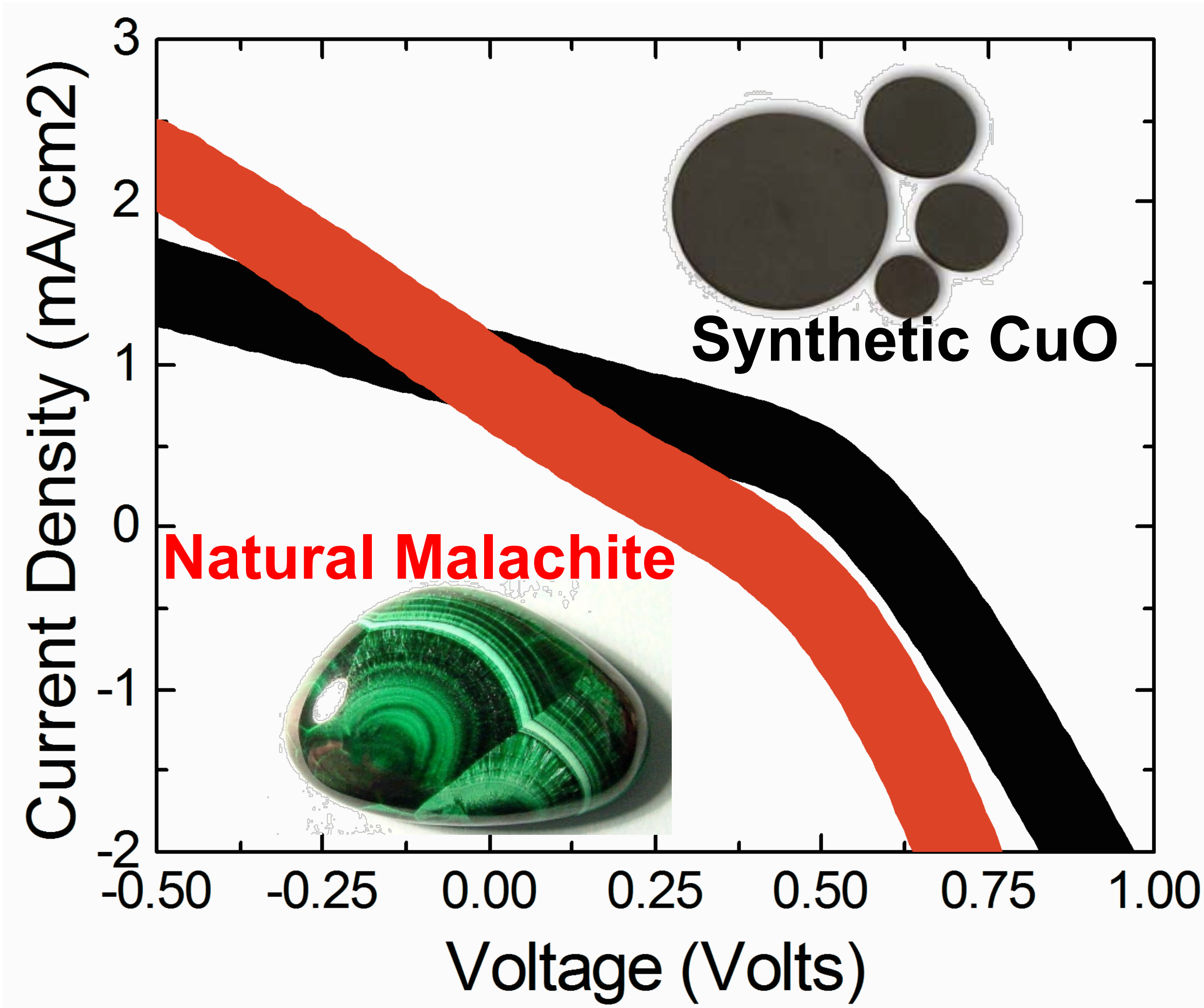
Top 10 most widely produced (Millions of tons):

•C (8,600), Fe(716), P (153), Ca (112), S (54), Cu (6.45), Mn (6.22), Ba (6.0), Zn (5.02), Si (5.02, only 0.005 electronic grade)

Rock forming elements – found in Earth's crust, typically in oxide form… Fossil Fuel-like PV

Solar cells from Natural Minerals?





