Nanotech Superconductors:
Enabling an Energy Efficient Electricity Infrastucture

Paul M. Grant

Visiting Scholar in Applied Physics, Stanford

IBM Research Staff Member Emeritus

EPRI Science Fellow (Retired)

Principal, W2AGZ Technologies

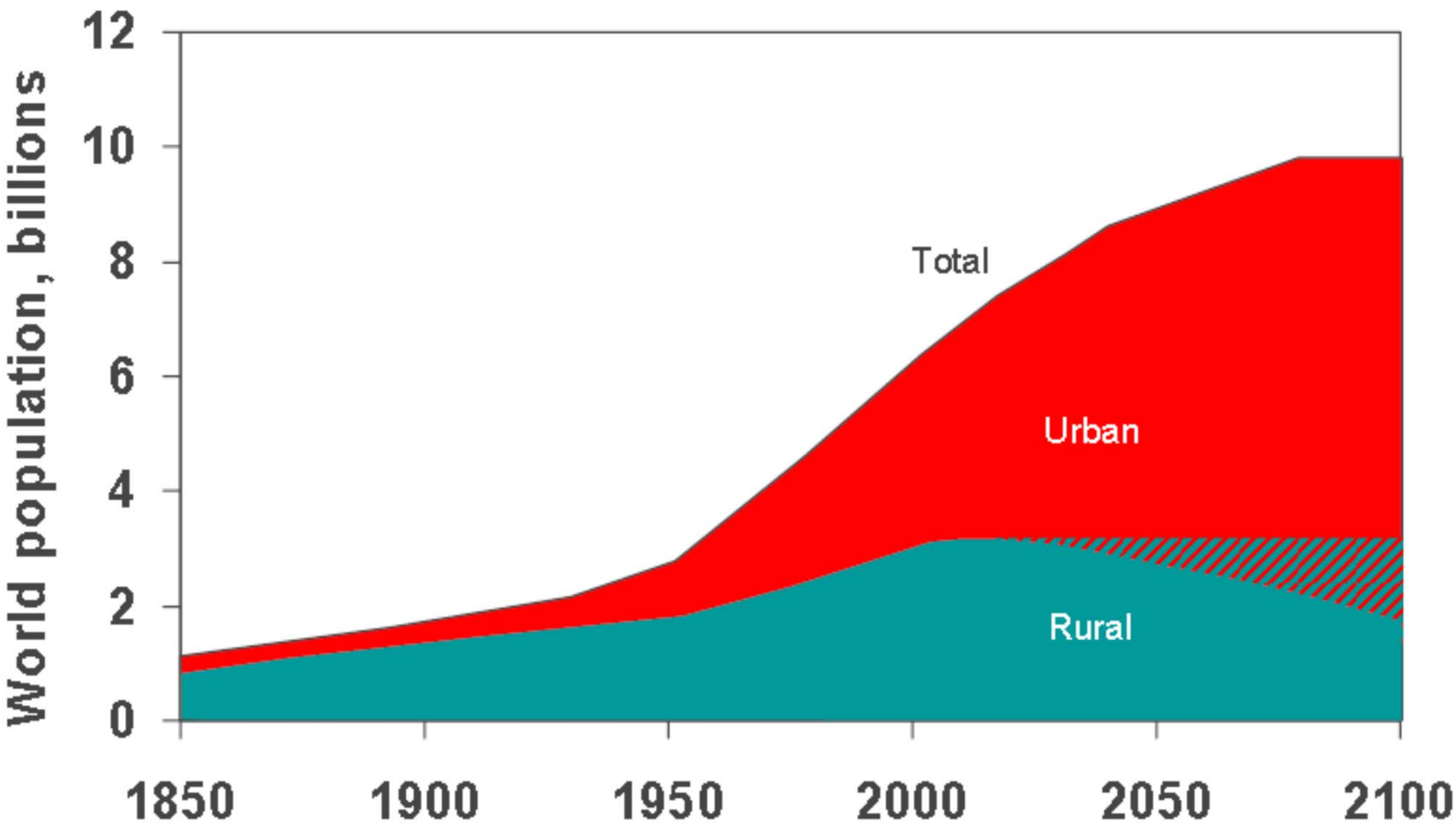
http://www.w2agz.com

Nano Energy Summit

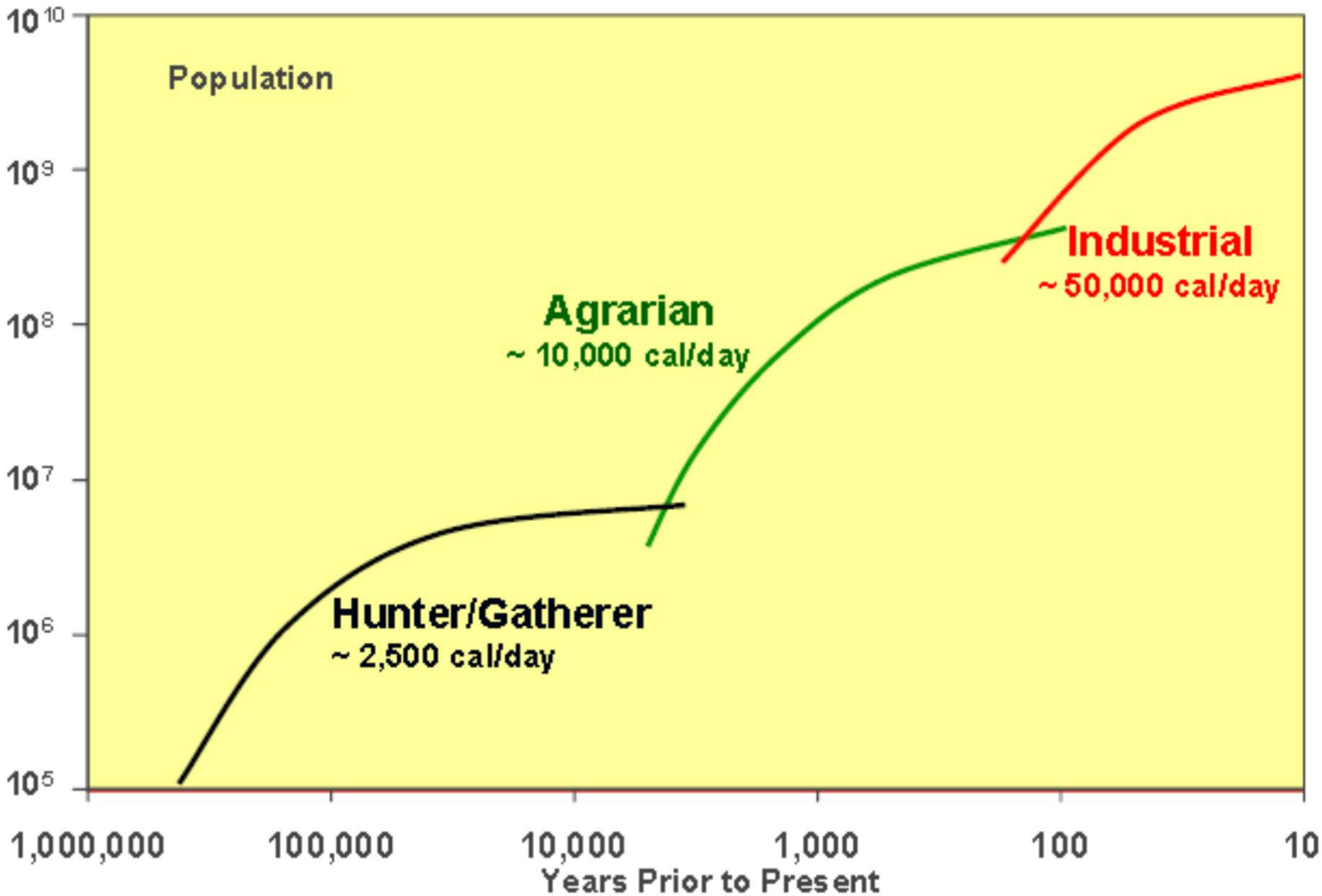
Nanotech Institute – UT Dallas

2 – 3 October 2007

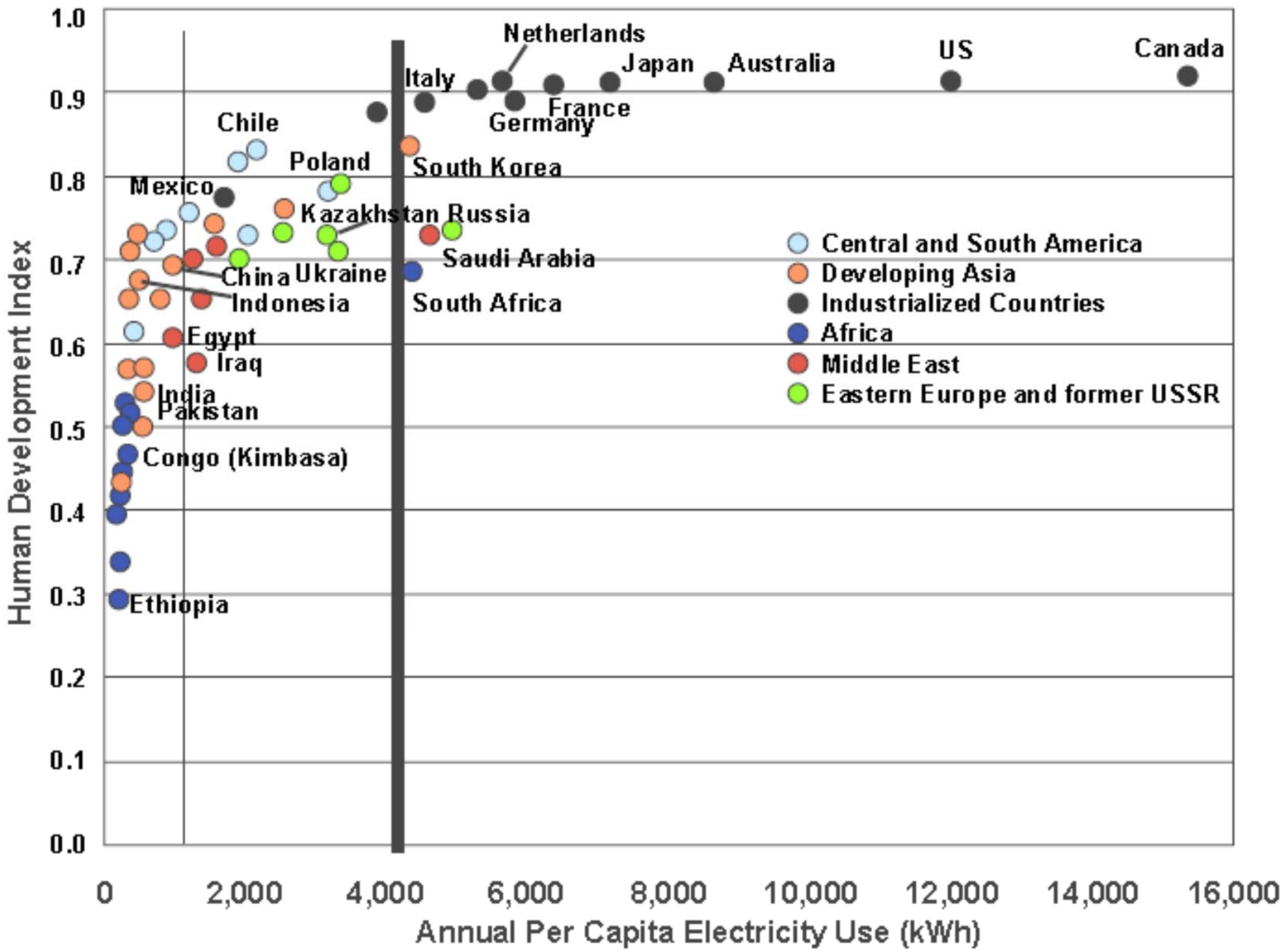
World Population: 1850 - 2100



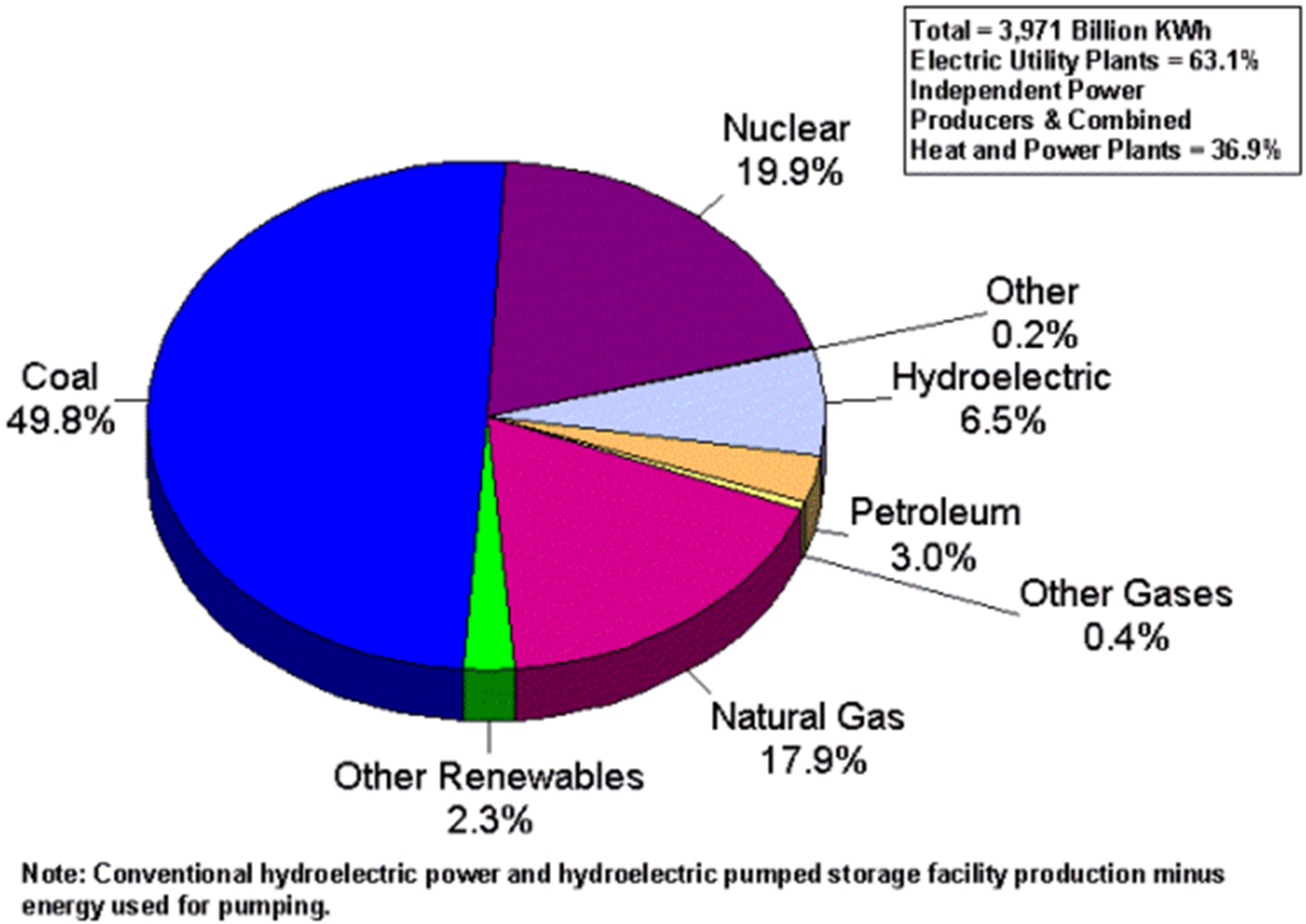
