Note. This pdf was created from a ppt original which contains animation and video which may not display properly. For the original ppt, contact w2agz@pacbell.net or w2agz@w2agz.com.

Wither Superconductivity?

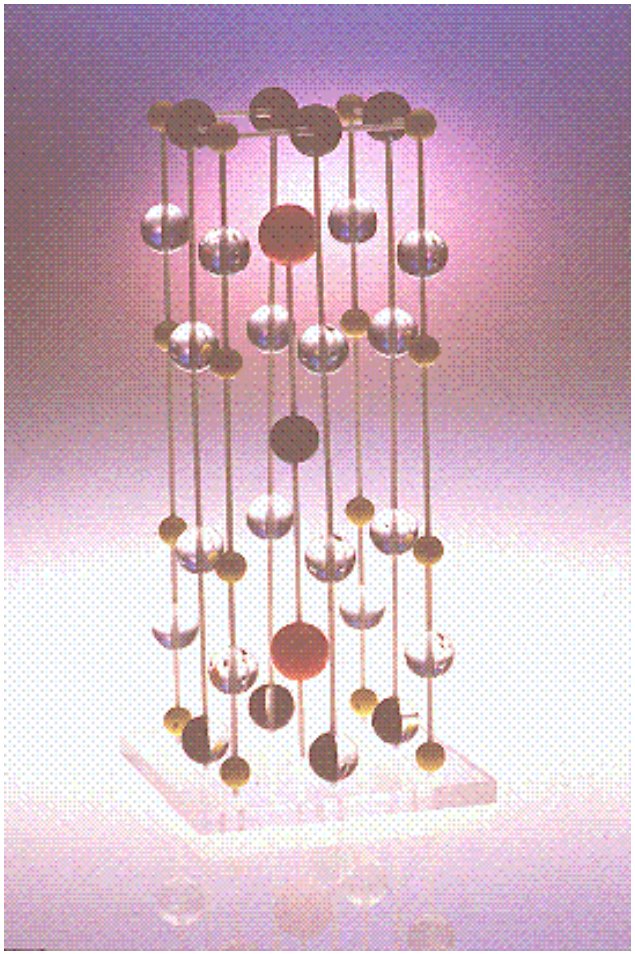
It is now 23 years since the discovery of high temperature superconductivity by Bednorz and Mueller, and nearly six decades removed from the development of the first practical low temperature superconductors, the Nb inter-metallic alloys fabricated by Kunzler, Matthias, Geballe and Berlingcourt. Practical wire embodiments exist for both families of materials, and many successful demonstrations of electric power prototypes ranging from cables, fault current limiters, transformers, magnetic energy storage to rotating machinery have been undertaken throughout the intervening years. But where are all the maglevs and cables and supercomputers carried on the covers of the supermarket news magazines and network newsreels of the 1980s? Will superconductivity become, like fusion, perpetually the energy technology of the future? Would a room temperature superconductor bring that future closer? Does superconductivity have a role in adaptation technologies to address climate change? In this talk, we will reveal our attempt at answering these cosmic questions.

1953

Project Sage – IBM/MIT

35 Years Later…

March 3, 1987: “123” Structure at ARC



Almaden Superconductivity Timeline

- Polysulfur Nitride
  - January, 1976
  - T_C = 0.3 K
- "ET" $(BEDT\text{-}TTF)_4(ReO_4)_2$
  - 1982
  - T_C ~ 2 K
- Undoped La_2CuO_{4+x}
  - January, 1987
  - T_C = 40 K
- Tl-2223 ($Tl_2Ba_2Ca_2Cu_3O_z$)
  - February, 1998
  - T_C = 125 K
- Tl-1223 ($TlBa_2Ca_2Cu_3O_z$)
  - March, 1998
  - T_C = 110 K

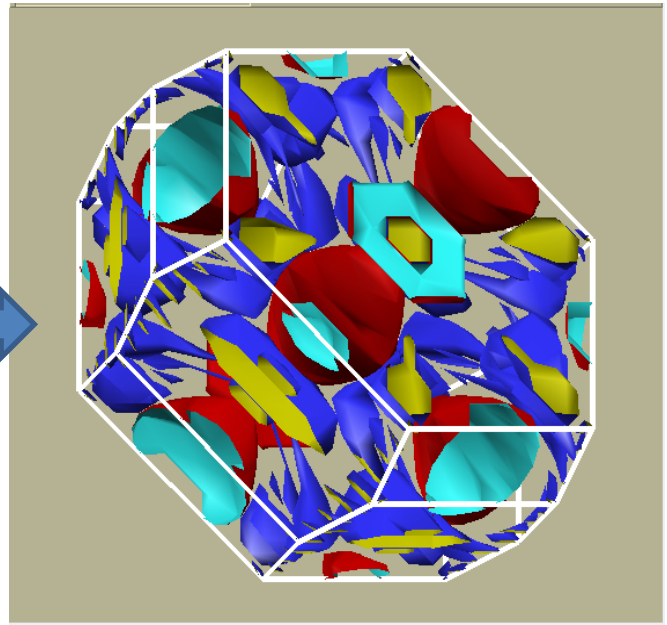
RD Scoreboard

Almaden	5
Zurich	2
Yorktown	0

Family Room Physics

Diego Grant's
Sony Playstation 3

DFT



Fermi Surface of
Antiferromagetic
Rocksalt Copper
Monoxide

Cold Fusion After 20 Years

Whither Superconductivity?

An Iconoclastic Assessment of Prospective Future Applications of Superconductivity

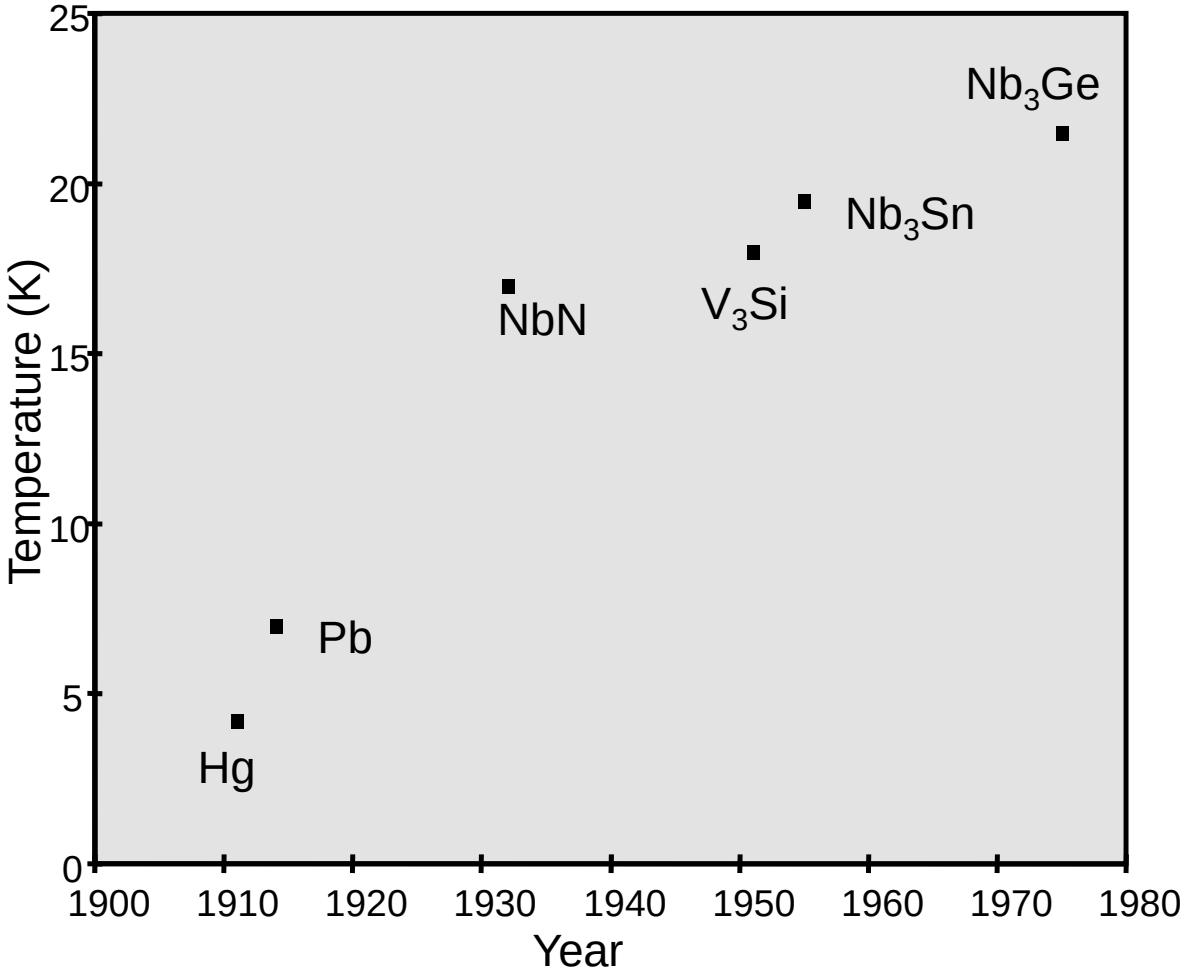
Paul M. Grant

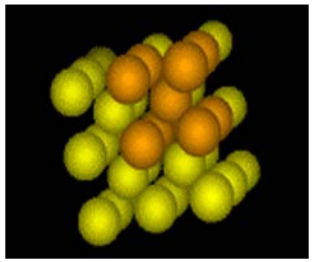
Principal, W2AGZ Technologies
Visiting Scholar, Stanford (2005-2008)
EPRI Science Fellow (*retired*)
IBM Research Staff Member Emeritus
w2agz@pacbell.net
www.w2agz.com

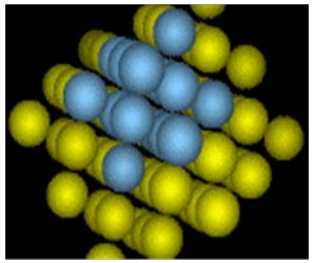
IBM Almaden Research Center
19 June 2009