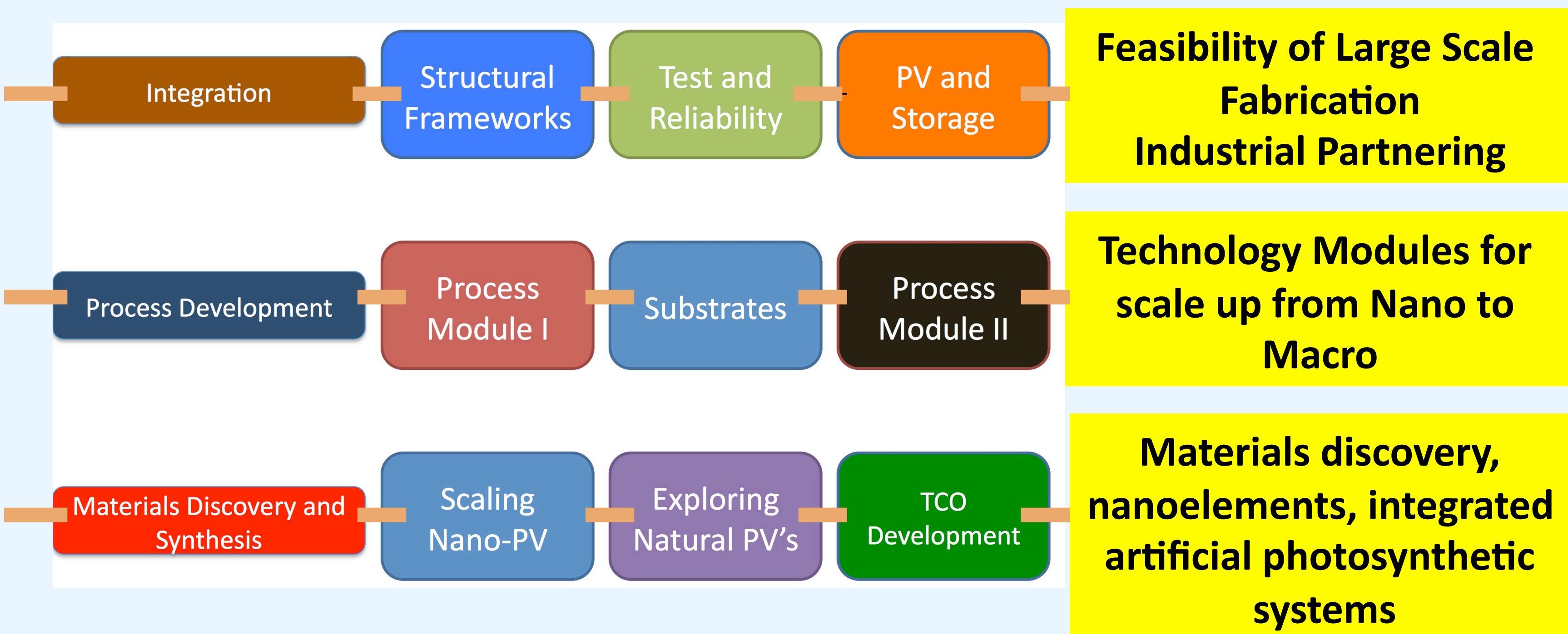
Collaboration among physicists, chemists, materials scientists and device engineers

A “Hub” for Solar Energy

Materials Process Product

Bay Area PV Consortium (BAPVC)