Energy/Demographics Timeline



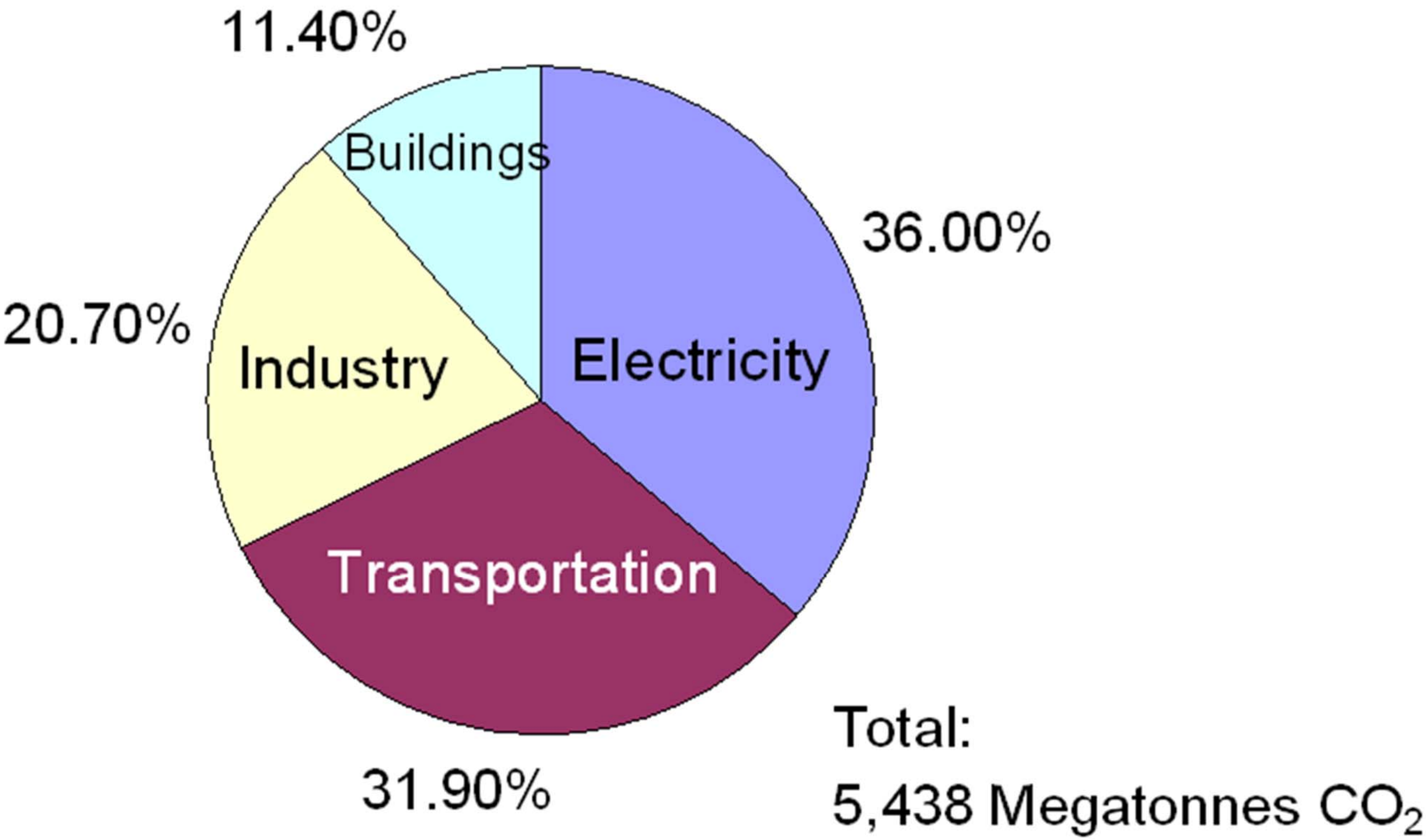
HDI vs per capita Electricity



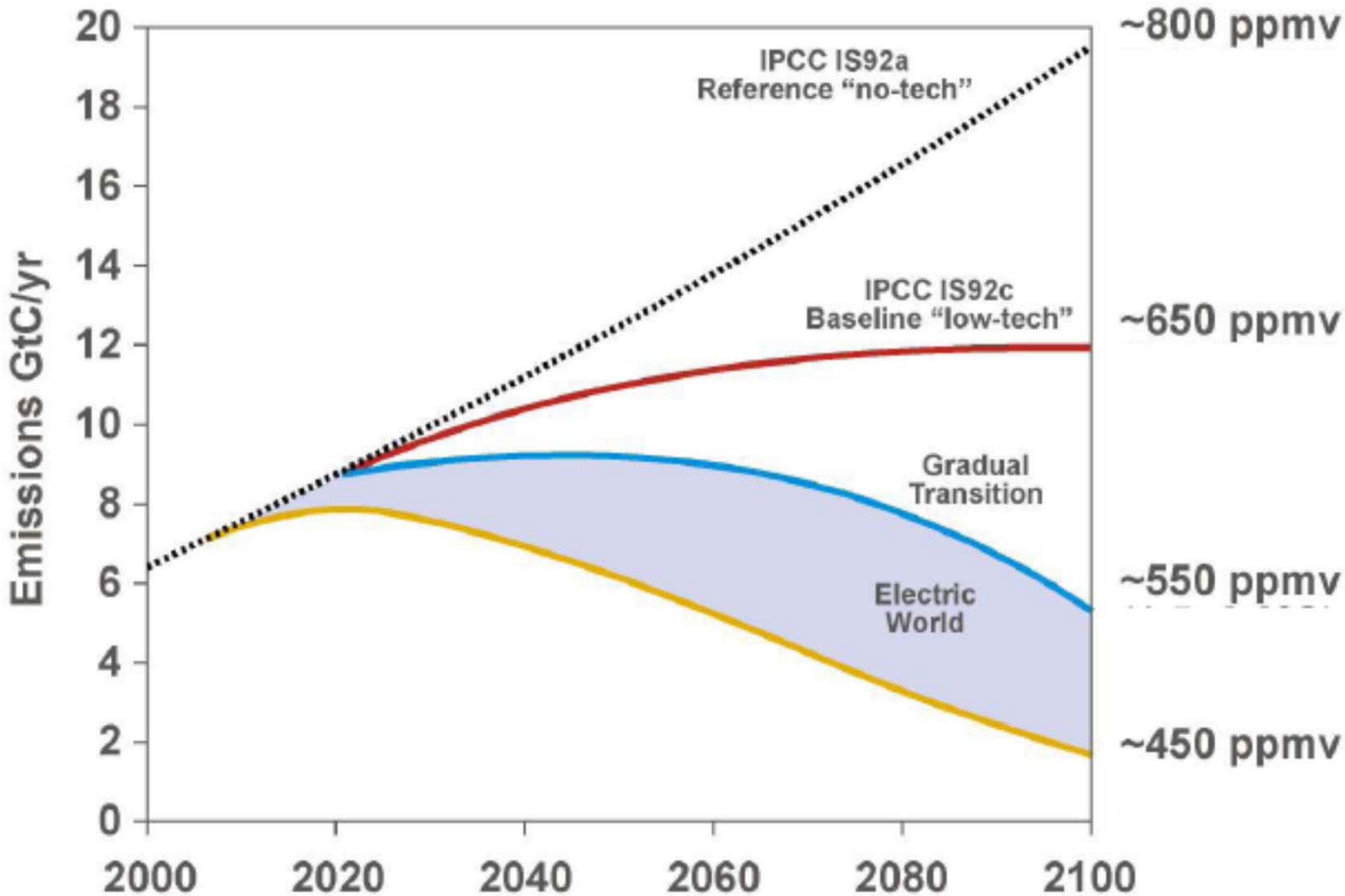
US Electricity Generation - 2005



CO_2 Emission Sources



CO_2 Emission Scenarios



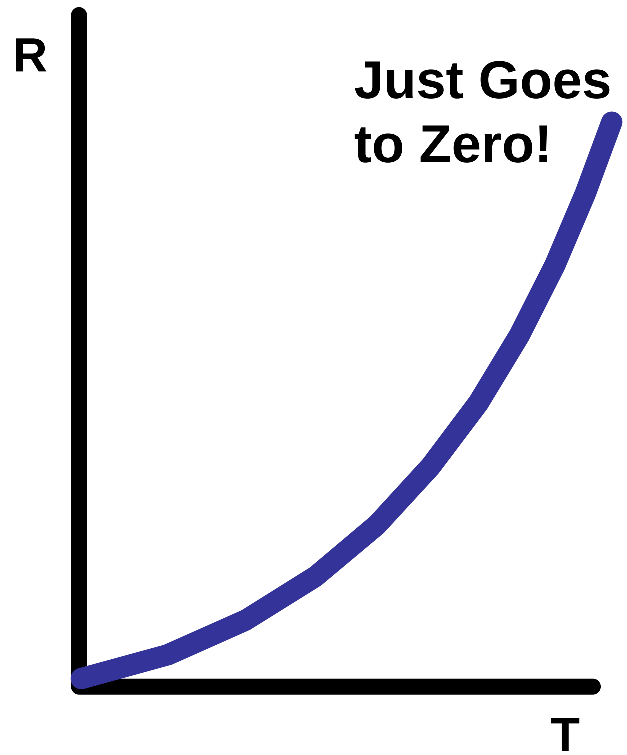
60 million years ago, the CO_2 concentration in the atmosphere was 7,000 ppmv!

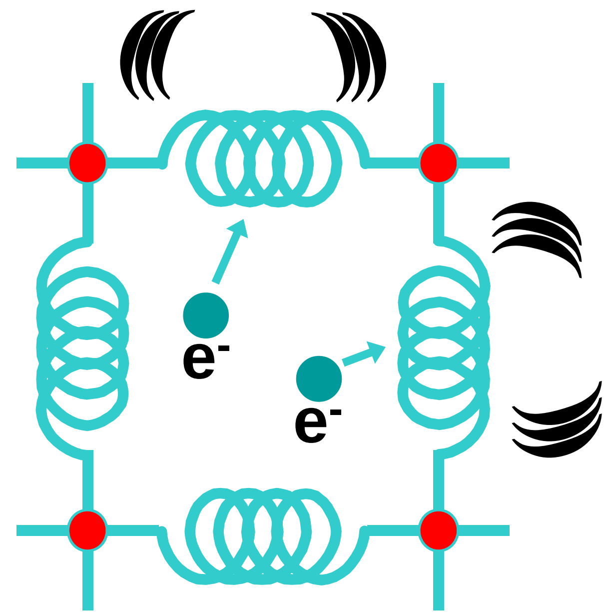
The Day After Tomorrow

An Inconvenient Truth

Models of Electrical Conductivity
1900

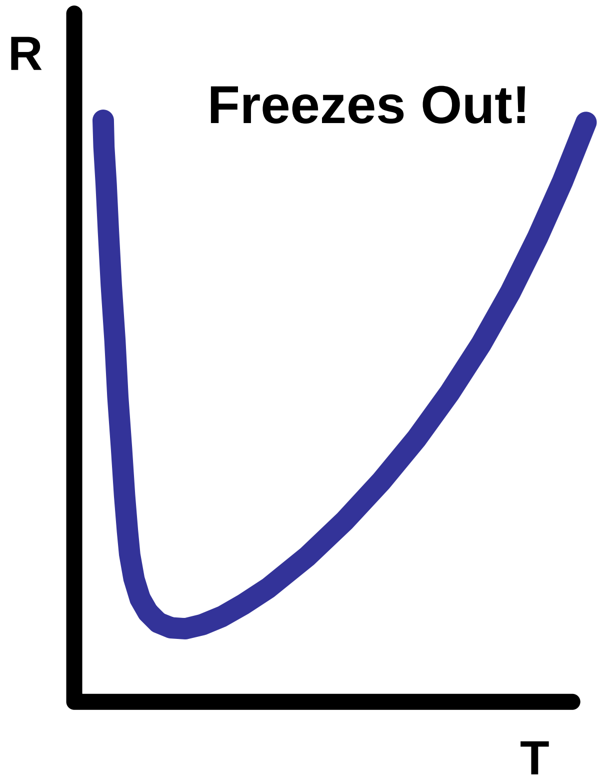
One Idea:

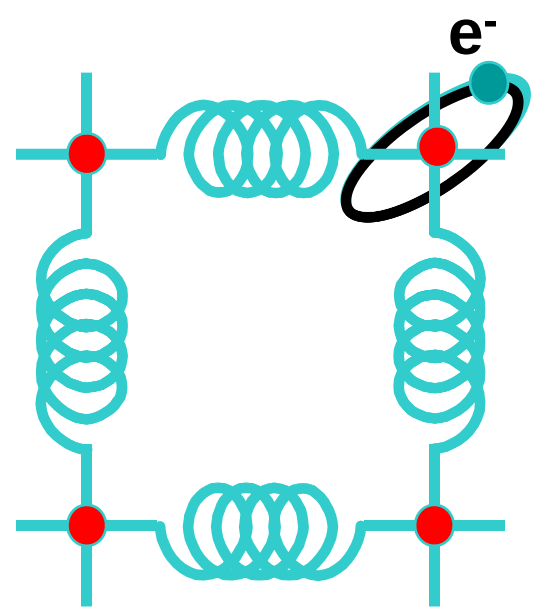




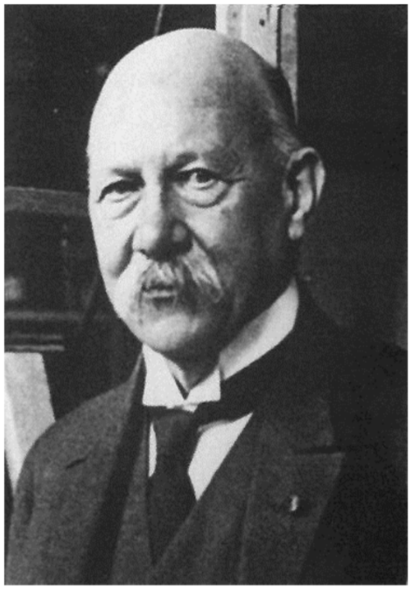
Models of Electrical Conductivity 1910

The Most Popular:

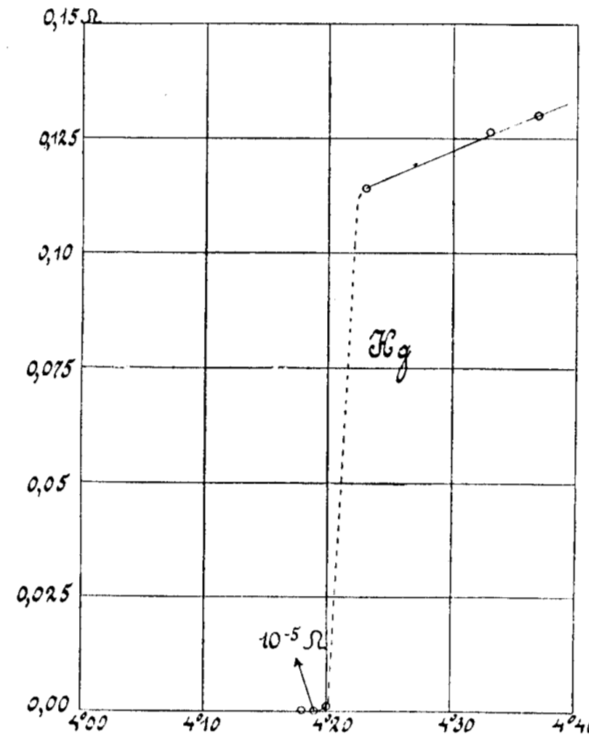




1911: A Big Surprise!

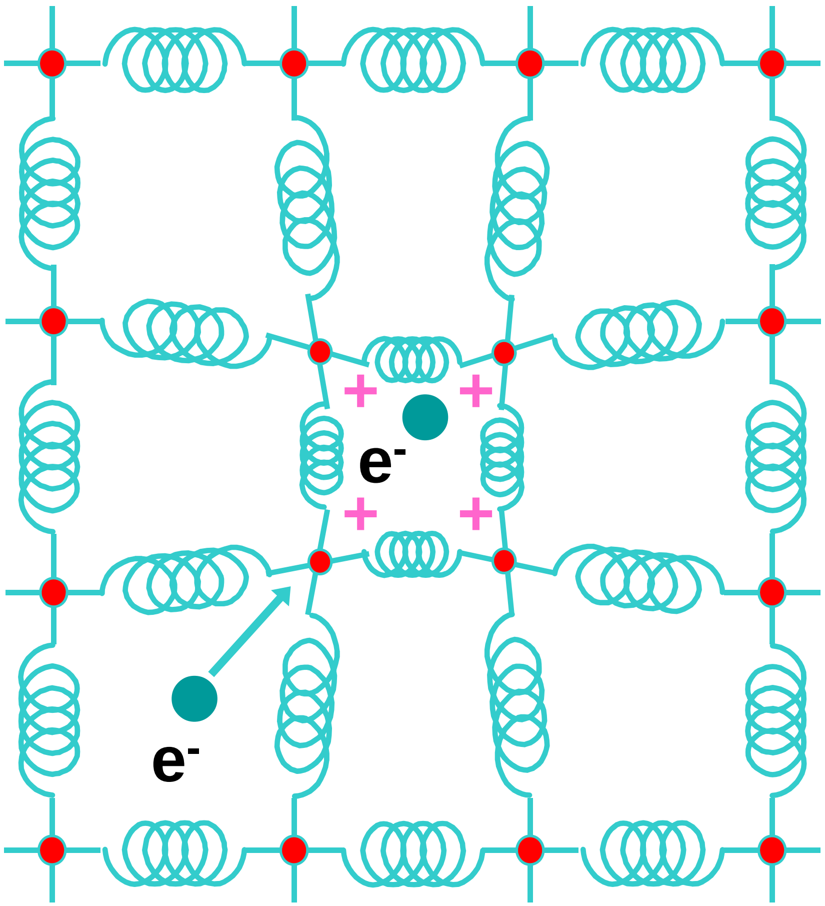


Thus the mercury at 4.2 K has entered a new state, which, owing to its particular electrical properties, can be called the state of *superconductivity*



H. Kamerlingh-Onnes (1911)

Physics of Superconductivity



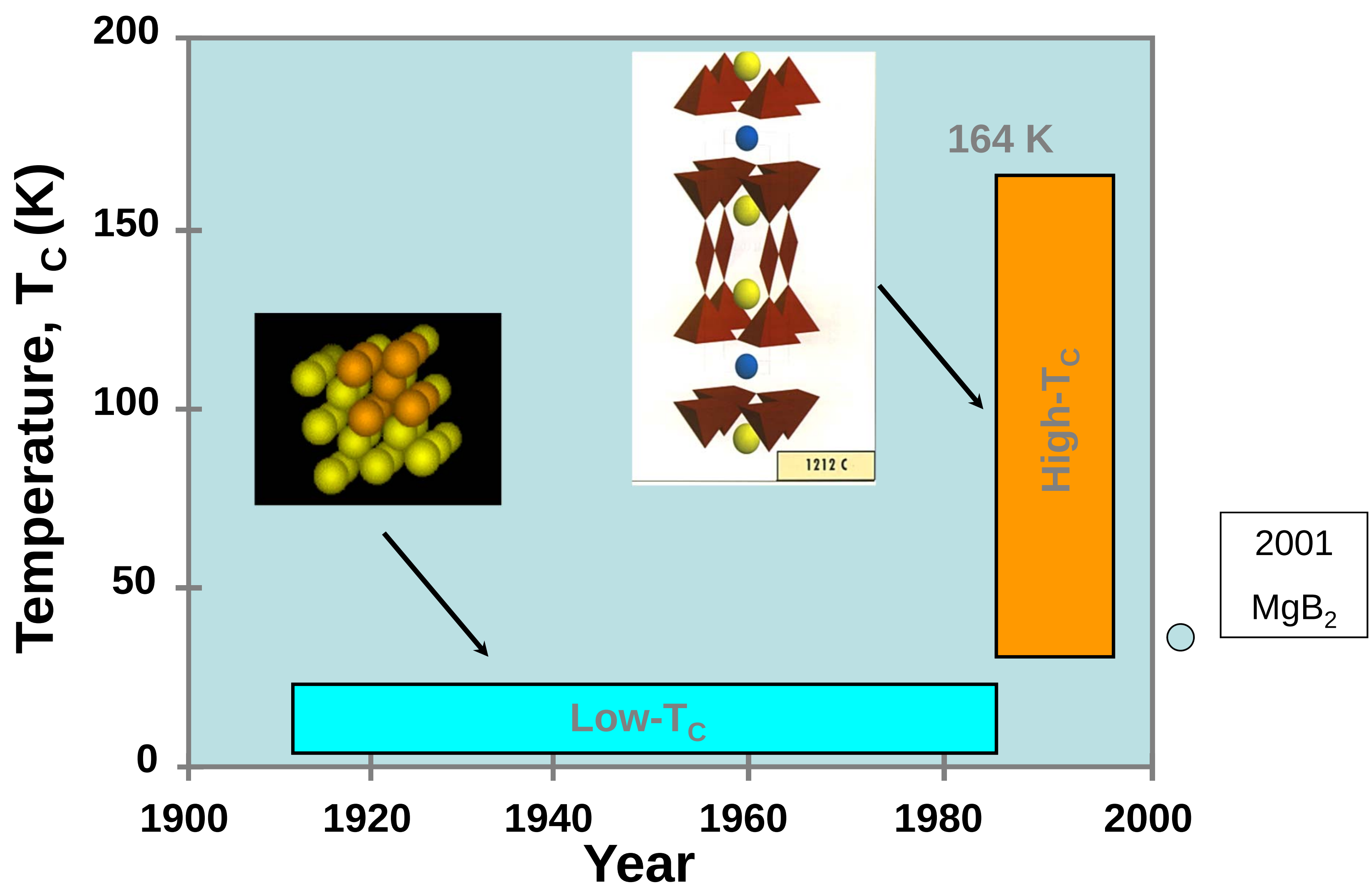
Electrons Pair Off!

BCS Equation

$$T_C = 1.14\,\theta_D \exp(-1/\lambda)$$

$$\theta_D = 275 \text{ K},$$
$$\lambda = 0.28,$$
$$\therefore T_C = \underline{9.5 \text{ K}} \quad \text{(Niobium)}$$

T_C vs. Year: 1911 - 2007

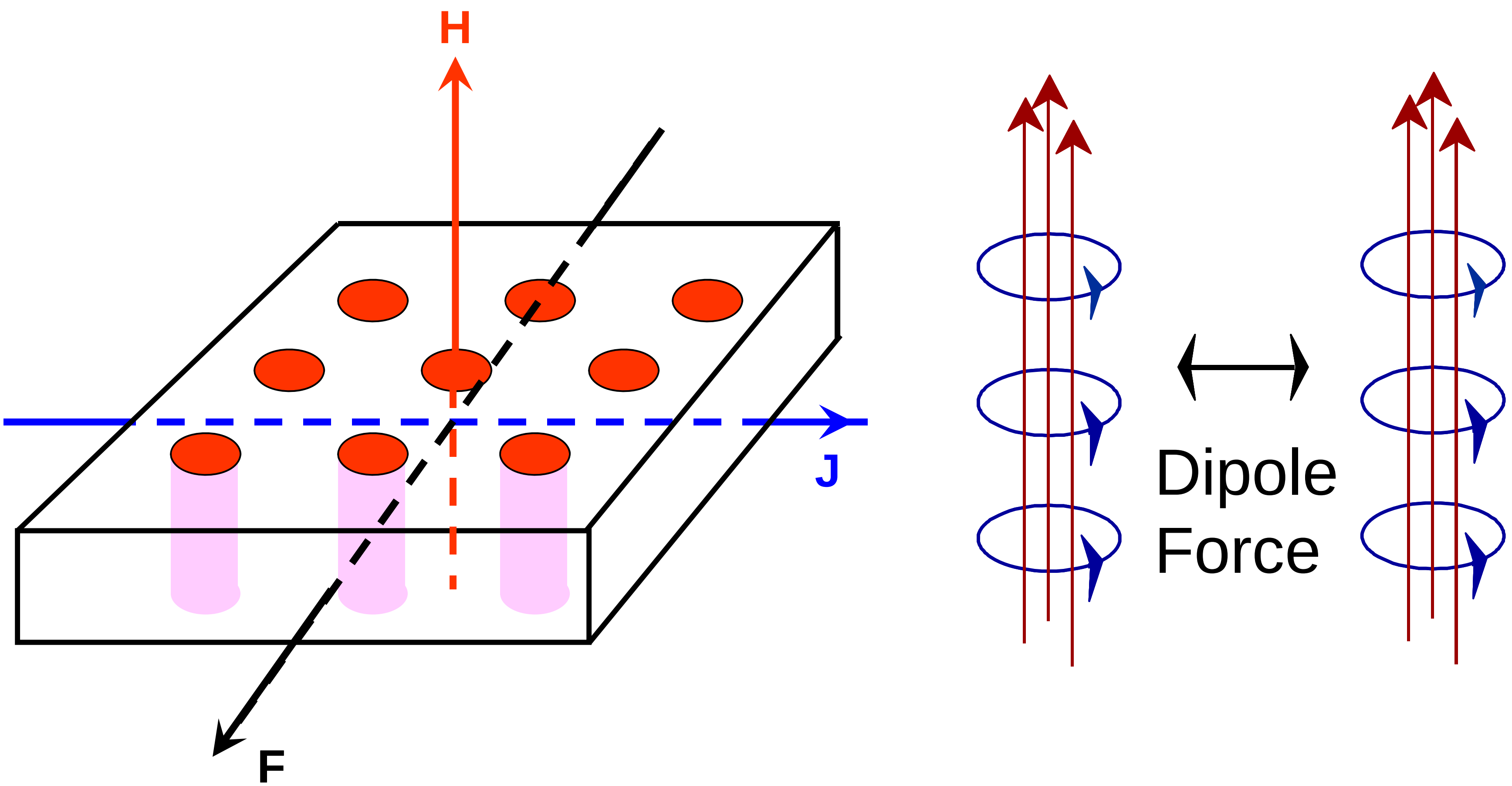


Important Numbers in Superconductivity

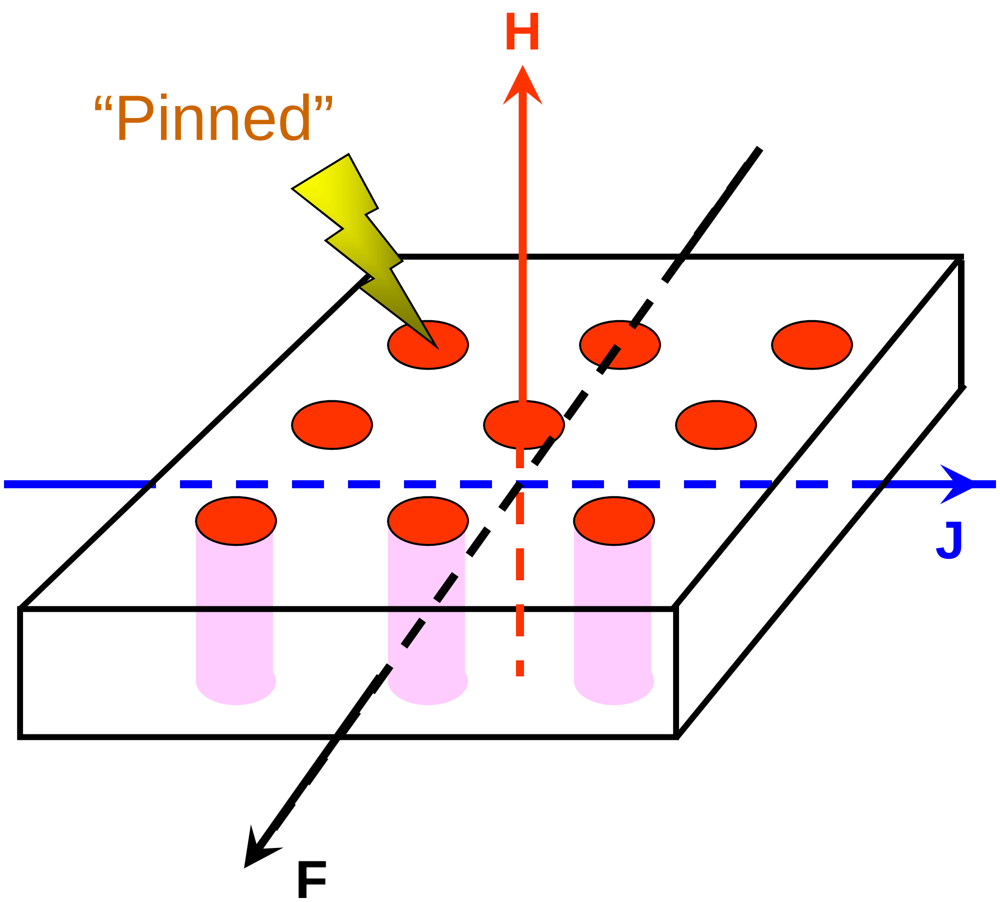
Transition Temperature, T_C	**Way below 300 K**
Critical Current Density, J_C	**10^{-2} - 10^{6} A/cm^2**
Critical Magnetic Field, H_C	**10^{-4} - 10 T**