Superconductivity 101

T_C vs. Year: 1911 - 1980



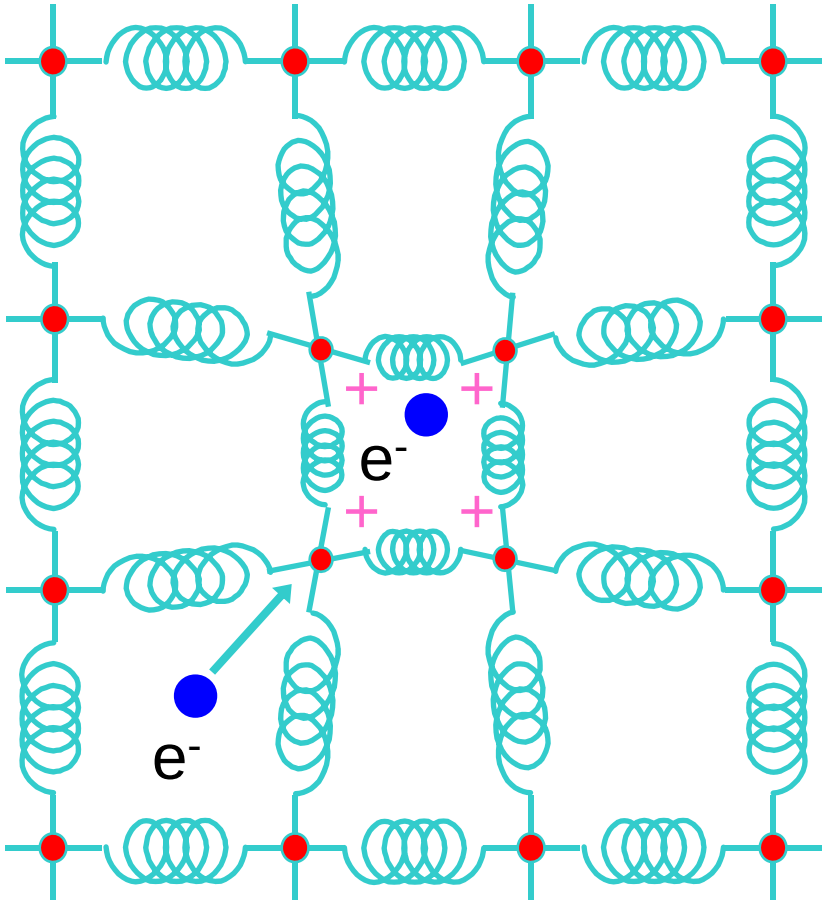




Cubic Metals

Physics of Superconductivity

Electrons Pair Off!



BCS Equation

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

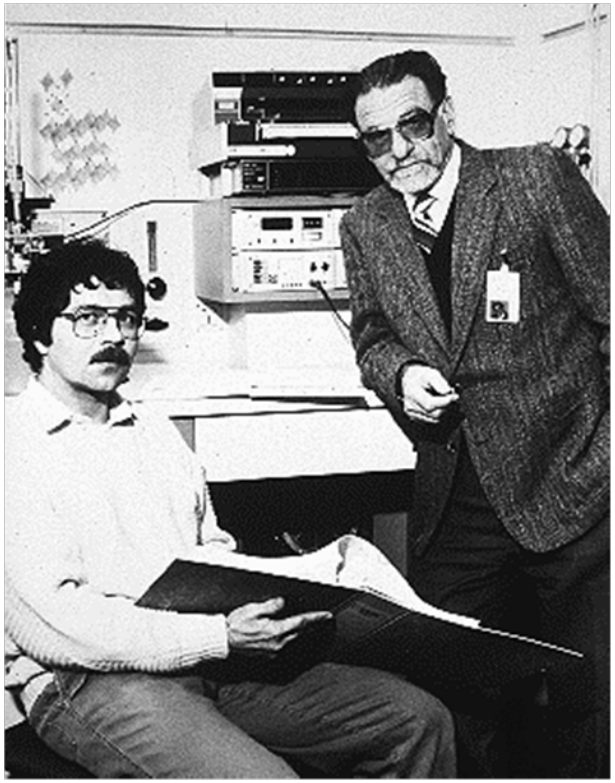
$\theta_D = 275\ \text{K}$,

$\lambda = 0.28$,

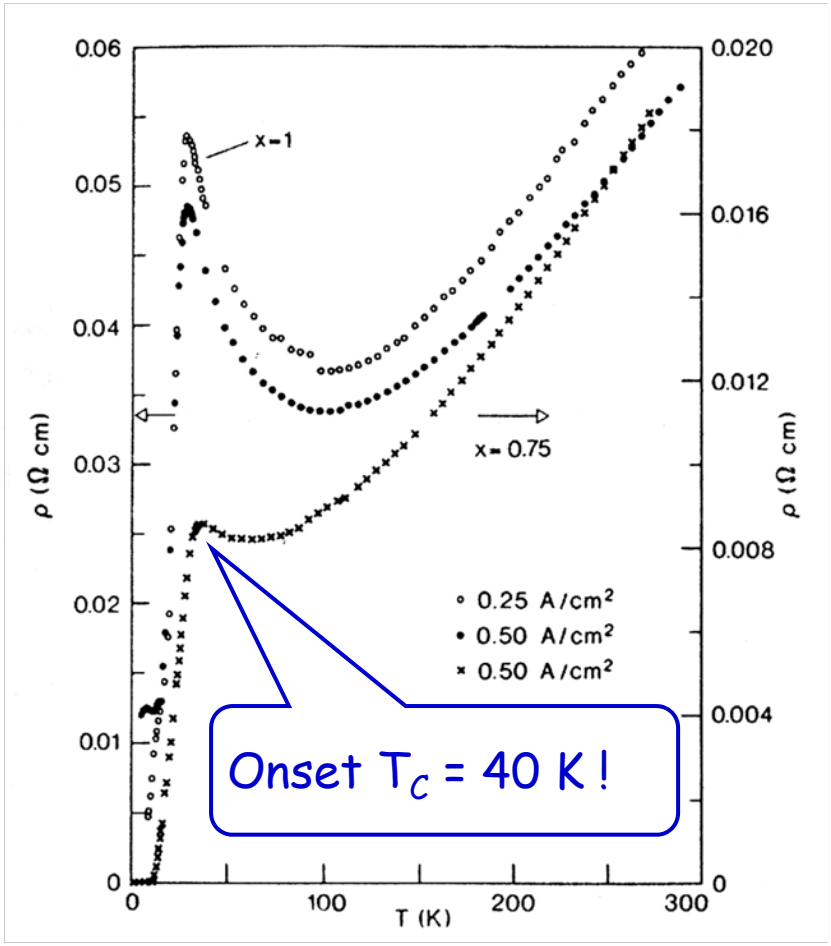
$\therefore\ T_C = \underline{9.5\ \text{K}}$ (Niobium)

$$\lambda \propto N(0) \propto \nu_F^{-1}$$

1986
A Big Surprise!

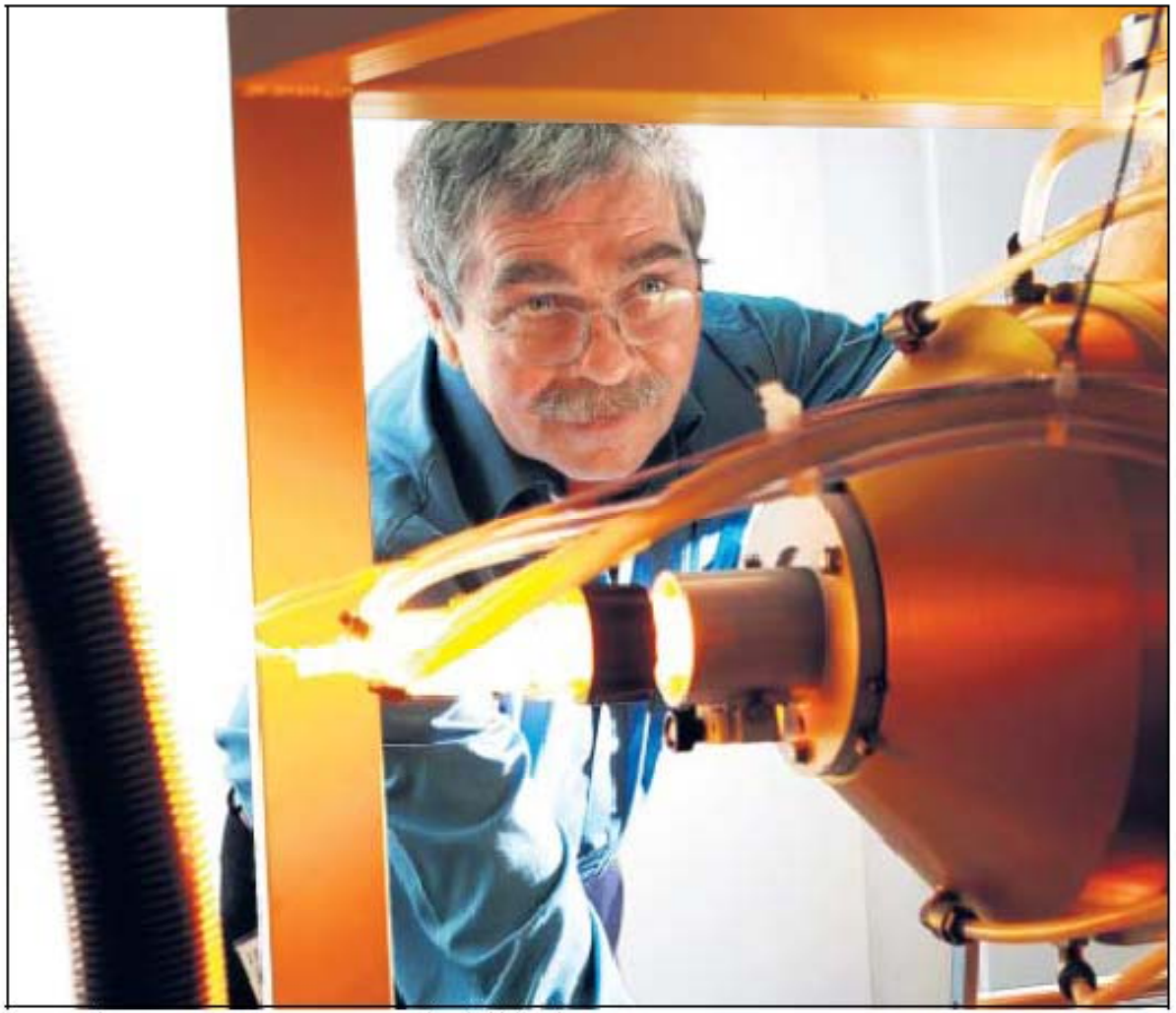


Bednorz and Mueller
IBM Zuerich, 1986



“Ich war wie in Trance”