Nano to Kilo: Meeting the Solar Energy Challenge



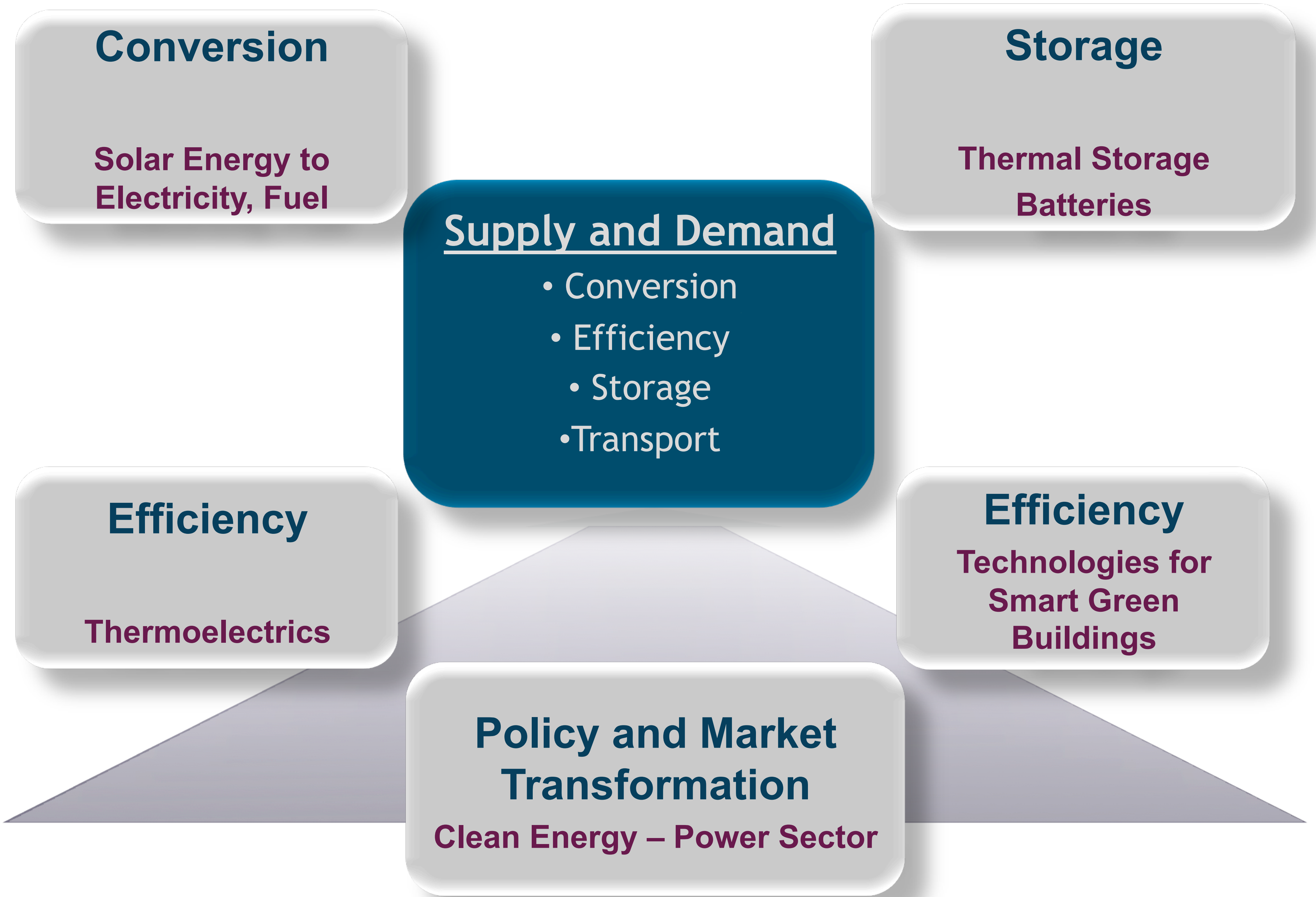
UC Berkeley, Stanford, LBNL, SLAC, NREL, Industry Partners