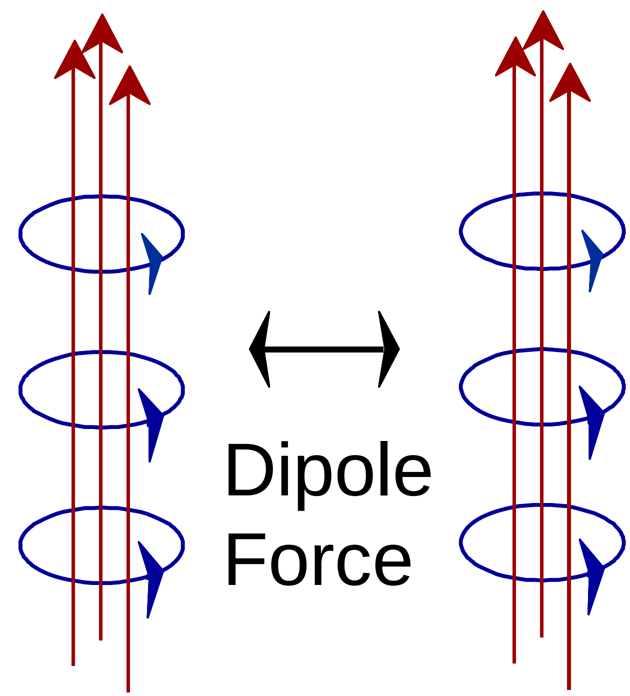
NB! All these numbers depend on each other.

Abrikosov Vortex Lattice

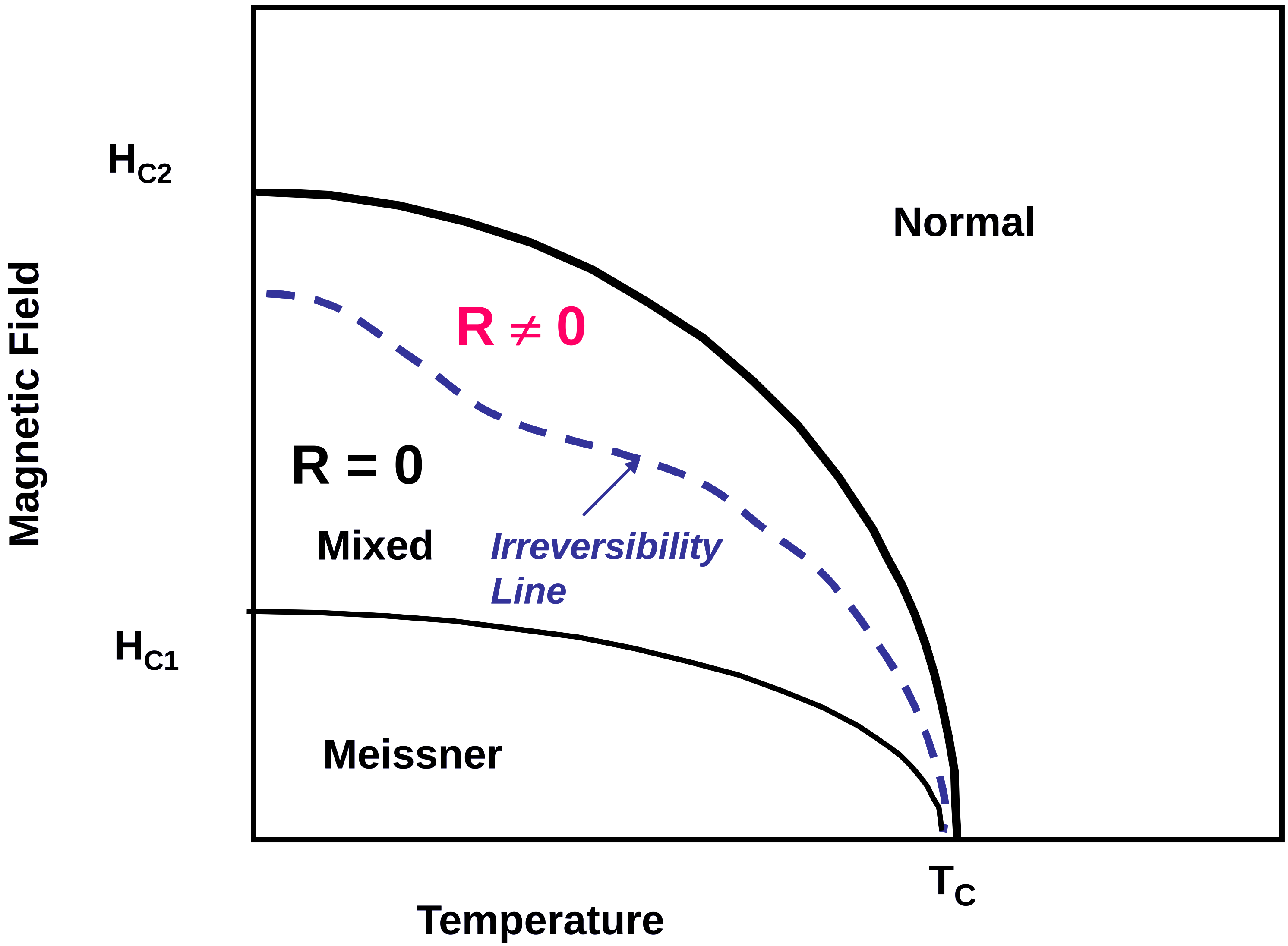


Abrikosov Vortex Lattice



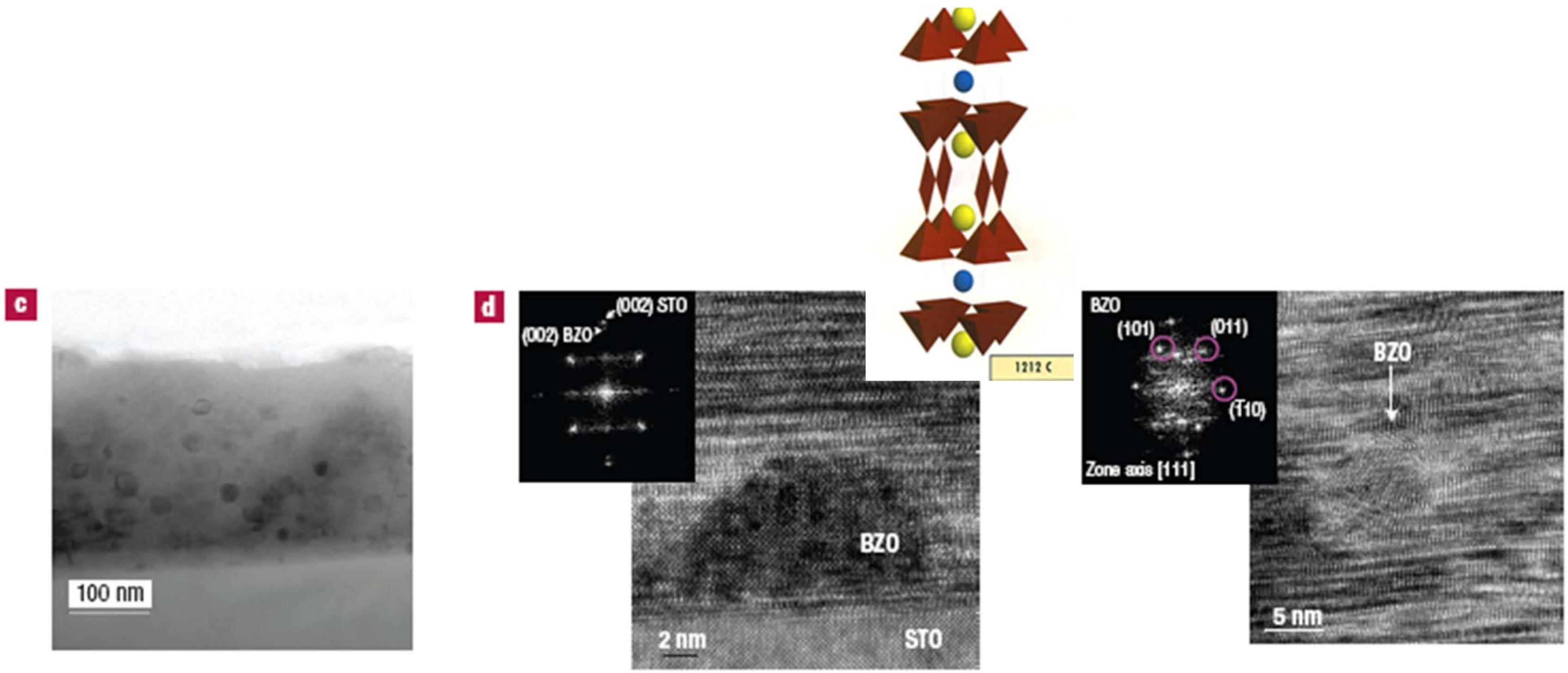


The Flavors of Superconductivity



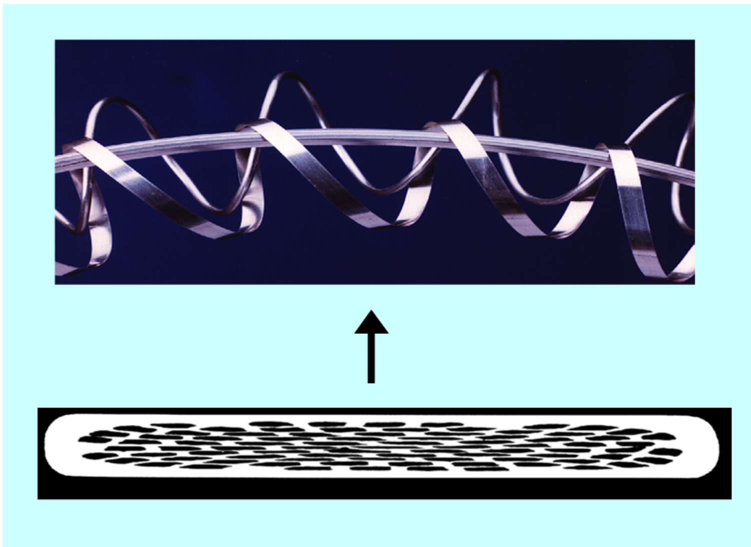
BZO “Nano-Pins”

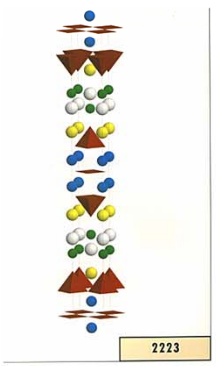
Obradors Group, Barcelona, Nature Materials, 2007