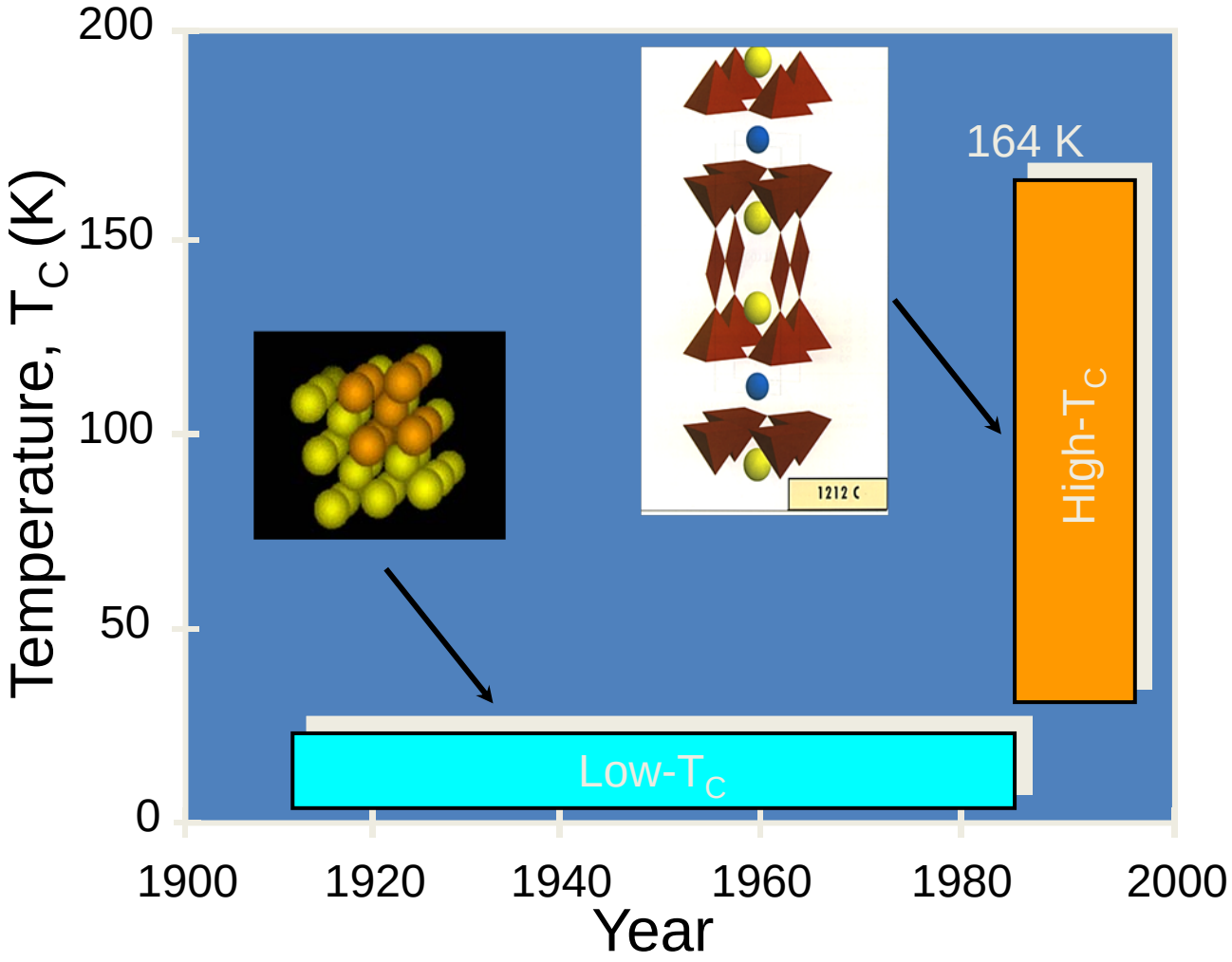
Vor genau **<u>20 Jahren</u>** entdeckten Forscher am IBM-Labor Rueschlikon die Hochtemperatur-Supraleitung



Georg Bednorz in seinem Labor in Rüschlikon. (Ursula Meisser)

NZZ am Sonntag – 22 Januar 2006

T_C vs. Year: 1911 - 1999

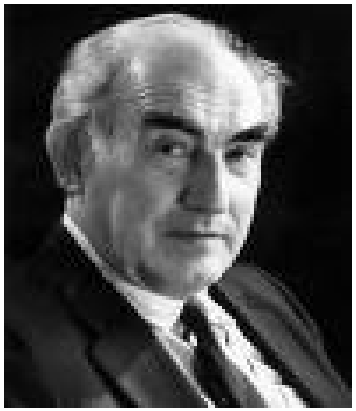


GLAG – "Engineering" Superconductors

$$G[\phi] \approx \int d^3r[\frac{1}{2m^*}(-i\hbar\nabla + e^*A)\phi^*(i\hbar\nabla + e^*A)\phi + a\phi\phi^* + \tfrac{1}{2}b\phi\phi^*\phi\phi^*]$$

$$-(i\partial\nabla - \mathscr{A})^2 f + f(1 - f^2) = 0$$

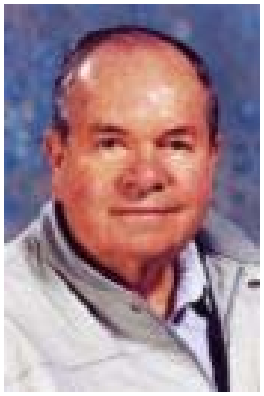
$$\kappa^2\nabla\times(\nabla\times\mathscr{A}) + \tfrac{1}{2}i(f^*\nabla f - f\nabla f^*) + \mathscr{A}f^2 = 0$$



$$\phi = (|a|/b)^{1/2} f$$

$$A = (\Phi_0 / 2\pi\xi)\mathscr{A}$$

$$\kappa = \lambda_L / \xi$$



$$\kappa < 1/\sqrt{2} \qquad \text{I}$$

$$\kappa > 1/\sqrt{2} \qquad \text{II}$$

Important Numbers in Superconductivity

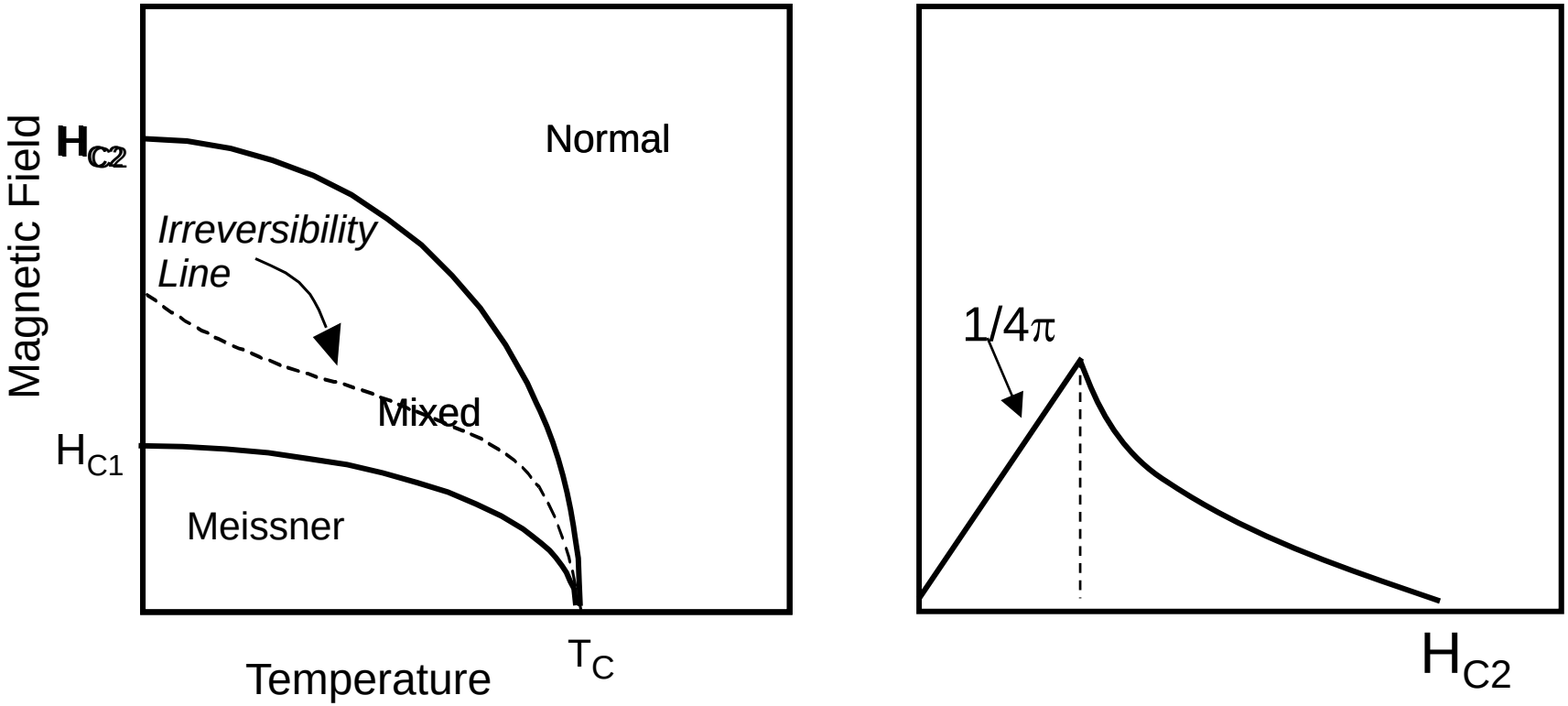
Transition Temperature, T_C	Way below 300 K
Critical Current Density, J_C	10^{-2} - 10^{6} A/cm^2
Critical Magnetic Field, H_C	10^{-4} - 10 T
London Penetration Depth, λ_L	10 - >1000 Å
Pippard Coherence Length, ξ	10 - >1000 Å
G-L Parameter, $\kappa = \lambda / \xi$	0.01 - 100