RISE : The Power of Partnerships

BIJLEE

BERKELEY • INDIA
JOINT LEADERSHIP
ON ENERGY & ENVIRONMENT

Initiatives within RISE



Long Term Vision

Explore Science and Technology of Matter within the broad Energy Framework

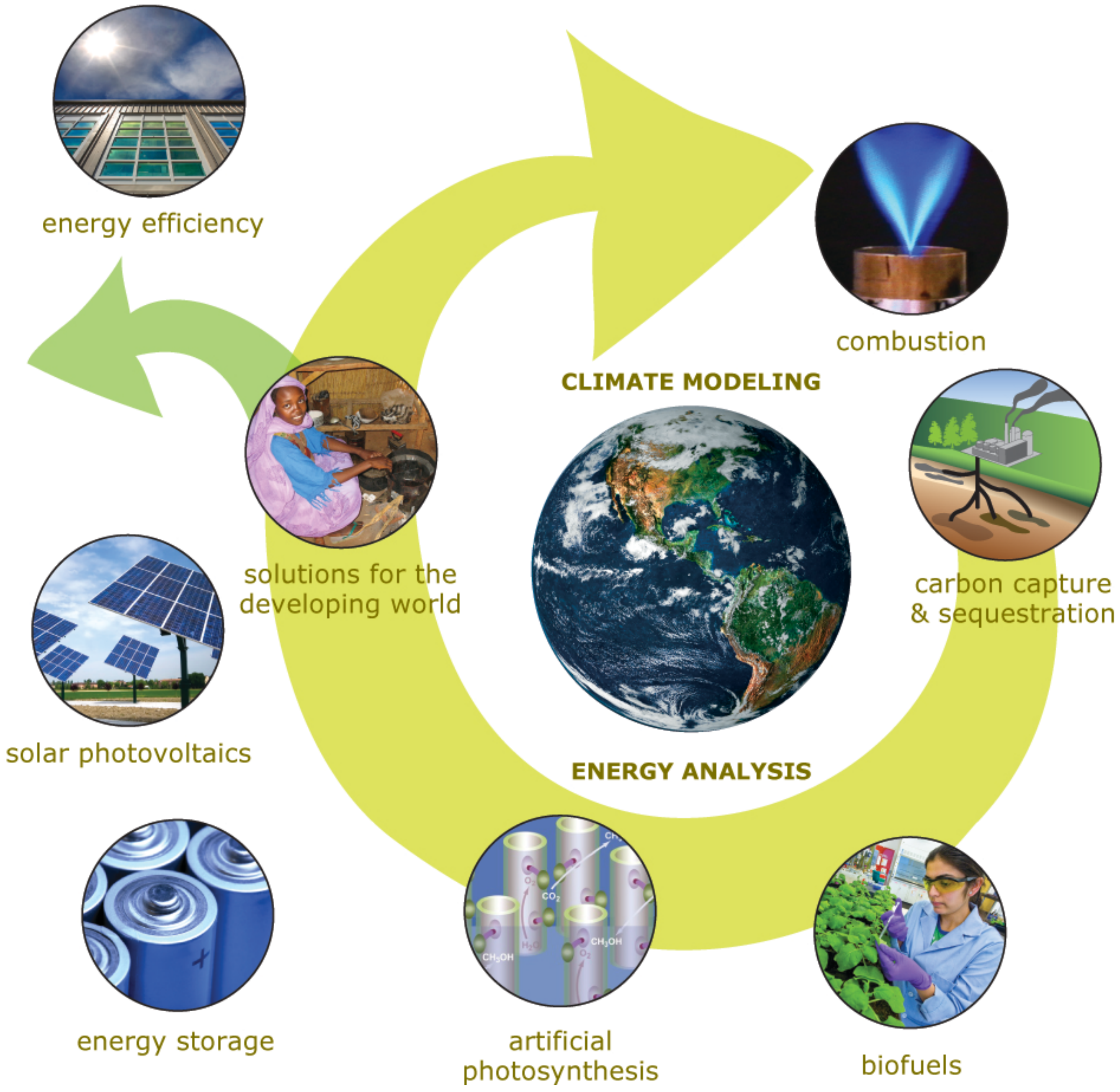
Exploit basic science to stimulate device technologies