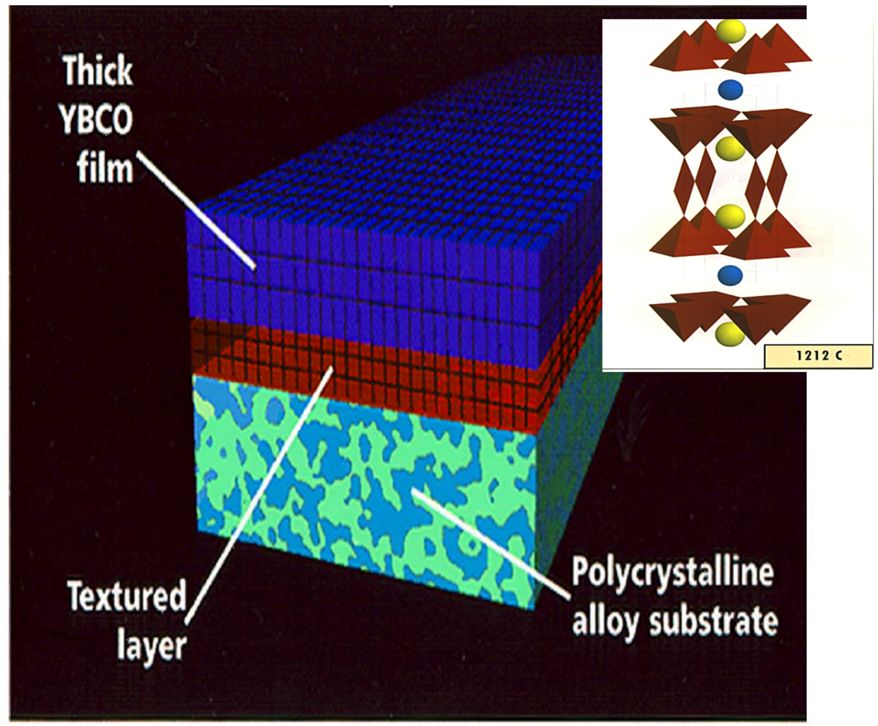
Wire

Gen 2



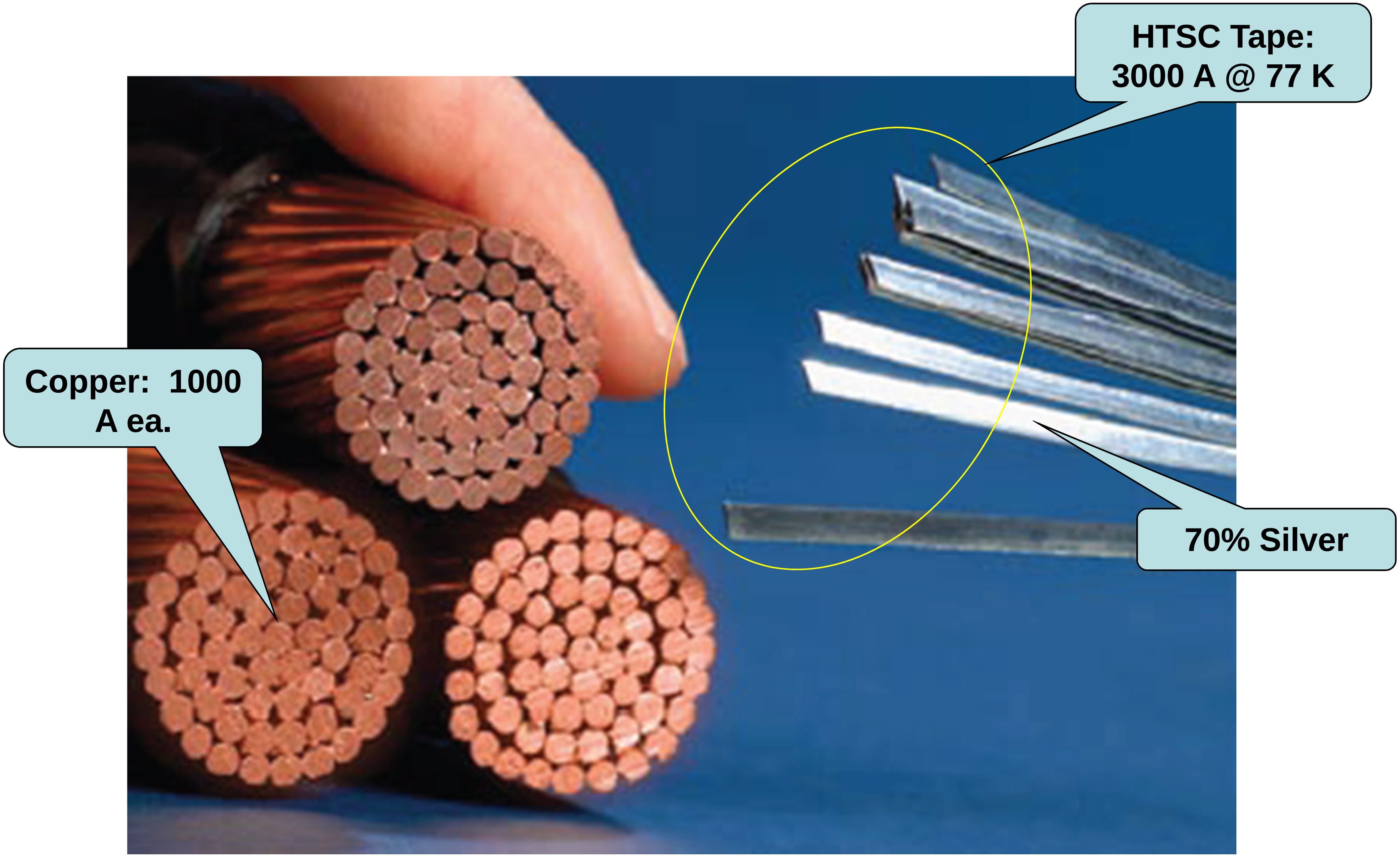


Gen 1

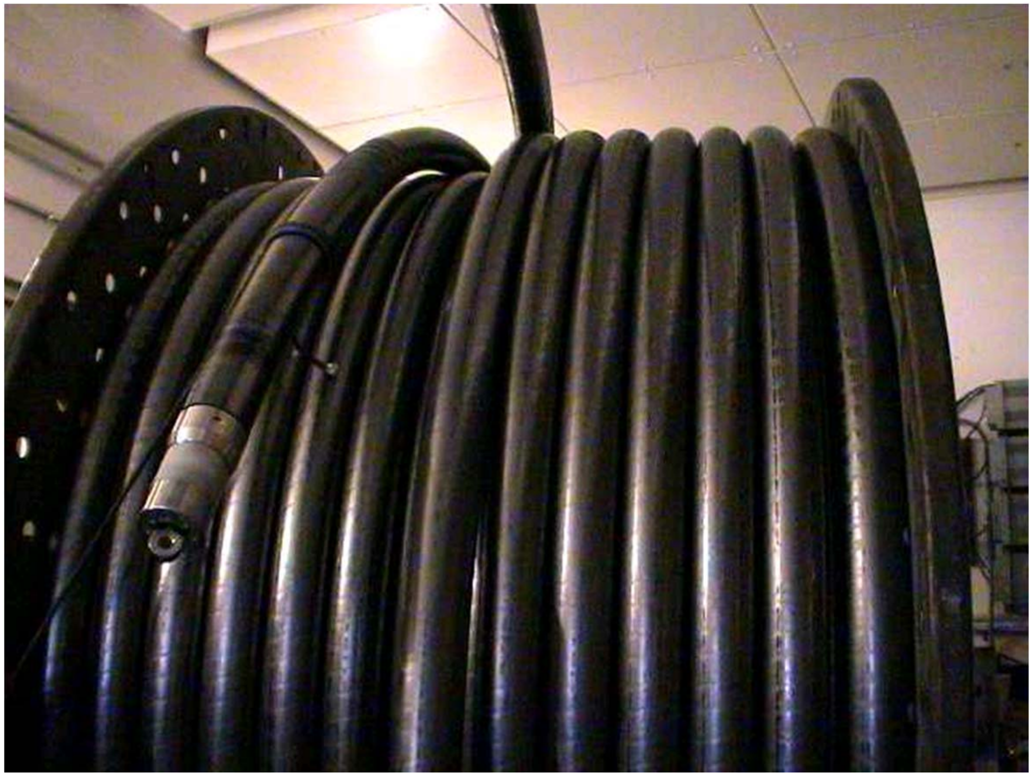


Major Players: US, Japan, China

HTSC Tape (AMSC)



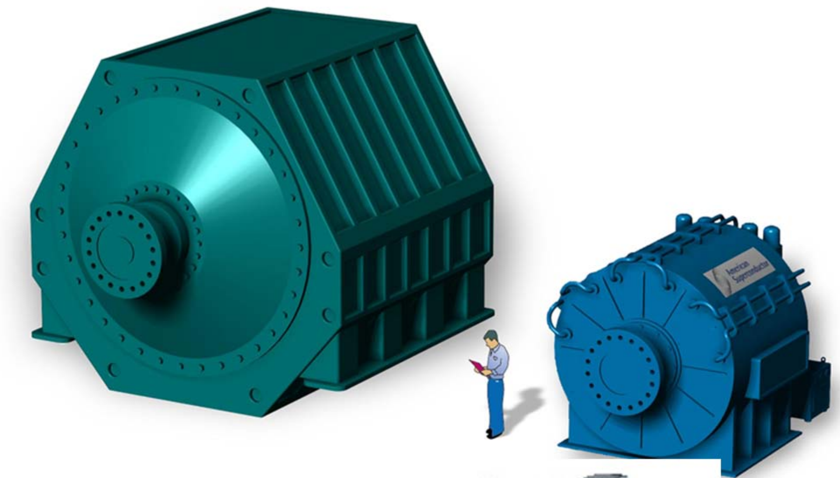
Finished Cable

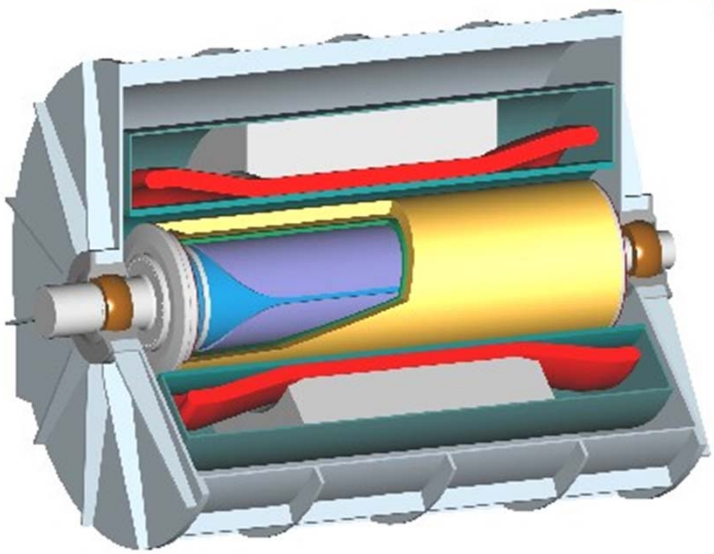


Cables

Rotating Machinery

Courtesy AMSC





Major Players:

- AMSC
- SEI

The 21st Century Energy Challenge

Design a communal energy economy to meet the needs of a densely populated industrialized world that reaches all corners of Planet Earth.

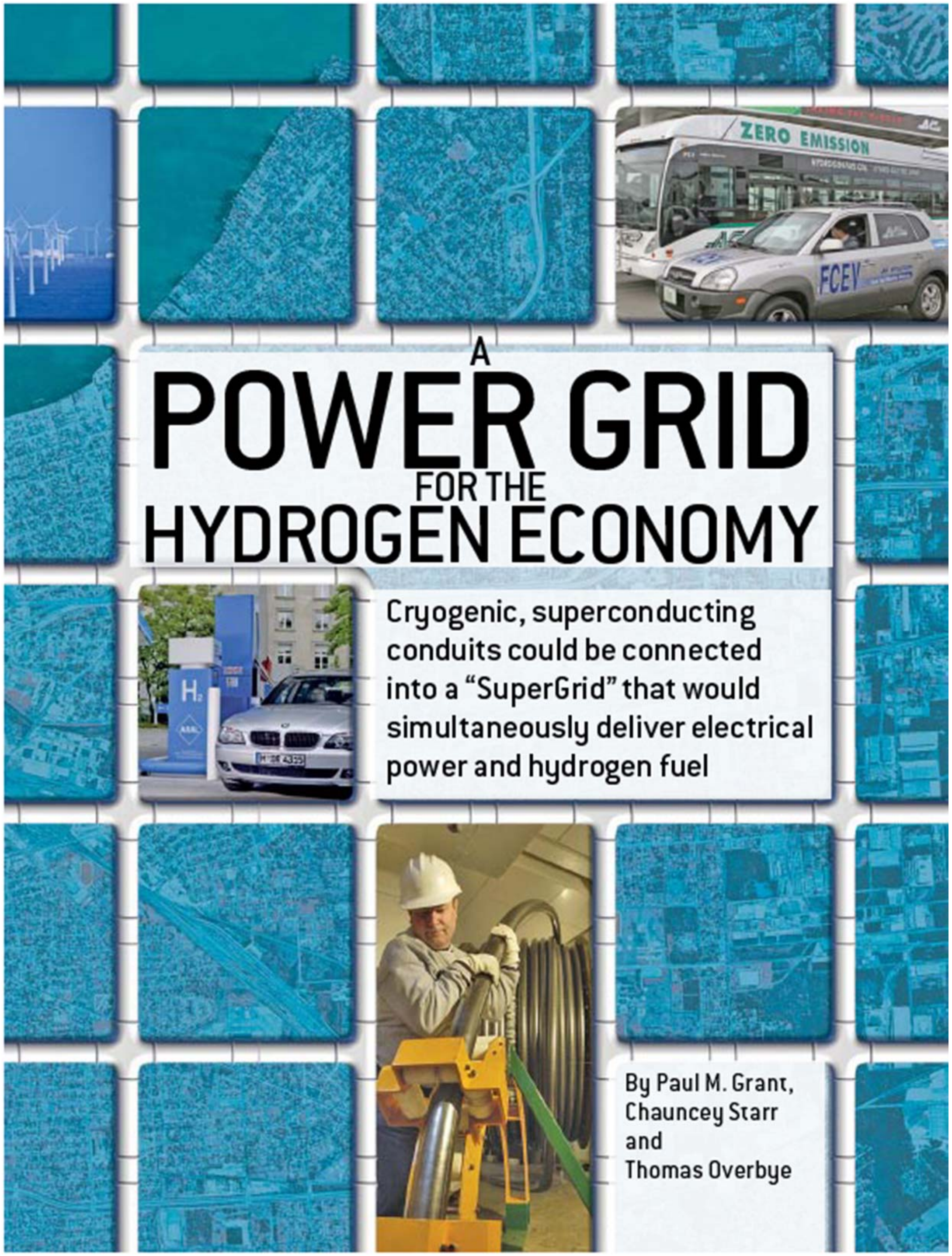
Accomplish this within the highest levels of environmental, esthetic, safe, reliable, efficient and secure engineering practice possible.

The Solution

A Symbiosis of

Nuclear/Hydrogen/Superconductivity

Technologies supplying Carbon-free, Non-Intrusive Energy for all Inhabitants of Planet Earth


A POWER GRID FOR THE HYDROGEN ECONOMY

Cryogenic, superconducting conduits could be connected into a "SuperGrid" that would simultaneously deliver electrical power and hydrogen fuel

By Paul M. Grant, Chauncey Starr and Thomas Overbye

On the afternoon of August 14, 2003, electricity failed to arrive in New York City, plunging the 10 million inhabitants of the Big Apple—along with 40 million other people throughout the northeastern U.S. and Ontario—into a tense night of darkness.