$$\lambda \propto N(0) \propto \nu_F^{-1}$$

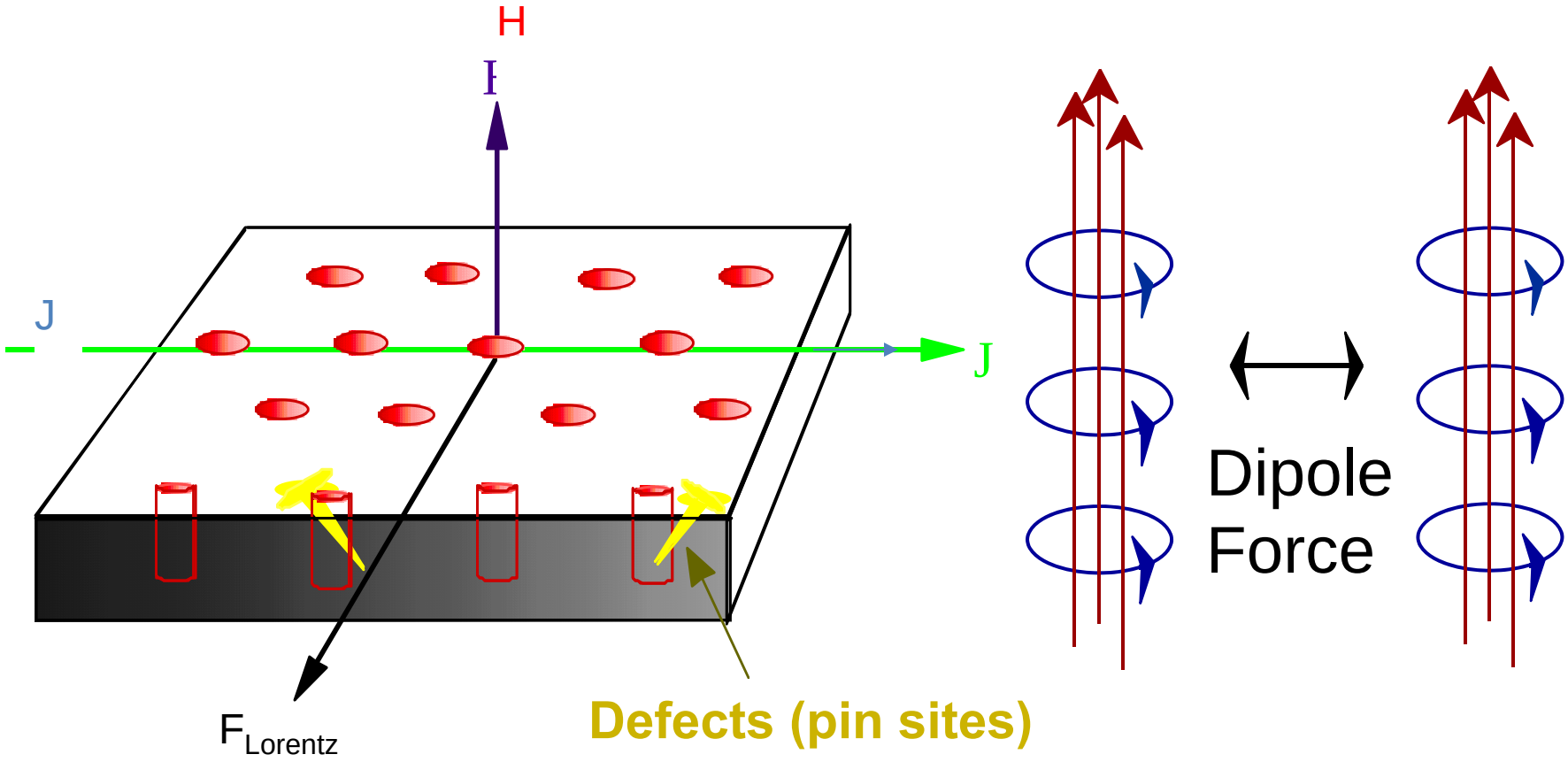
$$\xi = h\nu \propto 1/\lambda T_C$$

There will be a test!