Science, Technology and Energy Policy

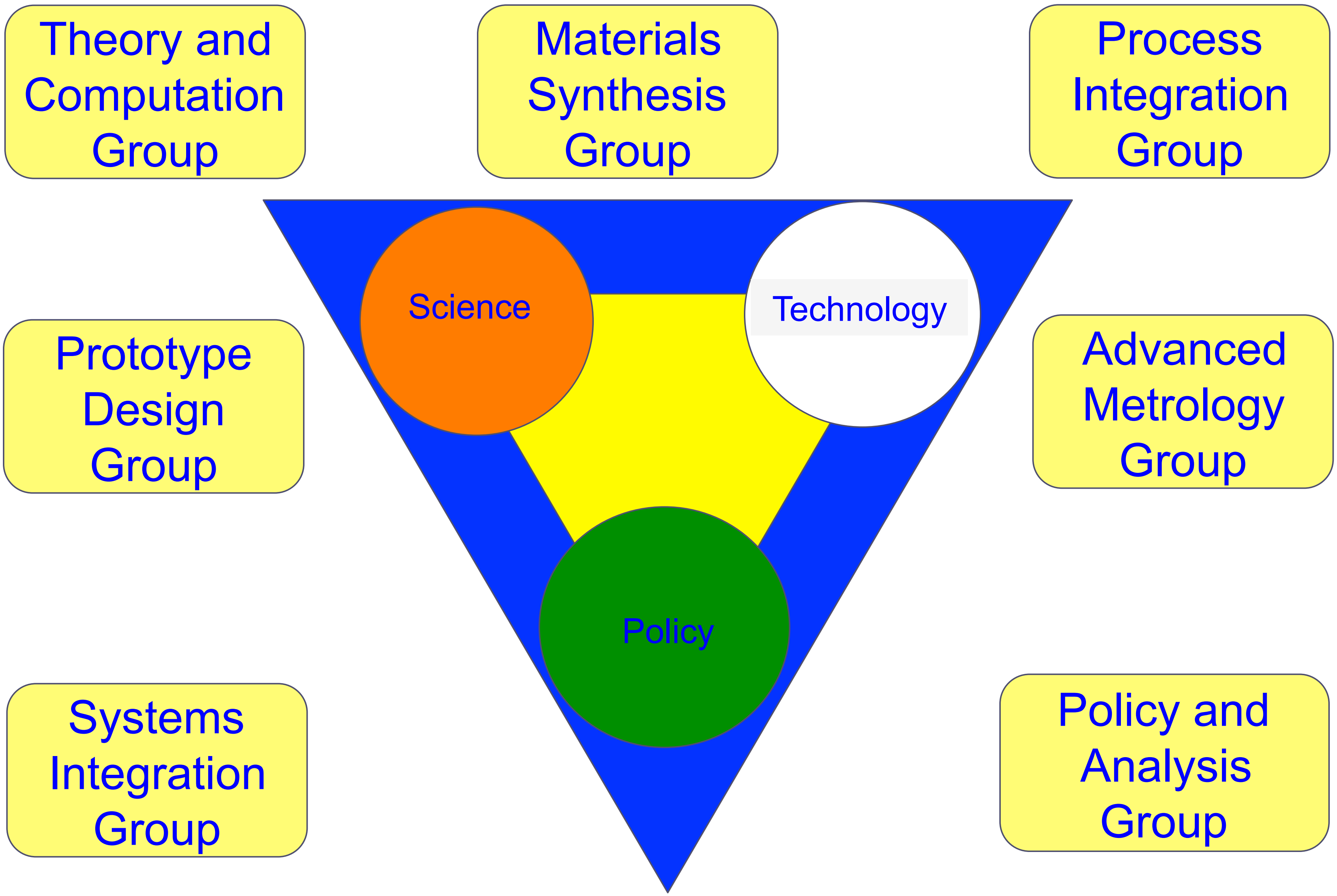
Partnerships

National labs, Academia, Industry, International

Impacting the Energy Landscape

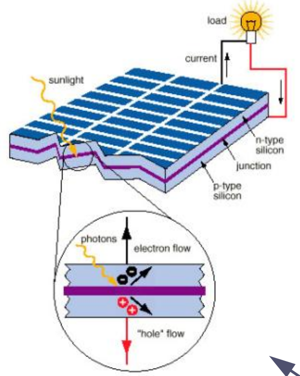


Research Institute for Sustainable Energy (RISE)
Core Competencies

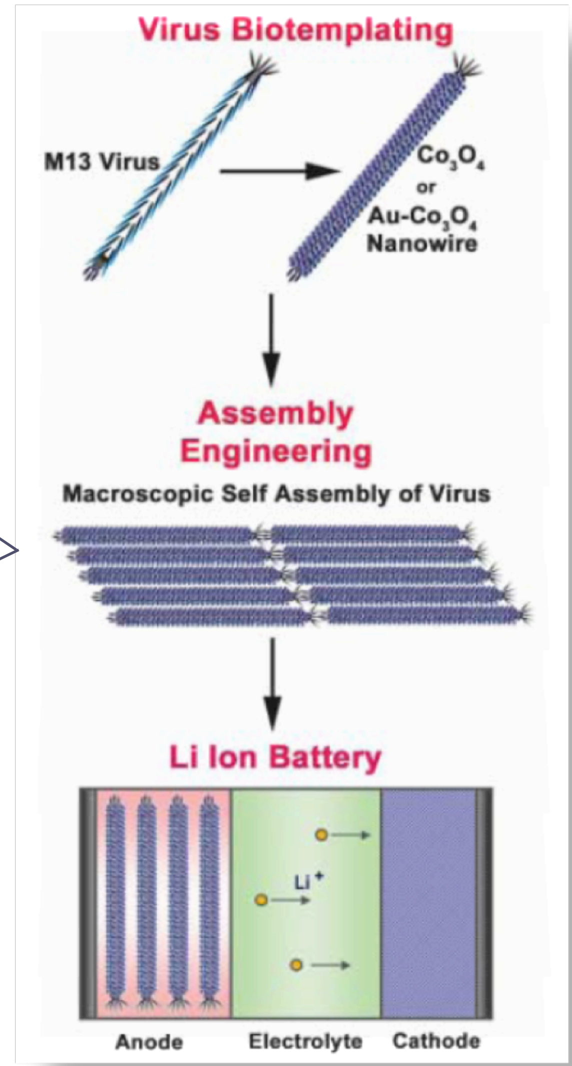


Biomolecular Approaches to Energy Stroarge and Conversion

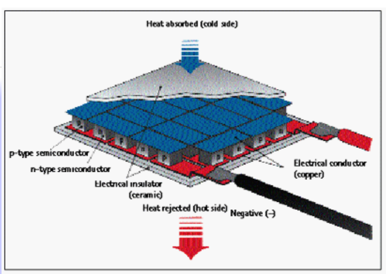
- Interface between
- Biological system s materials
- Bioinspired synth n
- Expand existing s i