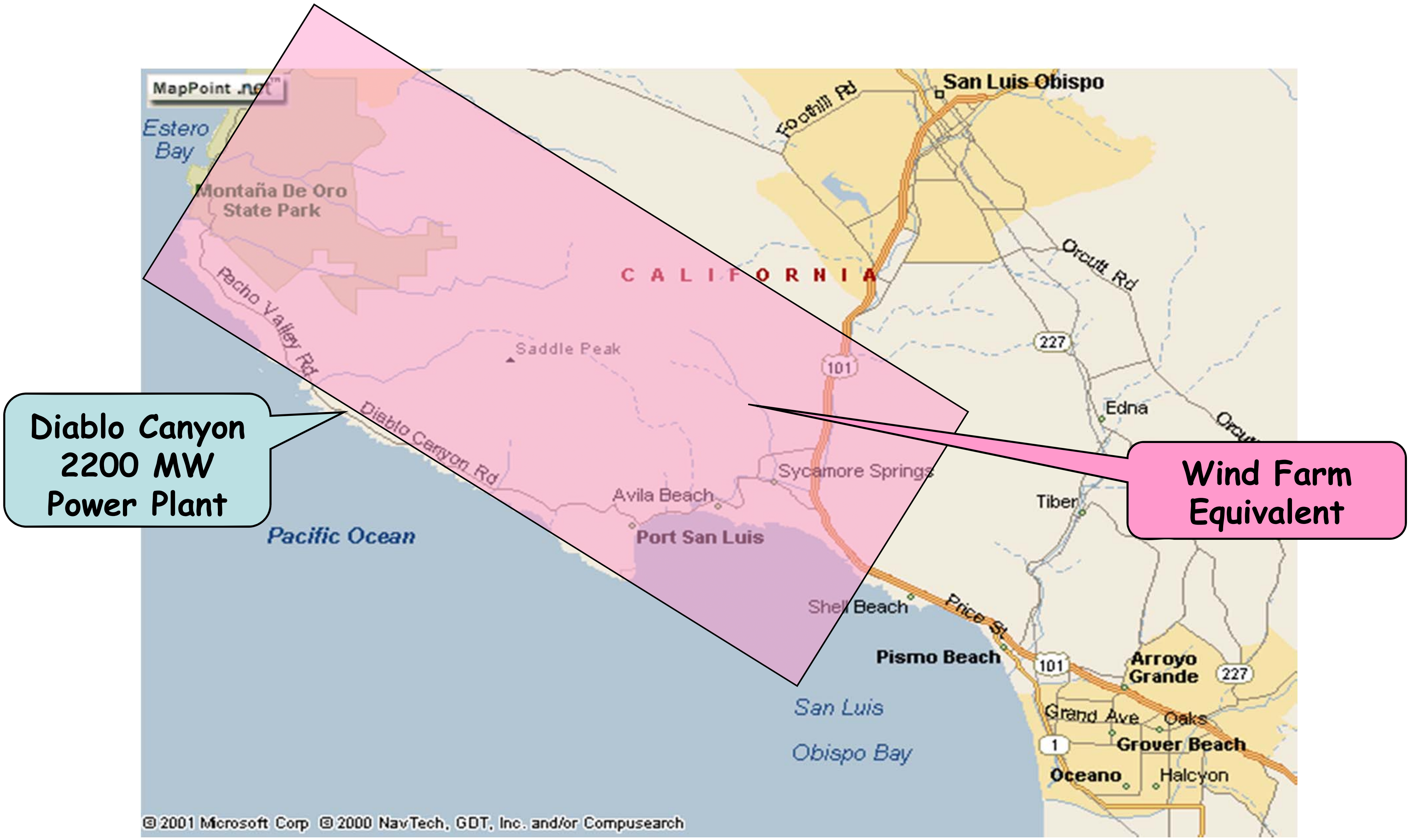
Published in

SCIENTIFIC AMERICAN

July, 2006

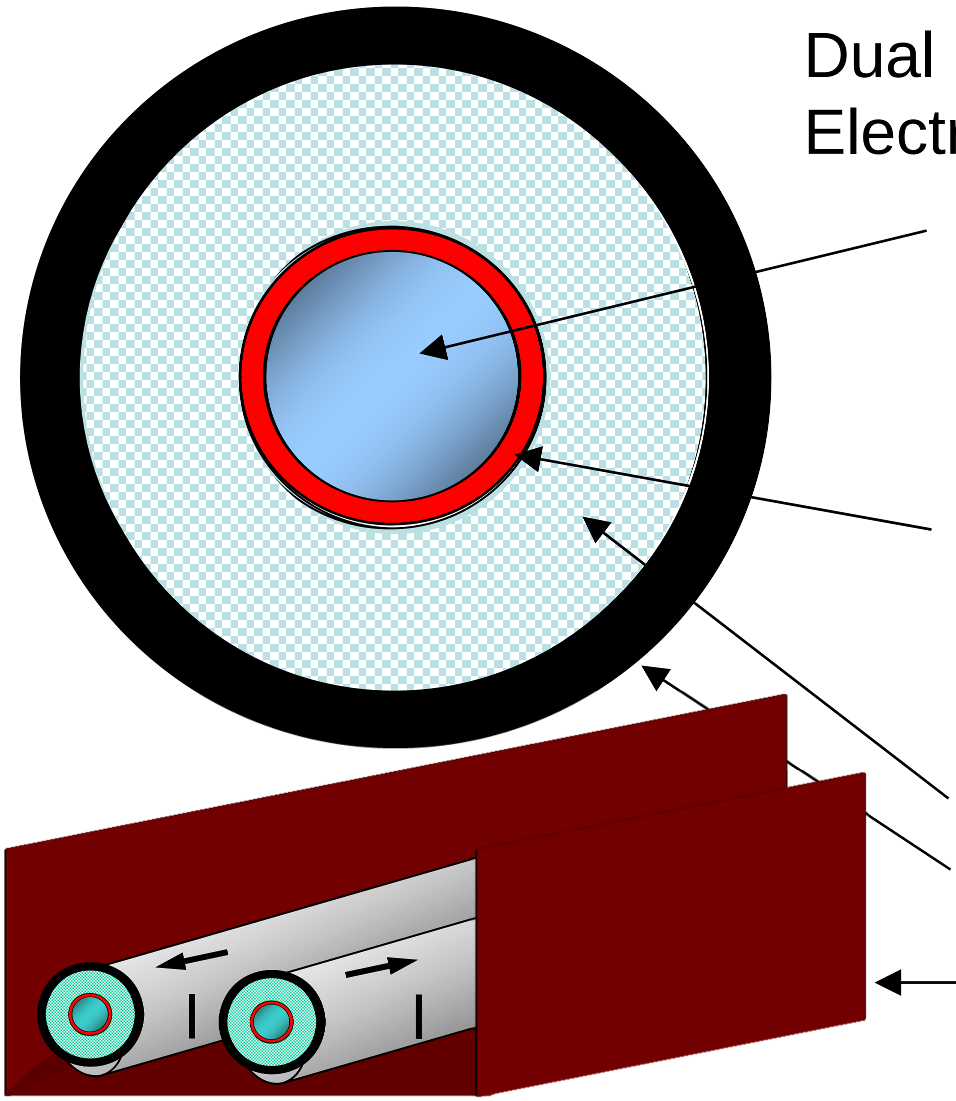
Diablo Canyon

California Coast Power



The Hydricity SuperCable

Dual Delivery of Hydrogen and Electric Power



Flowing liquid hydrogen or cold H_2 gas under pressure delivers power and also serves as the refrigerant to …

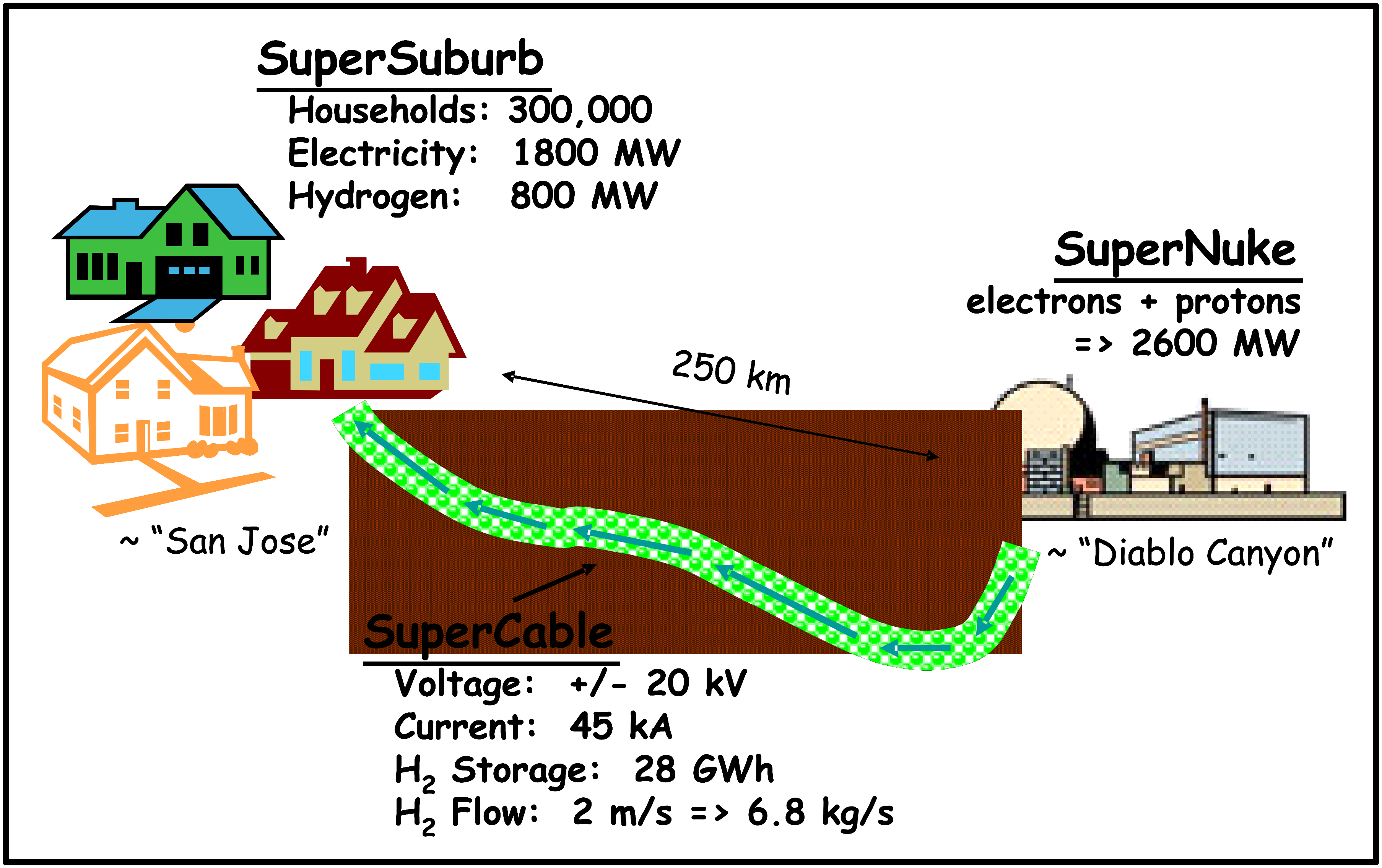
Enable the transmission of large amounts of electric power losslessly using superconductors

Thermal Insulation

Electrical Insulation

Enclosed in underground tunnel or trench

SuperSuburb



Road to Room Temperature Superconductivity

17-23 June 2007, Hotel Alexandra, Loen, Norway

AFOSR, Twente, Trondheim, HKUST

http://www.srudesigns.com/road2rts/

http://www.w2agz.com/rtsc07.htm

Chu	Varma	Cohen	Bosovic	Kivelson
Kresin	Mannhart	Scalapino	Beasley	Antipov
Akimitsu	Gurevich	Fischer	Pavuna	Hasuo
Ashcroft	Rice	Shimizu	Geballe	Uchida
Sudbo	Klemm	Zakhidov	Raveau	Grant

When "electron-electron" interactions are involved,
the phrase "pairing glue" can be a dirty word!

$$T_C = a\Theta e^{-\frac{1}{\lambda-\mu^*}}$$

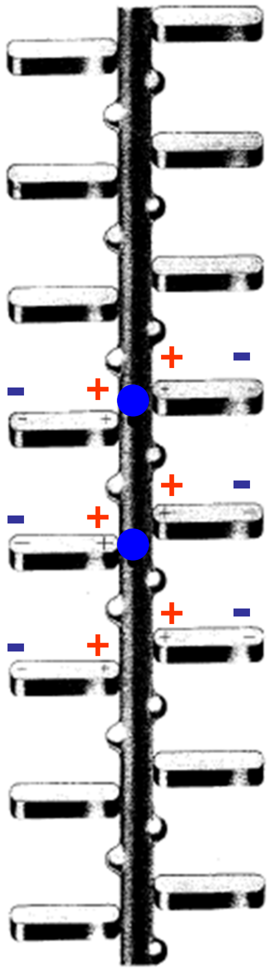
Insert your favorite "on" here

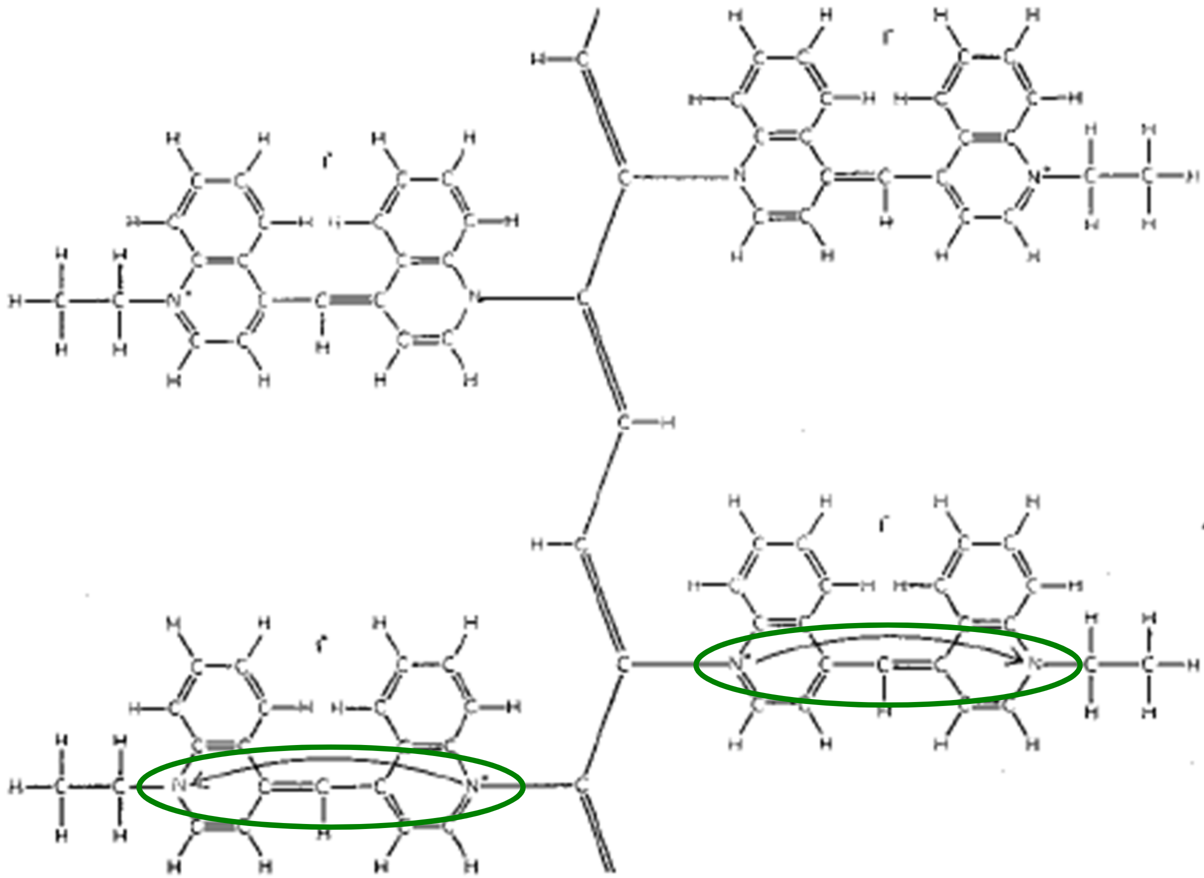
(phonon, magnon, exciton, plasmon, anyon, moron …)

"Put-on !"