Type II Superconductivity



Abrikosov Vortex Lattice

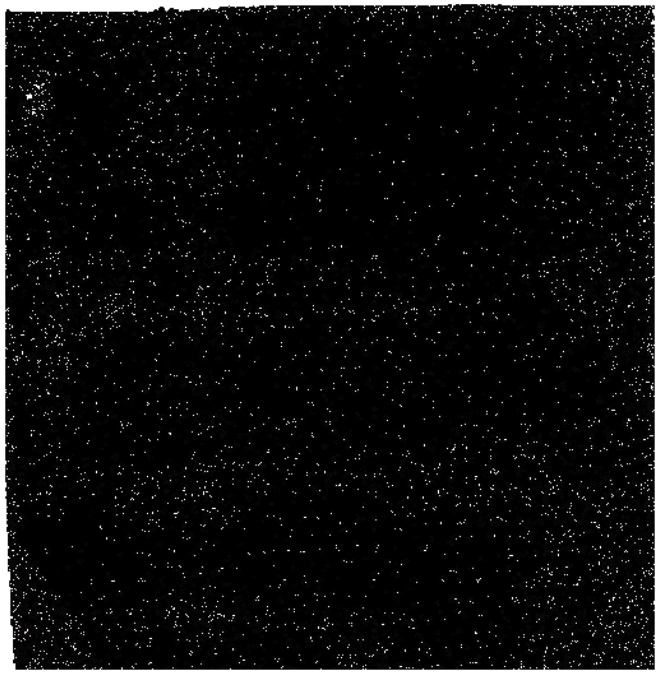


Type II Superconductor in the Mixed State

Extrinsic Pinning

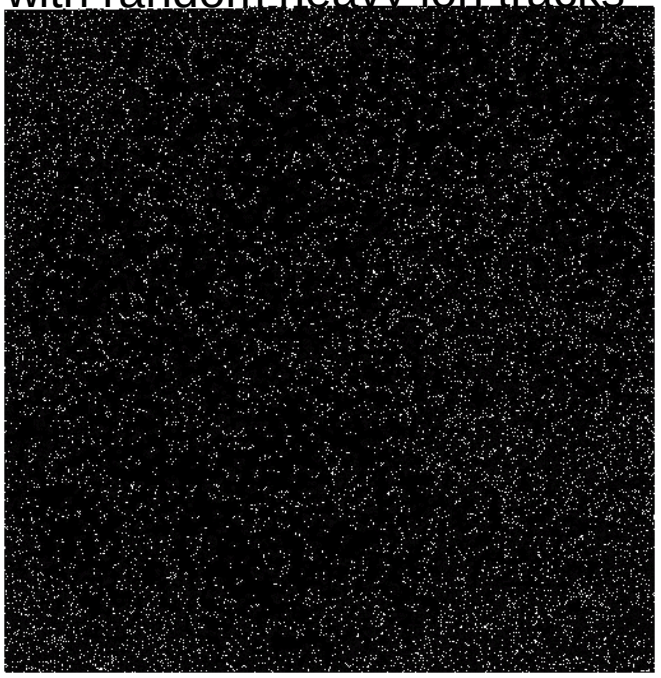
DECORATED VORTEX ARRAYS

clean



10 μm

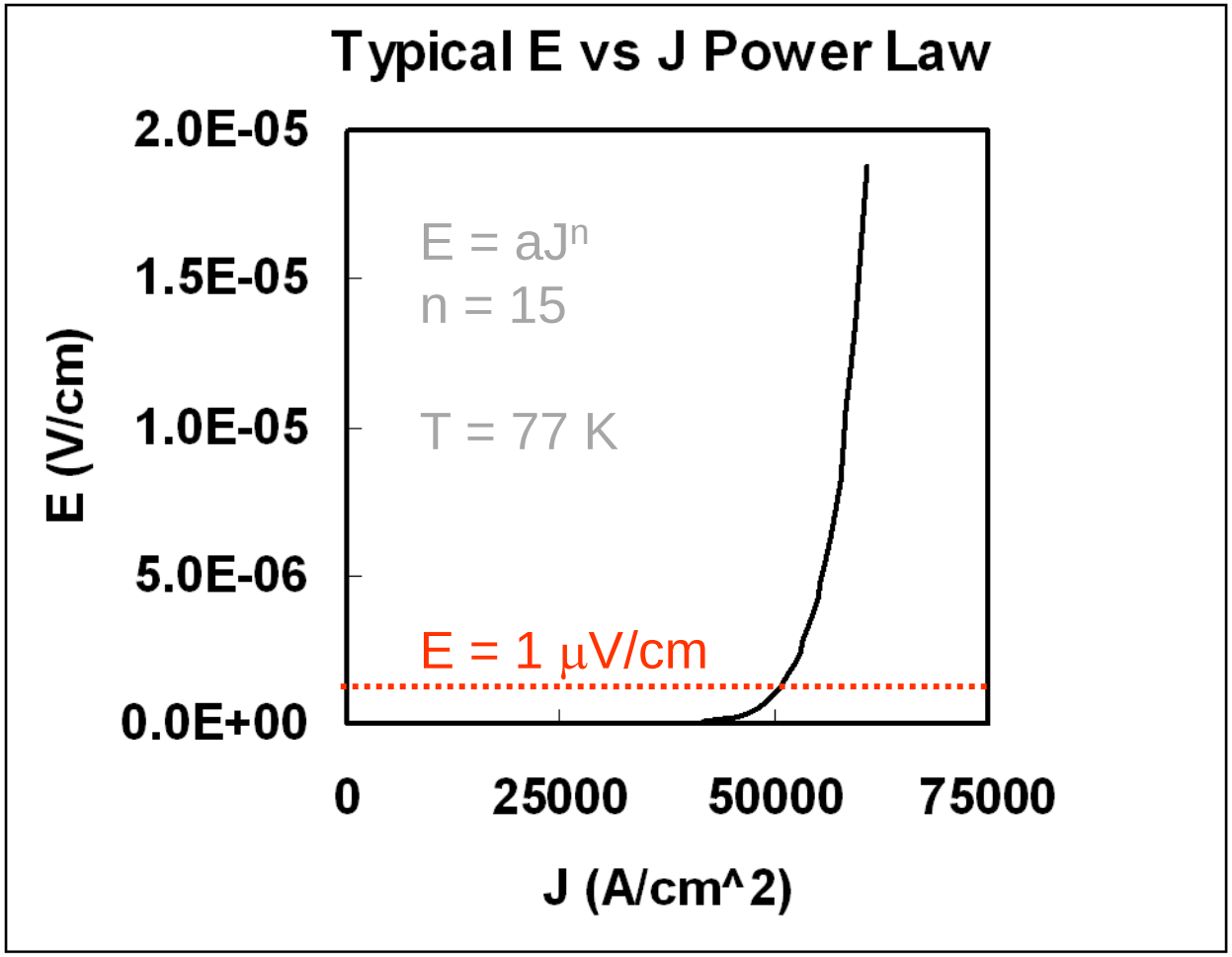
with random heavy ion tracks



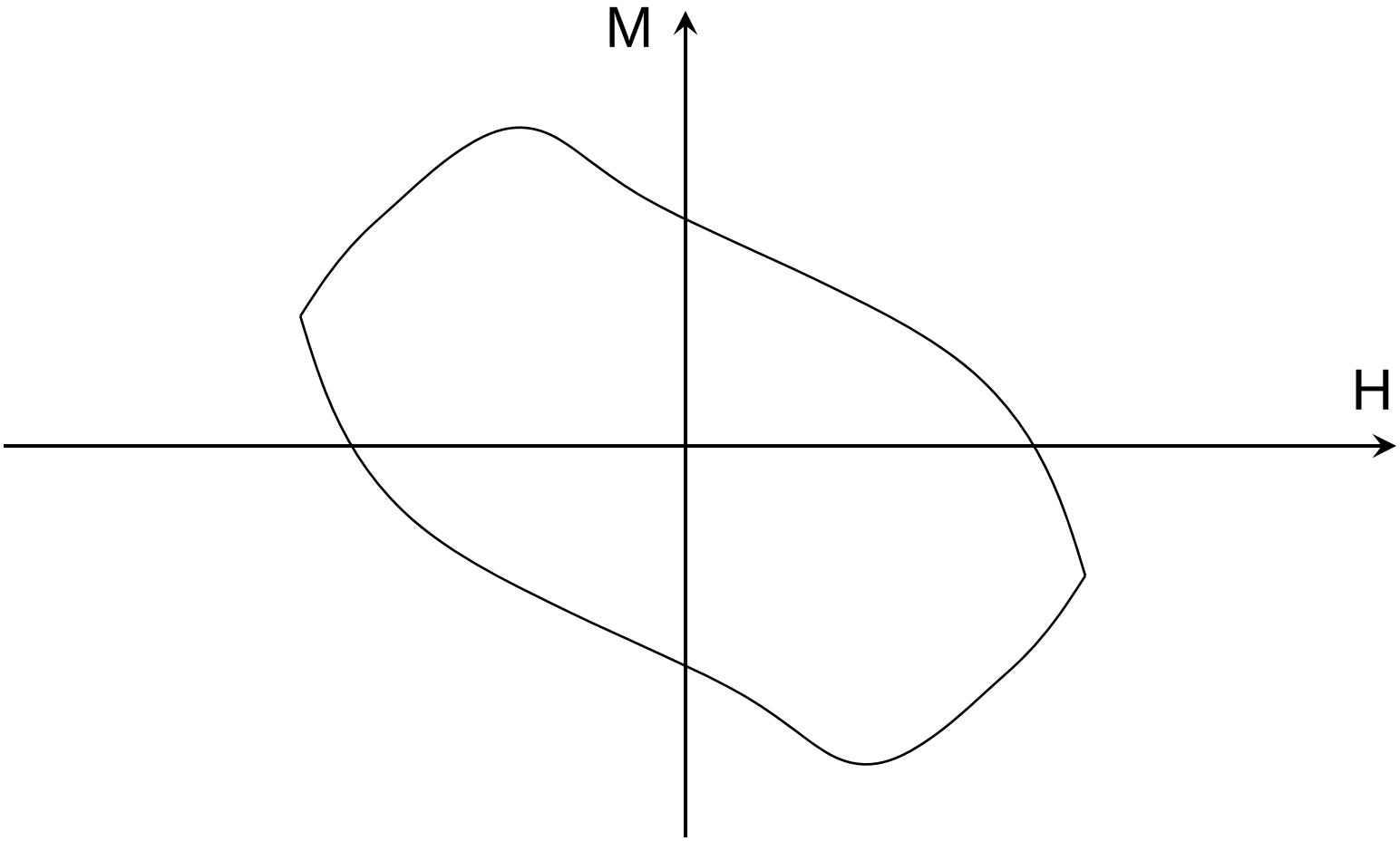
10 μm

M. Leghissa, et al. Phys. Rev. B 48, 1341 (1993)