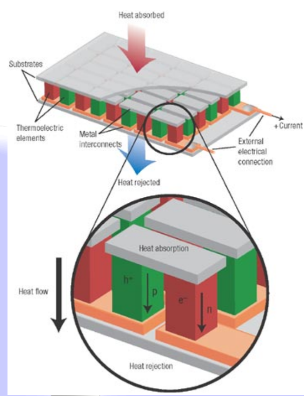


Biologically assisted production of Photovoltaics



Nam, *et al. Science* **312**, 885 (2006)





Self-assembly g recognition

Biologically assisted production of Thermoelectrics

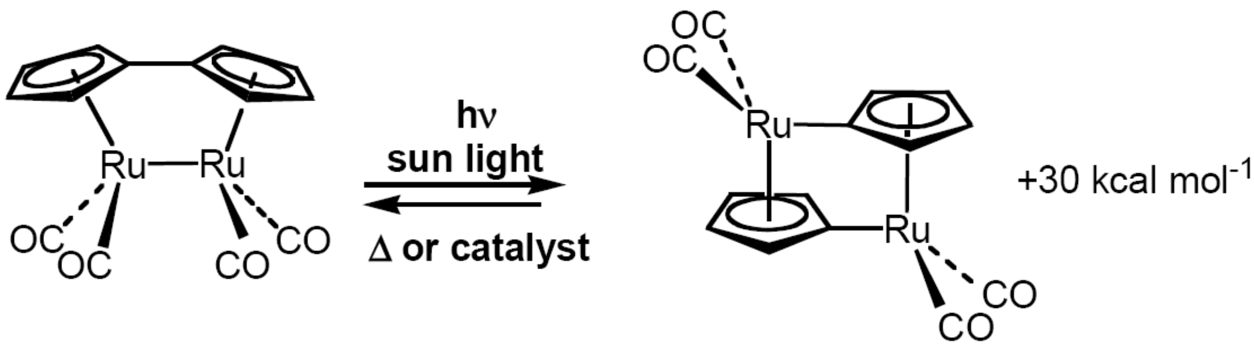
Lee, Zuckerman,…

gineering: Amplification Fabrication Templated growth

Acknowledge: S.W. Lee (BioE, PBD); K. Nam (MF)

Energy Storage in Phase Transitions

Explore reversible, controllable phase transformations using light to store energy …