Mike Norman, Alexandria, VA 2006

Little, 1963





Diethyl-cyanine iodide

Davis – Gutfreund – Little (1975)

PHYSICAL REVIEW B VOLUME 13, NUMBER 11 1 JUNE 1976

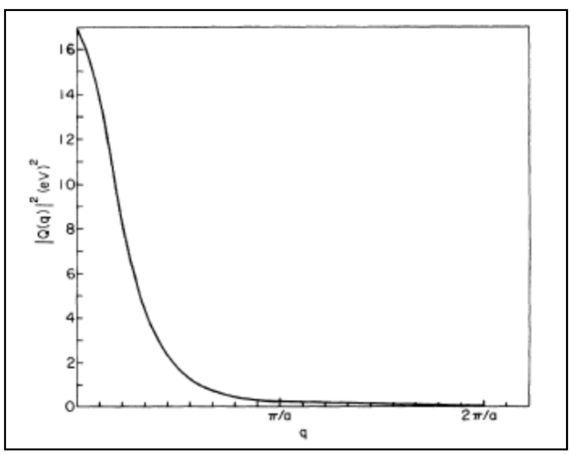
Proposed model of a high-temperature excitonic superconductor*

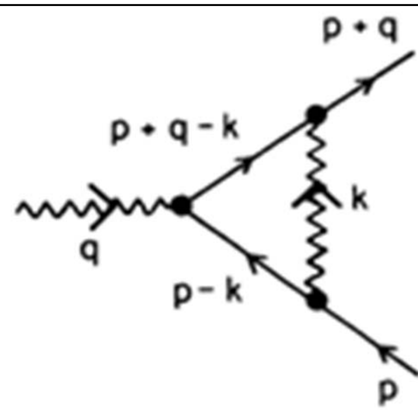
D. Davis,† H. Gutfreund,‡ and W. A. Little
Physics Department, Stanford University, Stanford, California 94305
(Received 16 October 1975)

$$g^{q\nu,mn}_{\mathbf{k}+\mathbf{q},\mathbf{k}} \longrightarrow$$ Kirzhnits, Maximov, Zhomskii

$$\phi^*(r_1-R_j)\,\phi(r_1-R_h)e^{i[kR_h-(k-q)R_j]}V(r_1r_2)\sum_{m,l,\nu}\left[u^{\nu}_{\alpha l}(q)+iv^{\nu}_{\alpha l}(q)\right]e^{-iqR_l}\,\Psi^*_{\nu}(R_{ml})\Psi_{00}$$

$$Q_\alpha(q)=\frac{1}{N^{3/2}}\int\sum_{j,k}\phi^*(r_1-R_j)\,\phi(r_1-R_h)e^{i[kR_h-(k-q)R_j]}V(r_1r_2)\sum_{m,l,\nu}\left[u^{\nu}_{\alpha l}(q)+iv^{\nu}_{\alpha l}(q)\right]e^{-iqR_l}\,\Psi^*_{\nu}(R_{ml})\Psi_{00}\,d^3r_1d^3\tau$$





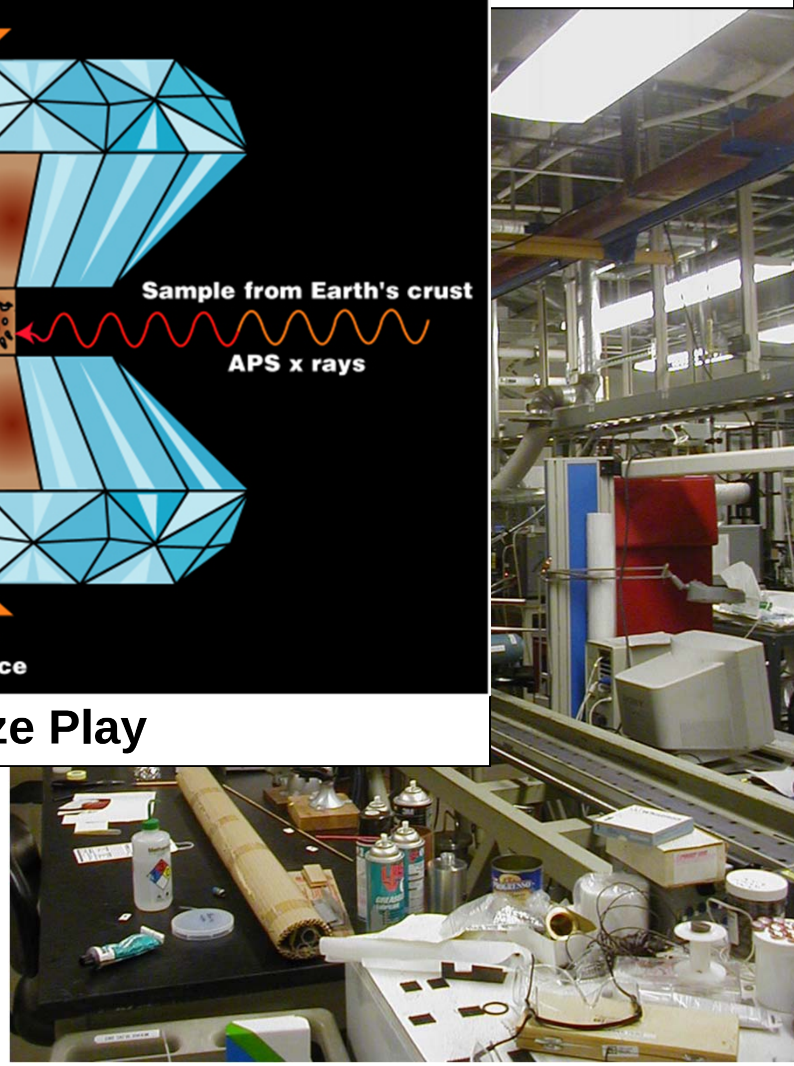
Migdal Issues:
- Only small exciton q's, $v_q > v_F$, couple to the electrons.
- Thus vertex corrections are of order λ^2/θ and we're OK.
- DGL claim this is NOT the case for ABB.
- IMHO, this is an item amenable to numerical analysis.

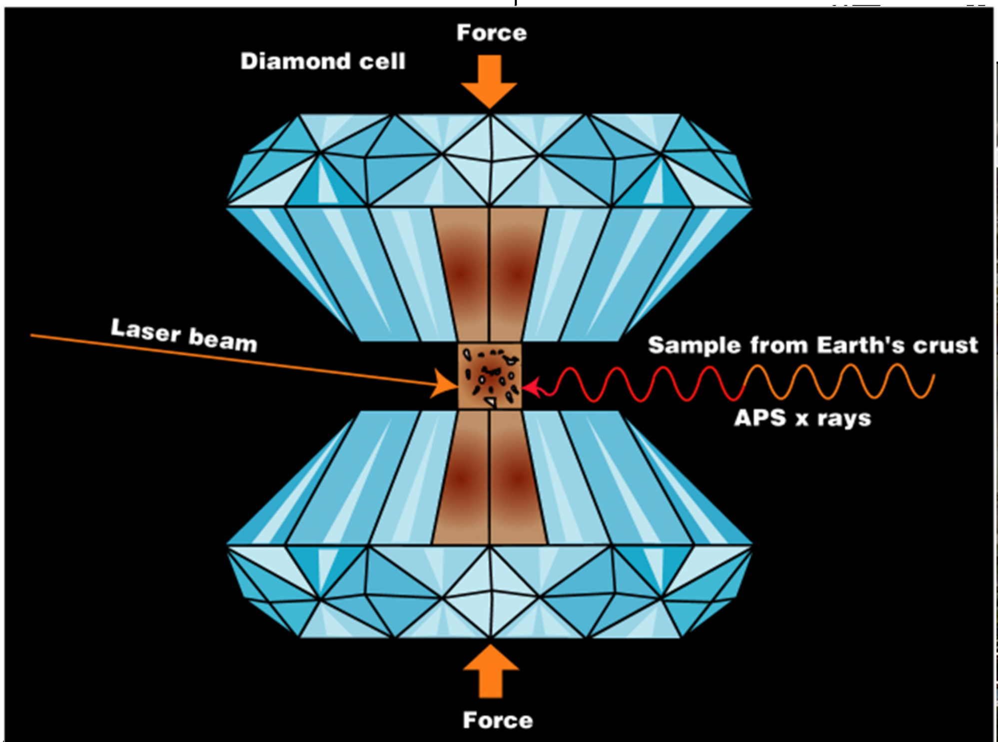
Norwegian Dreams

- Geballe (“Negative U”)
- Kresin (“Magic Clusters”)
- Mannhart-Bosovic (“Interfaces”)
- Zakhidov (“Opals are a Girl’s Best Friend”)
- Fischer (“Dig out $2\Delta = (8?)kT_c$”)
- Ashcroft (“Keep it light”)
- Grant (“da Vinci Code”)