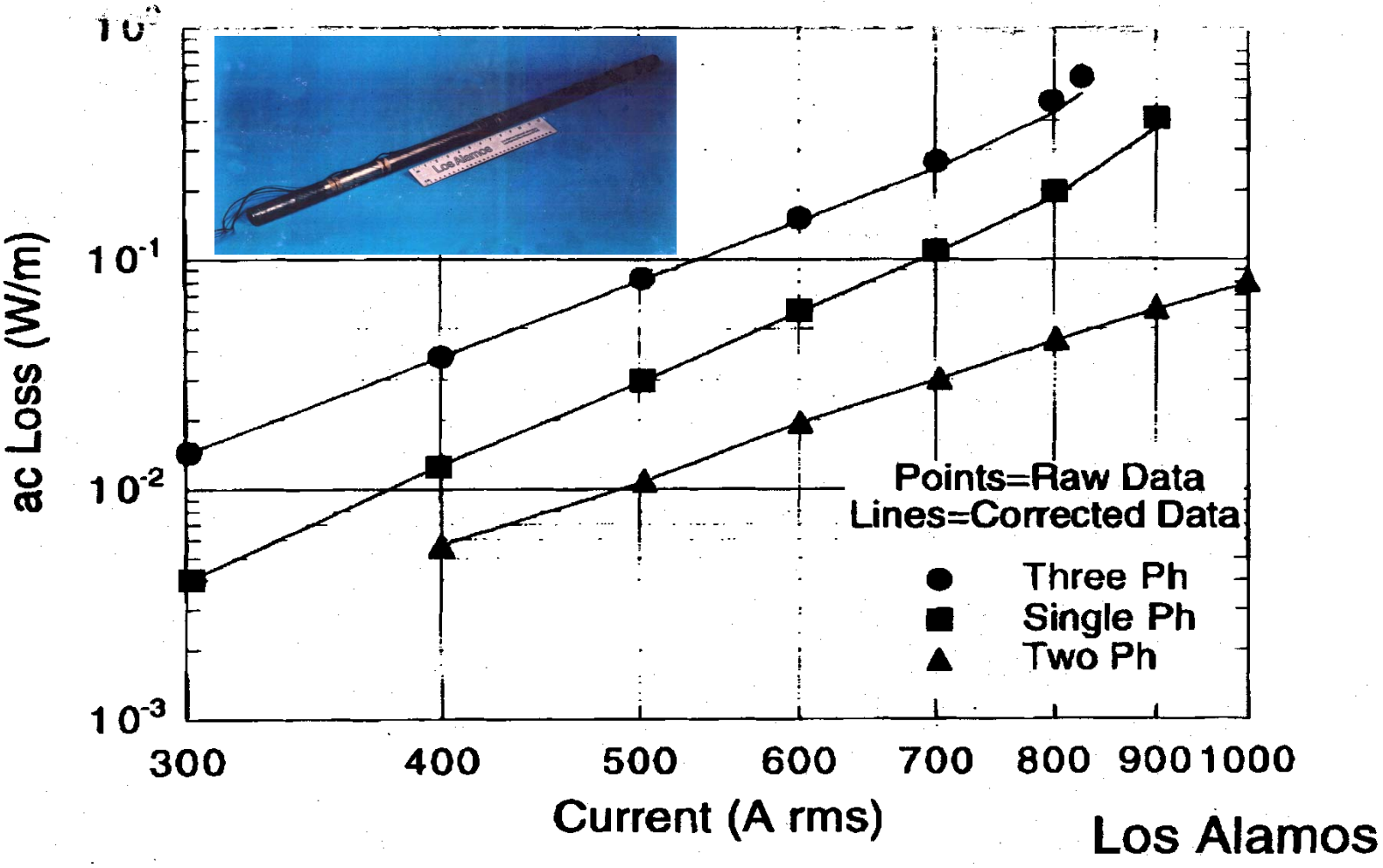
BSCCO OPIT/Ag
E-J Characteristic



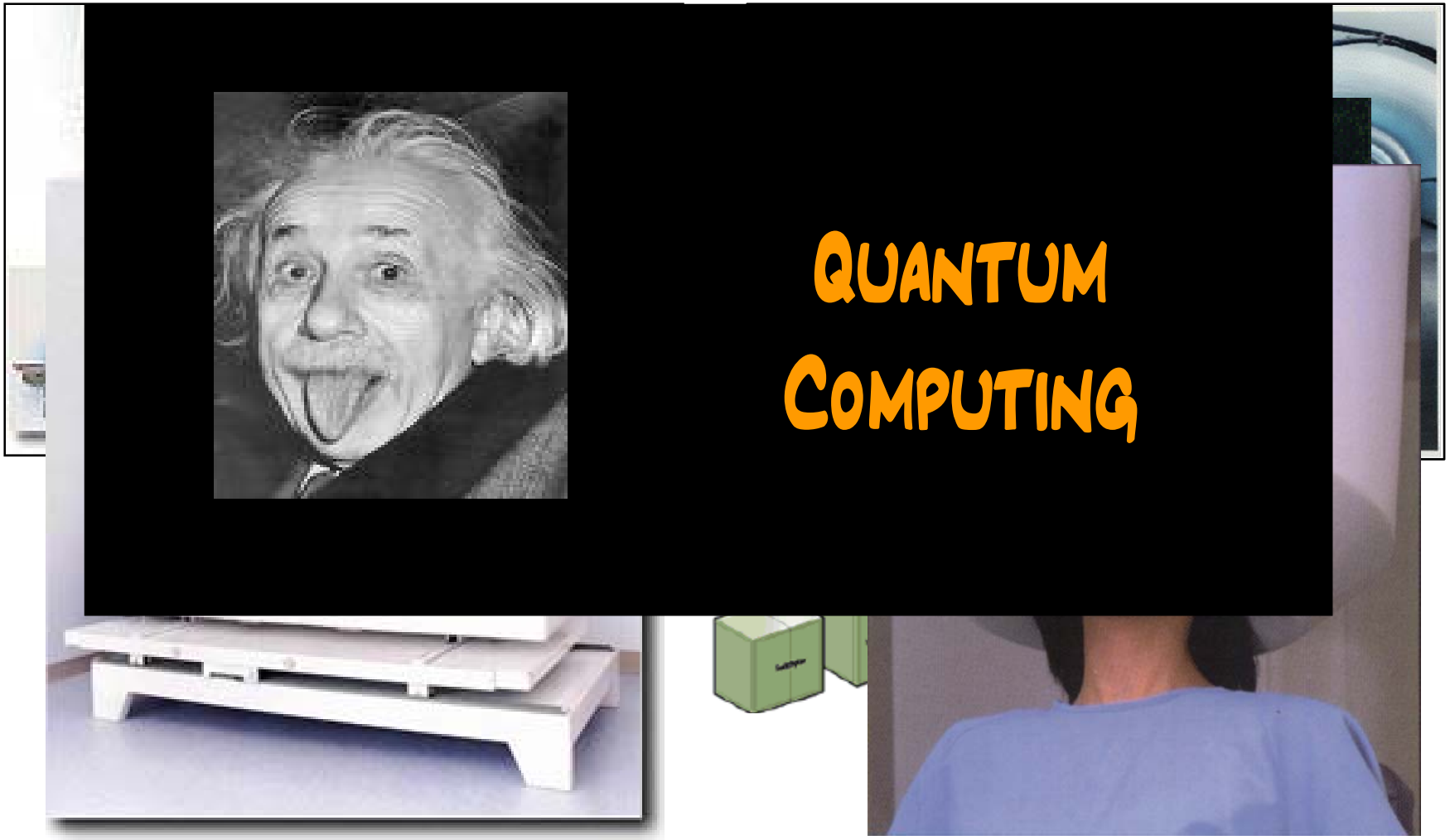
Type II Hysteresis



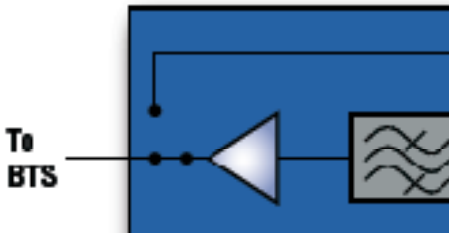
Hysteretic ac Loss

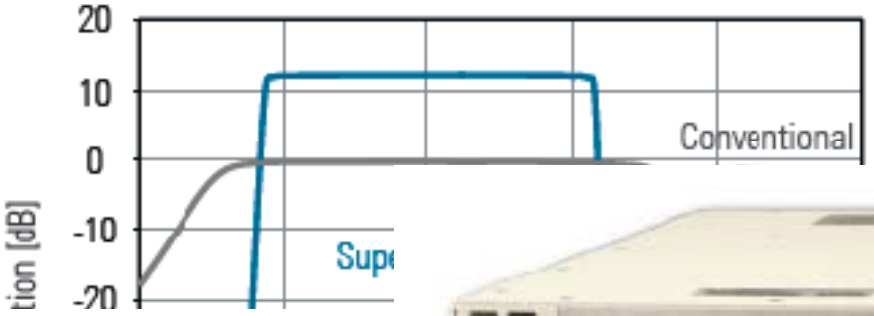


Low-Tc Today



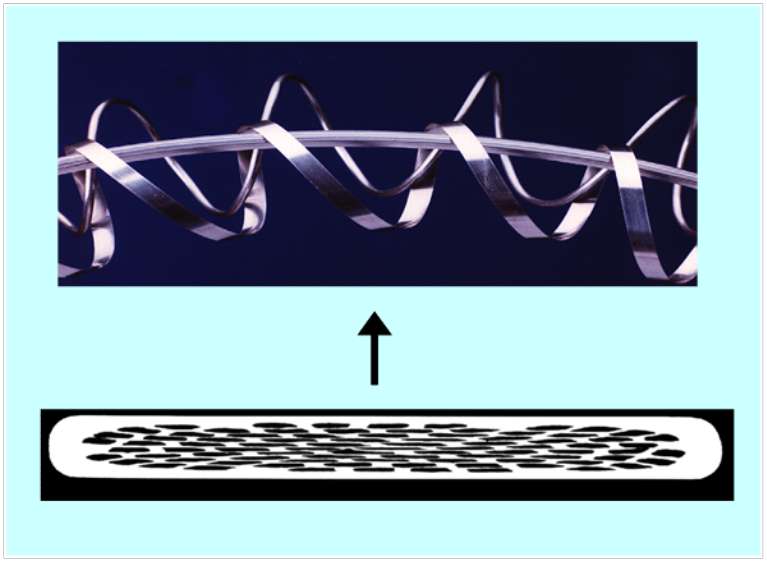
Electronics



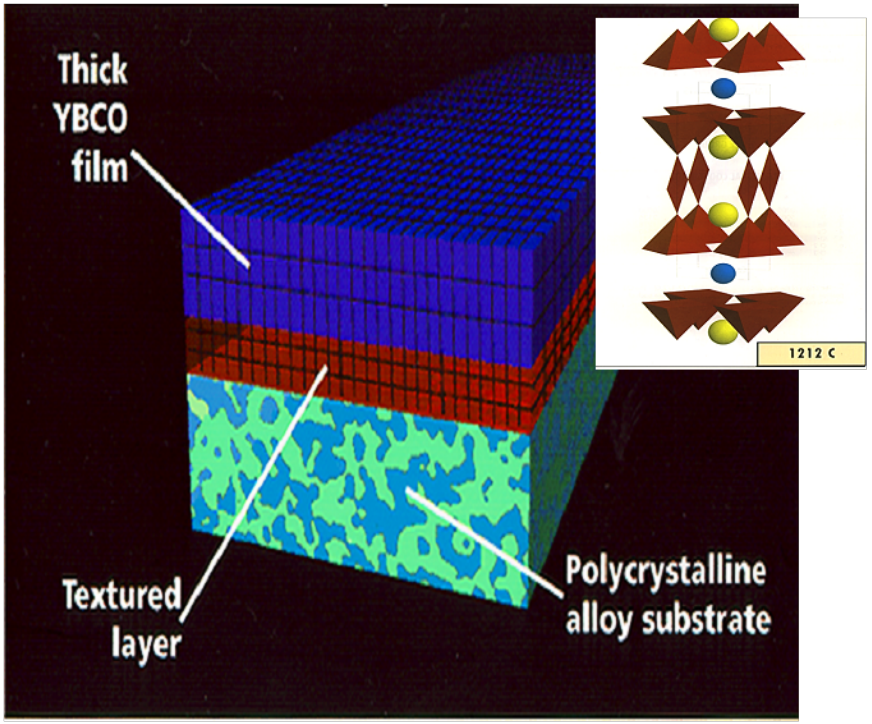


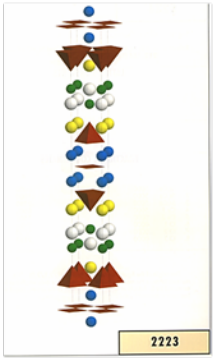
“A room temperature device !”