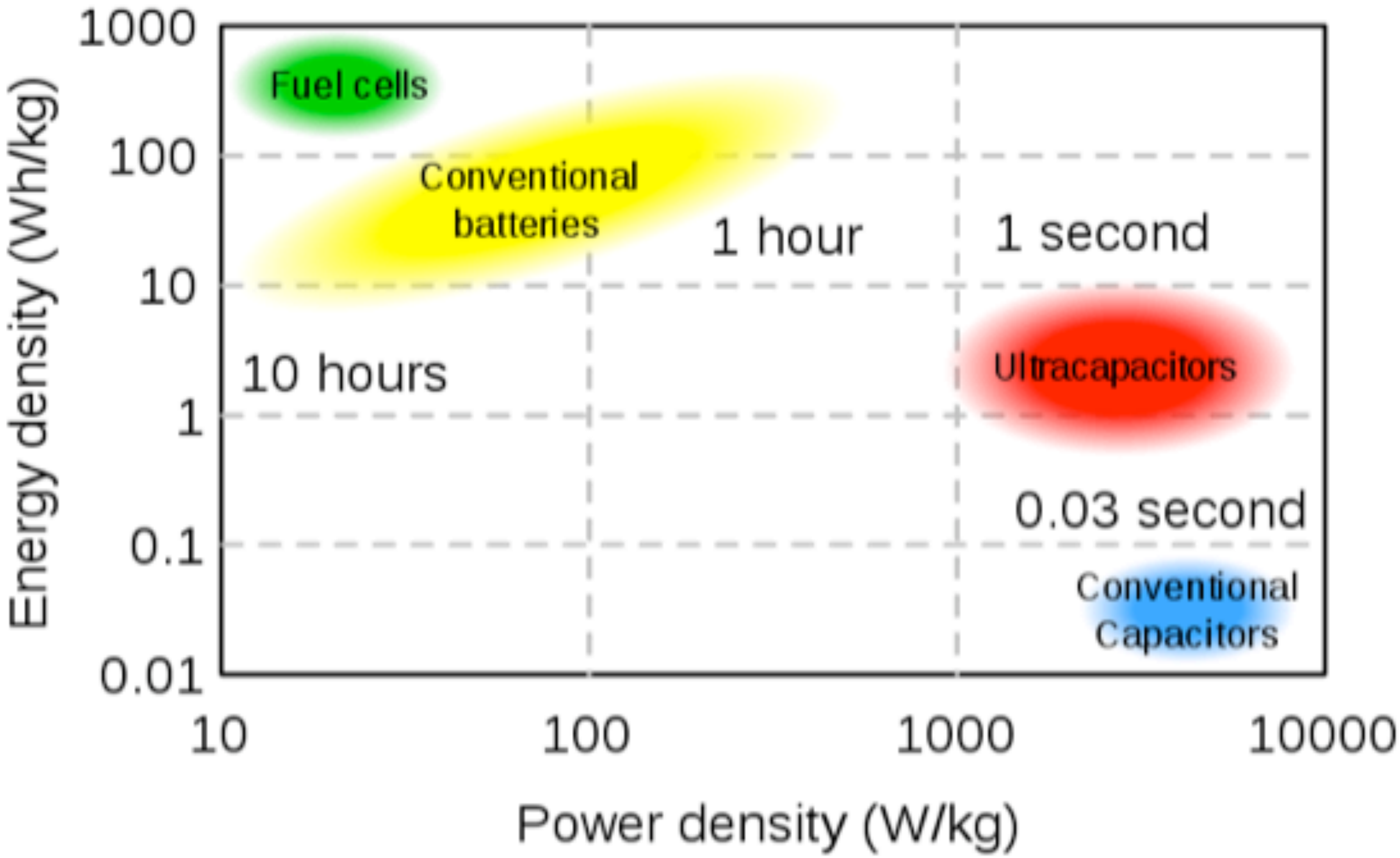
Vollhardt, Segalman, Majumdar

- Capture Solar Energy
- Store in Chemical/Structural/ Electronic/ Phase Trans

- Release Energy into Electrical/Magnetic /Thermal Cycle
- Return to Original State