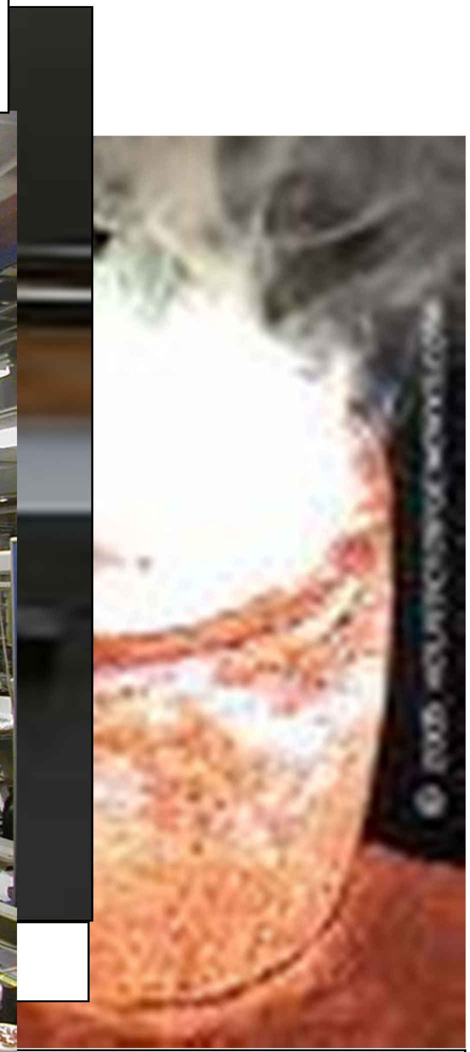
Fabrication

Superconductor Sandwiches



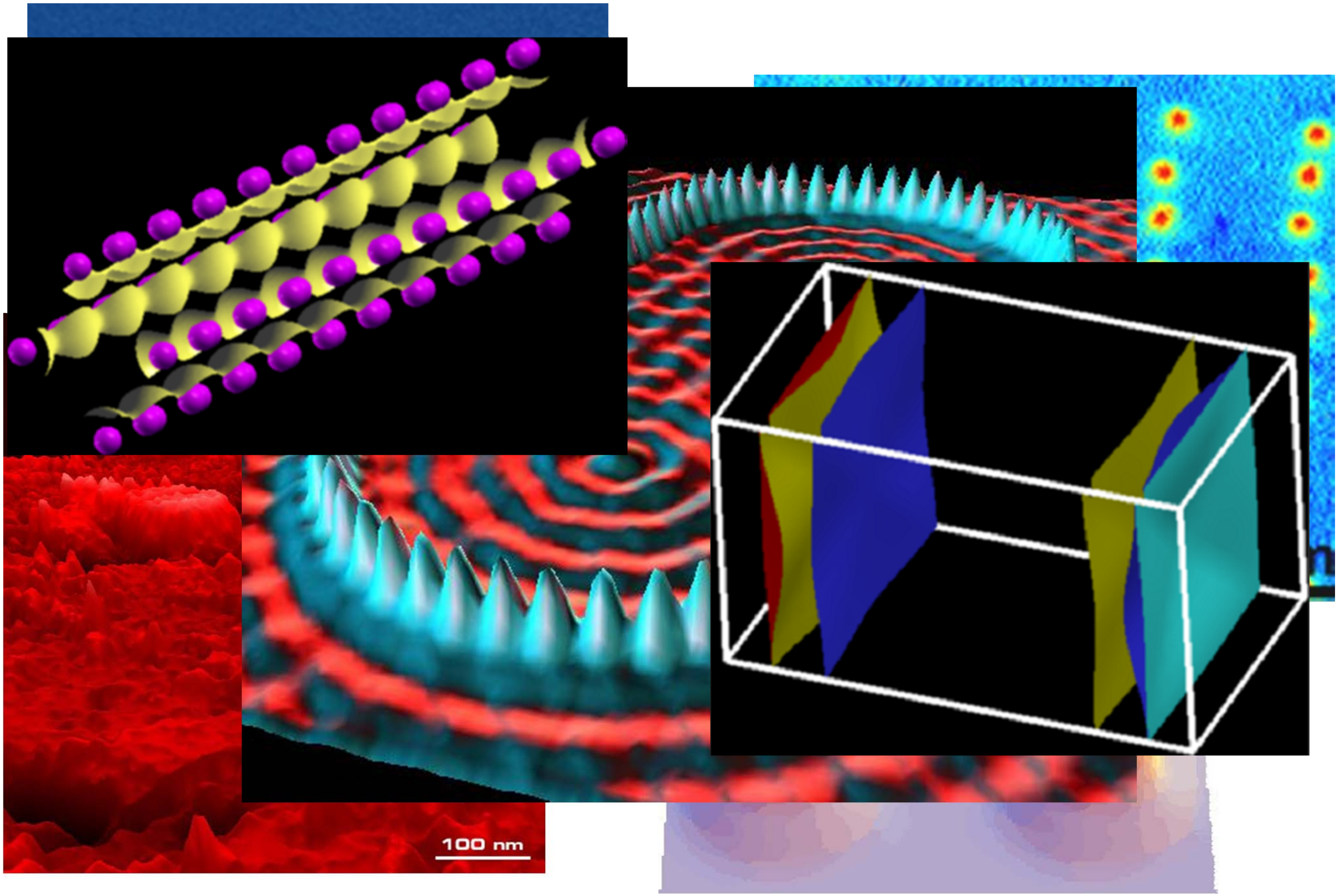


Squeeze Play

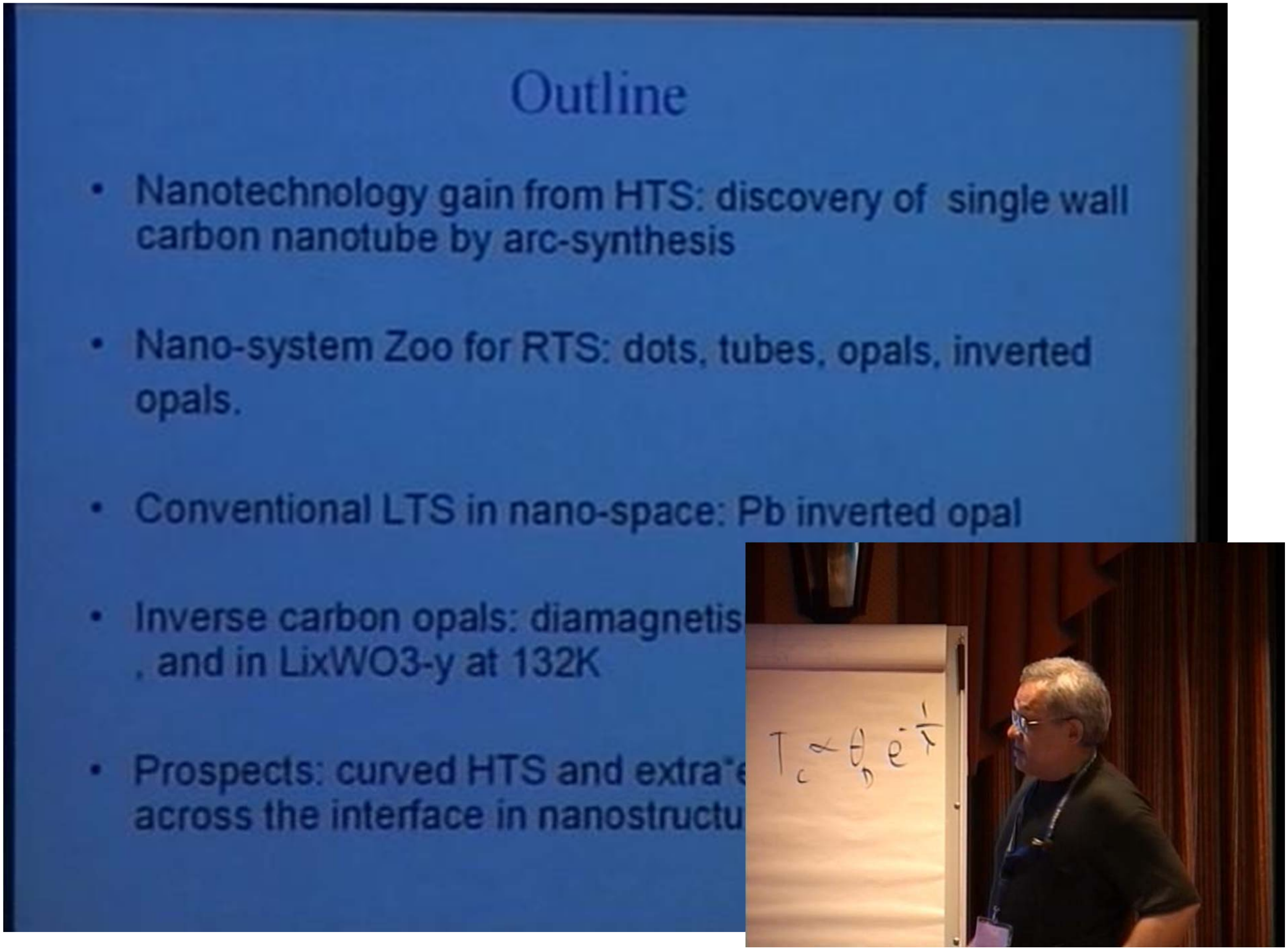


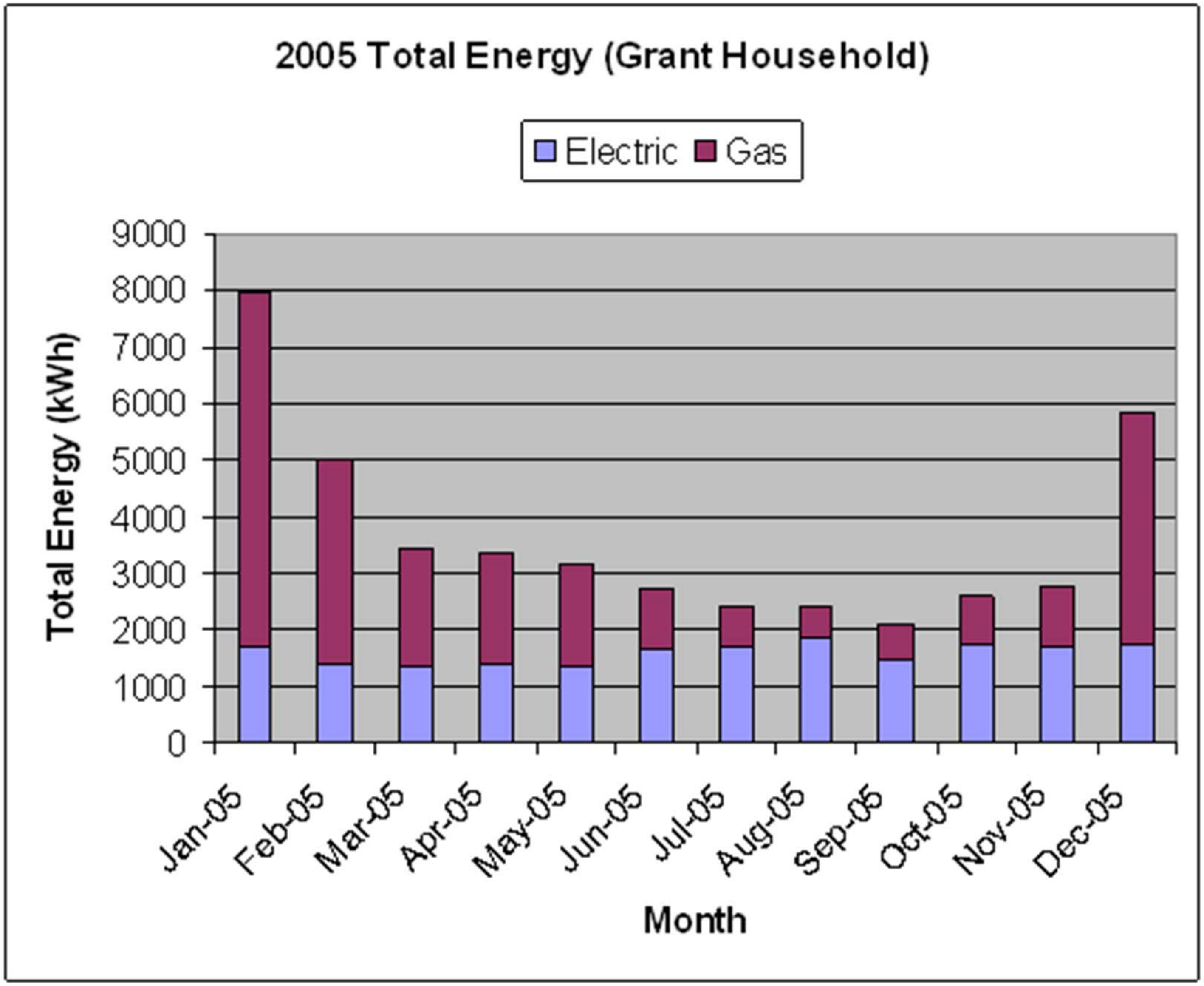
‘em ‘n’ Beat ‘em

NanoMachining



From “Texas” with Love




2005 Total Energy (Grant Household)
Electric
Gas
Total Energy (kWh)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Jan-05
Feb-05
Mar-05
Apr-05
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Oct-05
Nov-05
Dec-05
Month

GHE Statistics

Power (kW)	*Electricity*	*Natural Gas*	*Total*
Monthly Mean	2.16	2.84	4.99
Standard Deviation	0.24	2.39	2.39
Mean + STD	2.39	5.23	7.39
Mean - STD	1.92	0.45	2.60

GHE Load Centers

- Motors 40%
  - 12 @ ~ 0.75 hp (80%)
- Lights/Appliances 60%

- Assume Motor Efficiency at 90% for RTSC
- Energy Saving/yr for 50 M USA-HH =

  $3 B/yr

Big Motors

- > 1000 hp ~ 90% Efficient
- RTSC ~ 93% (maybe)
- Could be important for certain GCC adaptation strategies

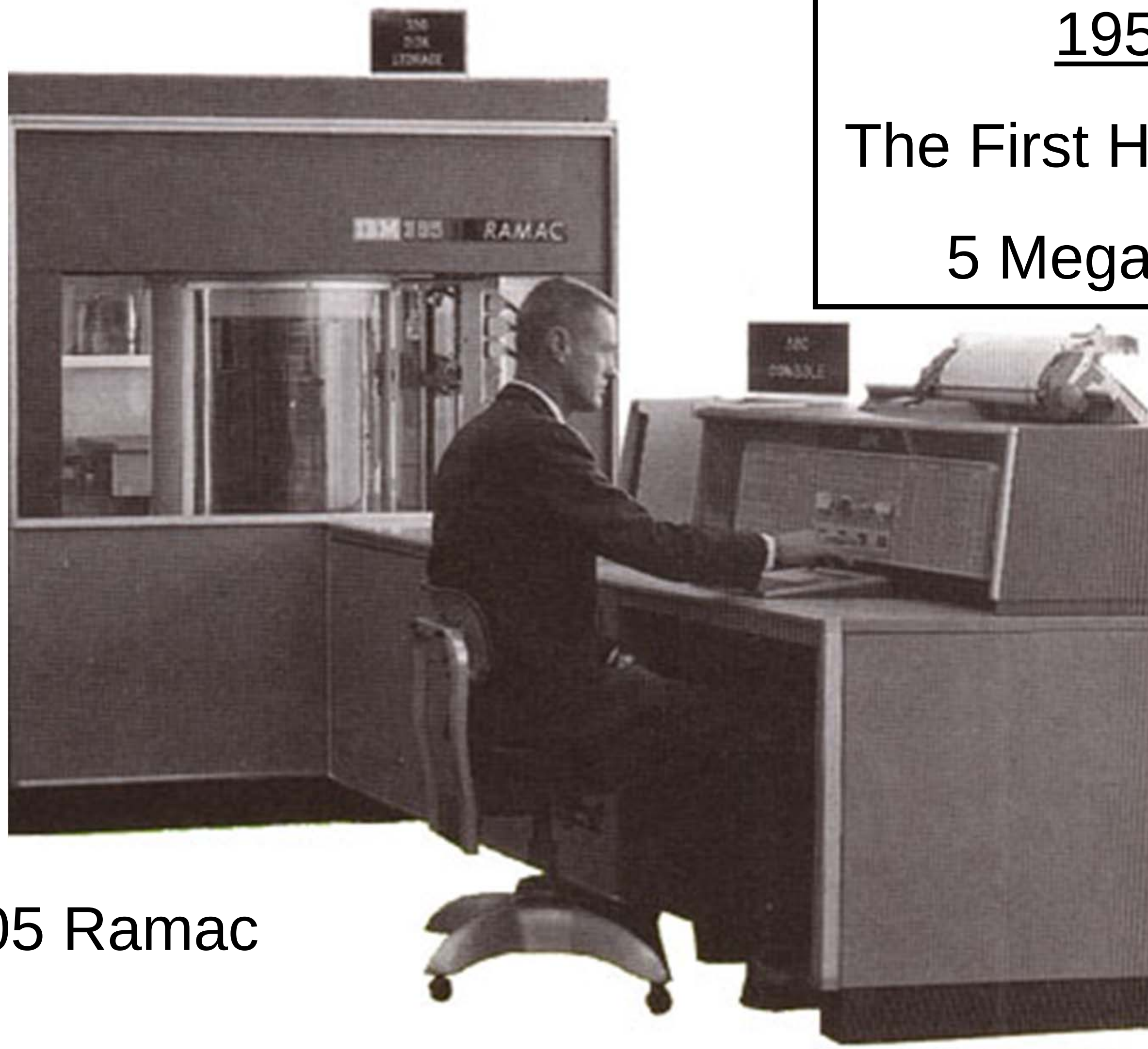
Enabling the Hydrogen Economy

- 400 GW for US H_2 Auto Fleet (Grant, Nature, July 2003)
- Electric Power Sent to “Gas Stations” for Electrolysis
- T&D Losses Presently ~ 10%
- RTSC Could Reduce to ~ 3%
- Thus Saving 28 GW (14 Diablo Canyons)

“You can’t always get what you want…”

"…you get what you need!"

…and old technology can go on and on and on…



1956

The First Hard Drive

5 Megabytes

IBM 305 Ramac

…Almost 50 Years Later

2004
The Apple iPod
40 GB

8000 times the
Ramac in your
hand