Wire



Gen 2

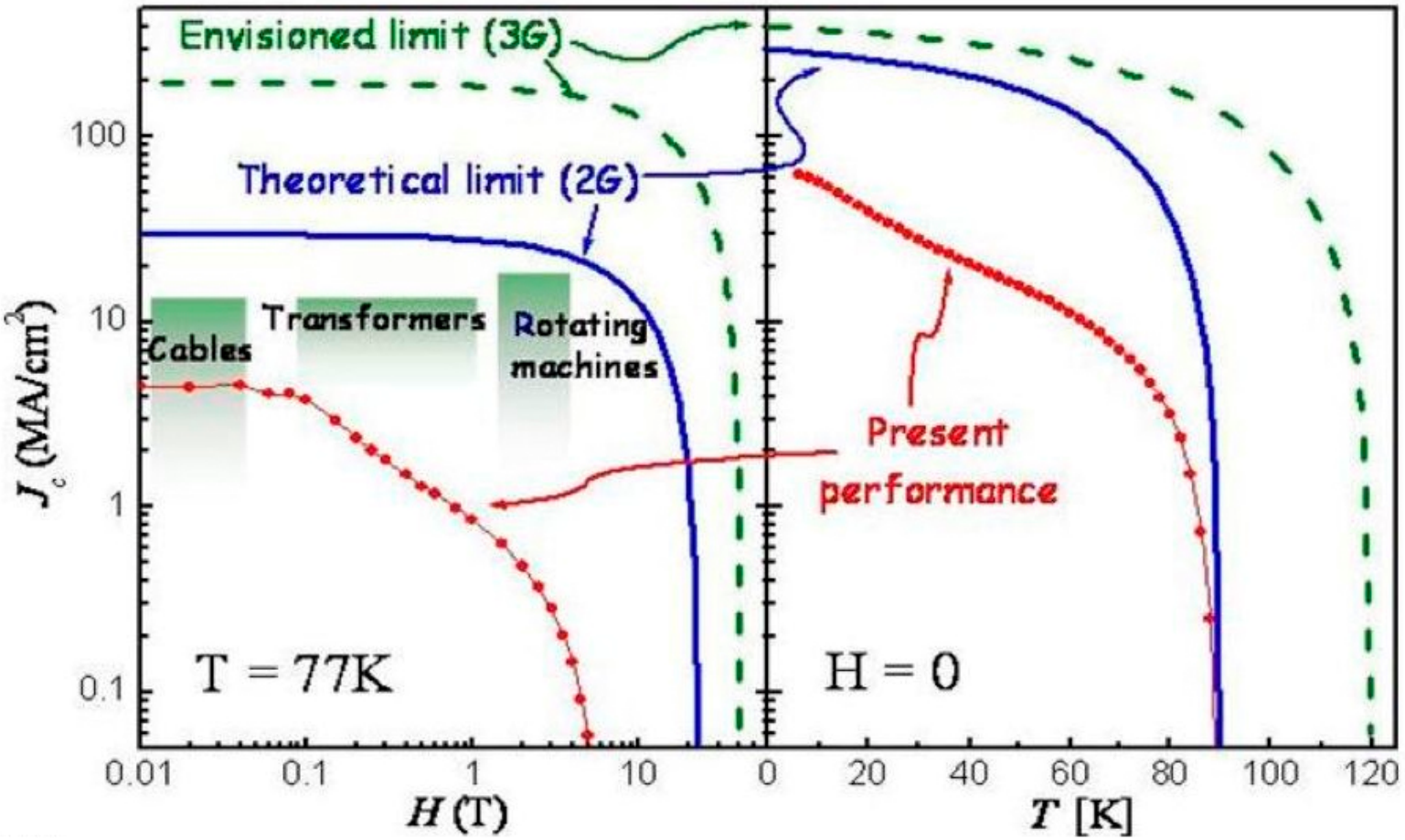




Gen 1

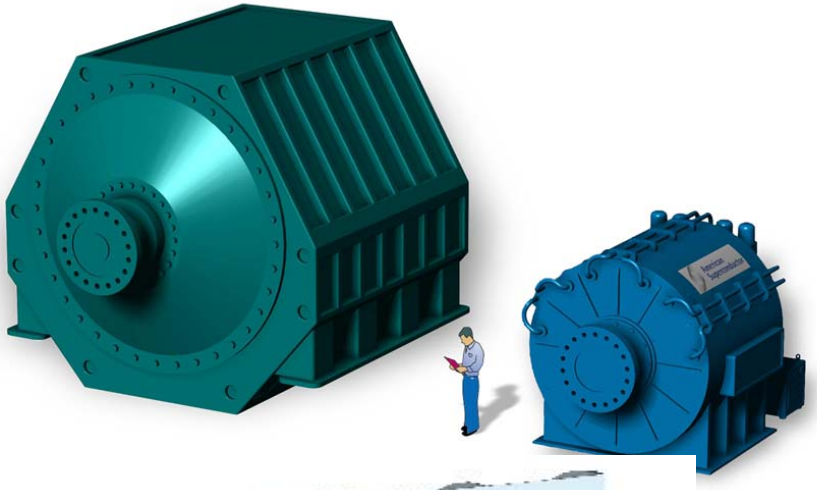
Major Players: US, Japan, China

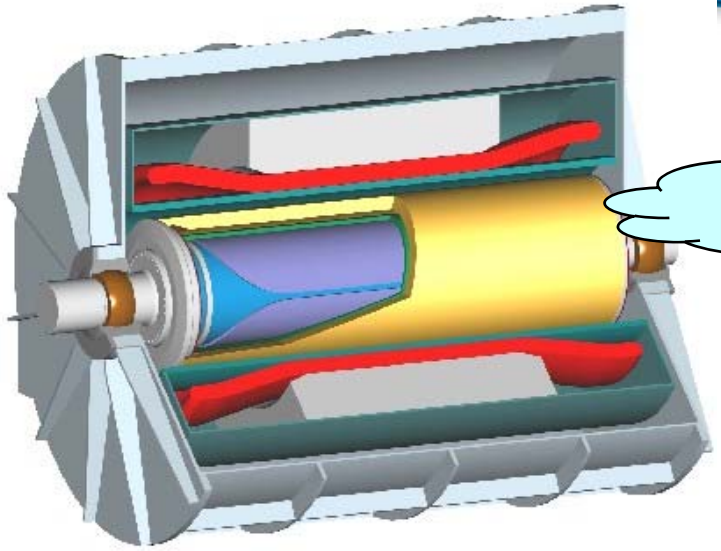
Wire Performance



Rotating Machinery

Courtesy AMSC





"Degaussing"

Major Players:

- AMSC
- SEI

Cables

Secure Super Grids

Two IBM Physicists (1967)

Superconducting Lines for the Transmission of Large Amounts of Electrical Power over Great Distances

R. L. GARWIN AND J. MATISOO

- Nb_3Sn (T_C = 18 K) @ 4.2 K
- 100 GW (+/- 100 kV, 500 kA)
- 1000 km
- Cost: $800 M ($8/kW) (1967)

$4.7 B Today!

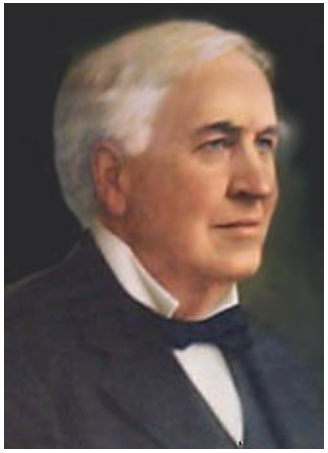
Electric Power 101

- Electricity -
The Crown Jewel of the US Economy

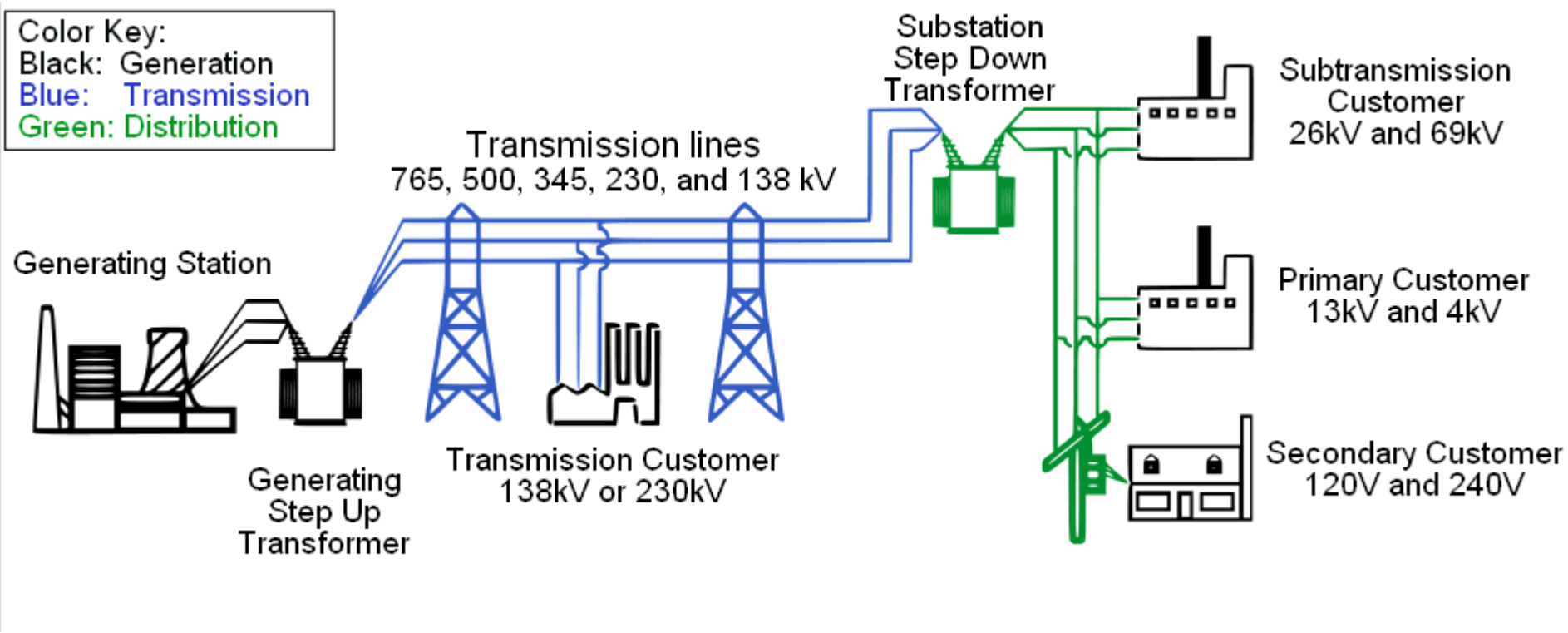
- **~$2 trillion total asset value**
- **$344 billion annual revenues**
- **142 million customers**
- **3273 utilities**