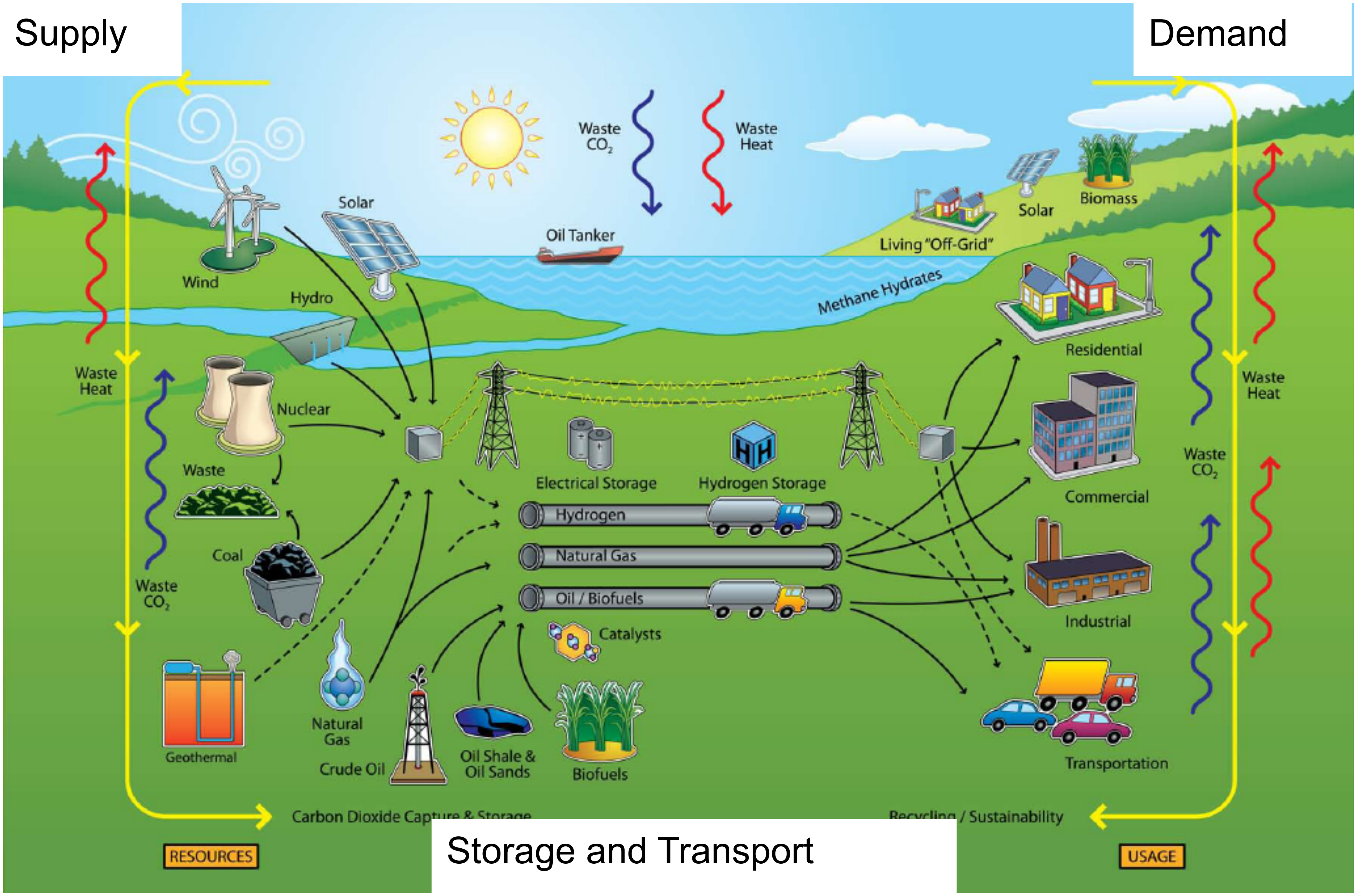
Vollhardt, Urban, Segalman,…

- Electrocalorics
- Magnetocalorics
- Other Phase Transitions??



1000
100
10
1
0.1
0.01
Energy density (Wh/kg)
Fuel cells
Conventional batteries
1 hour
1 second
10 hours
Ultracapacitors
0.03 second
Conventional Capacitors
10
100
1000
10000
Power density (W/kg)

The Energy Landscape



MRS Bulletin, Vol. **33**, April 2008