Without electric power the $14.3 trillion U.S. economy would come to a halt

Fathers of Electric Power

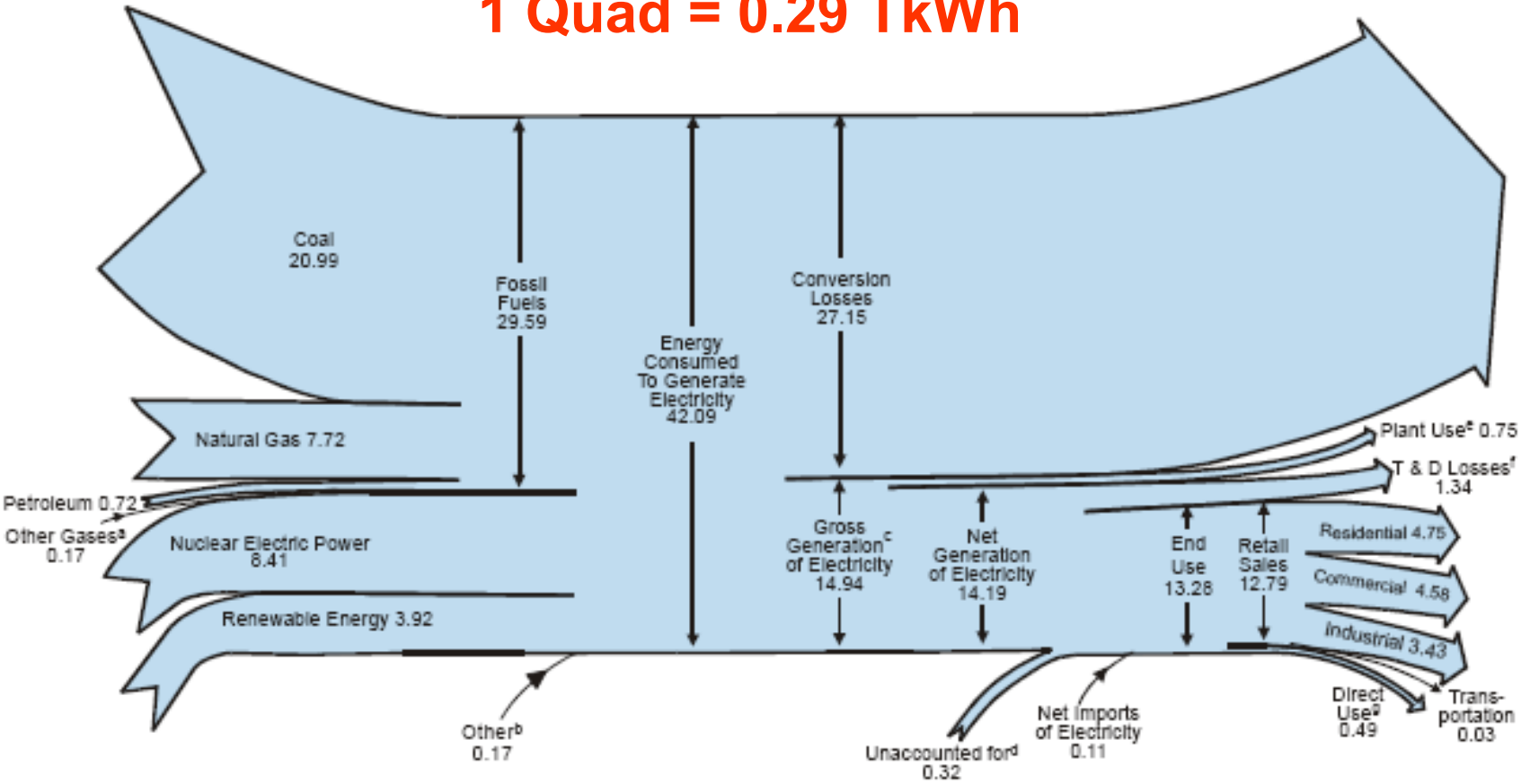


The US Electrical System



US Electricity Flow - 2007

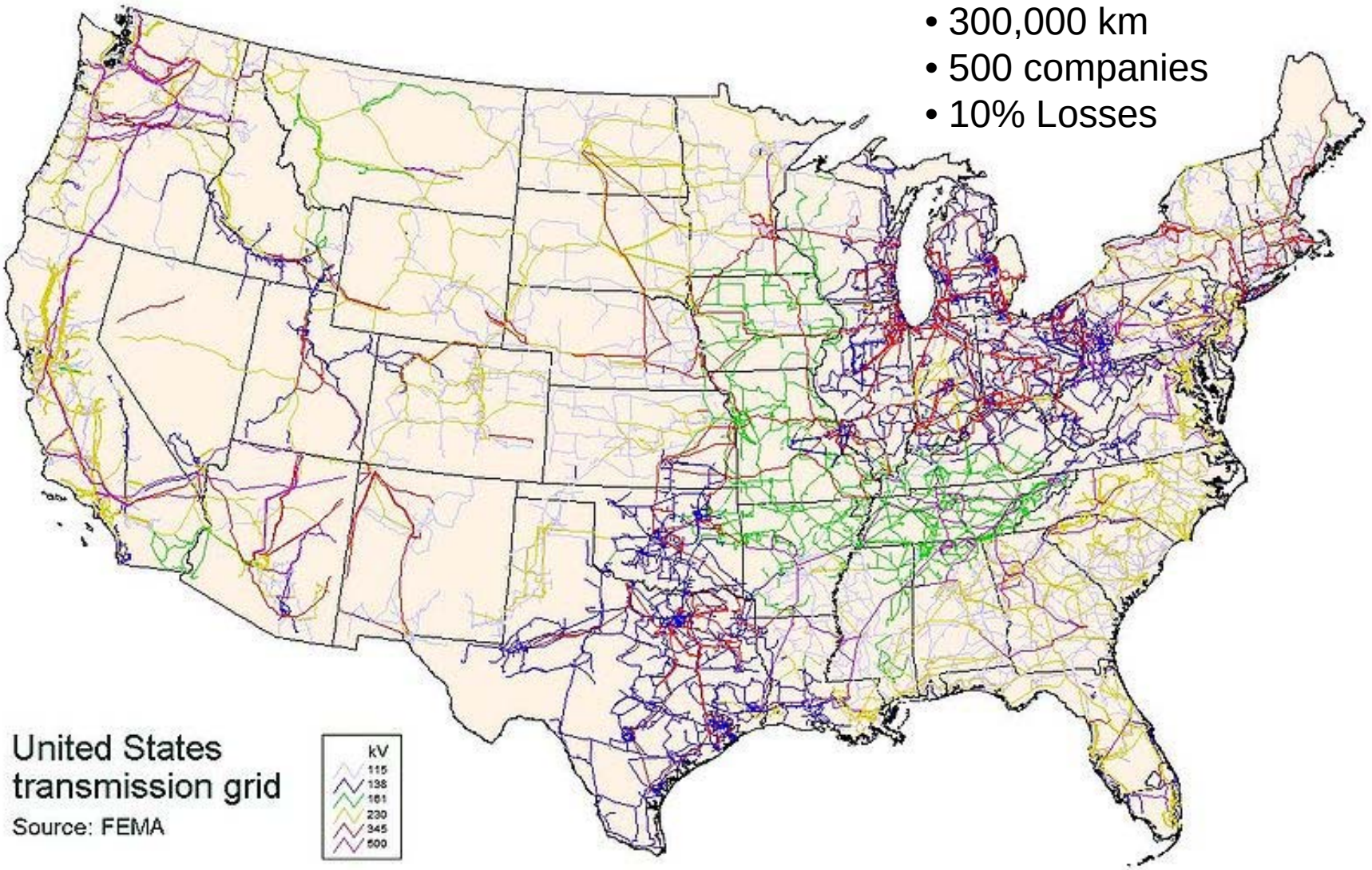
1 Quad = 0.29 TkWh



US Generation Capacity = 1.1 TW
Gross Generation = 4.33 GWh
(T&D Losses)/(End Use) = 10%

The US Transmission Grid(s)

- 300,000 km
- 500 companies
- 10% Losses



Pacific Intertie

- HVDC, +/- 500 kV, 3.1 kA, 3.1 GW
- 1,362 km
- ~50% of LA Power Consumption
- T&D Losses ~ 10%

Celilo I/C Station
“A Mountain of Silicon”

Blackouts


Texas ‘03
New York ‘99
Chicago ‘99
Detroit ‘00
Northeast ‘03
Northern California ‘01
West Coast ’96
San Francisco ‘00
Atlanta ‘99
Delaware ‘99
New Orleans ‘99


The Big Blackout
Northeast 8/14
States affected
Major metropolitan areas affected
CANADA
VERMONT
Brief power failures in northern counties
Ottawa
Lake Michigan
Lake Huron
MAINE
MICHIGAN
Toronto
Lake Ontario
NEW YORK
N.H.
Rochester
Syracuse
Lansing
Buffalo
Albany
MASS.
Detroit
Lake Erie
Binghamton
Kalamazoo
CONN.
R.I.
Erie
Toledo
Cleveland
Canton
Akron
PENNSYLVANIA
New York City
IND.
OHIO
NEW JERSEY
Bergen, Essex and Hudson counties
MD.
DEL.
W. VA.
KY.
VA.
Atlantic Ocean
TENN.
N.C.
0 Miles 100

The Party Begins…

…and Continues…

As Night Falls…

It Gets Better…

and Better…

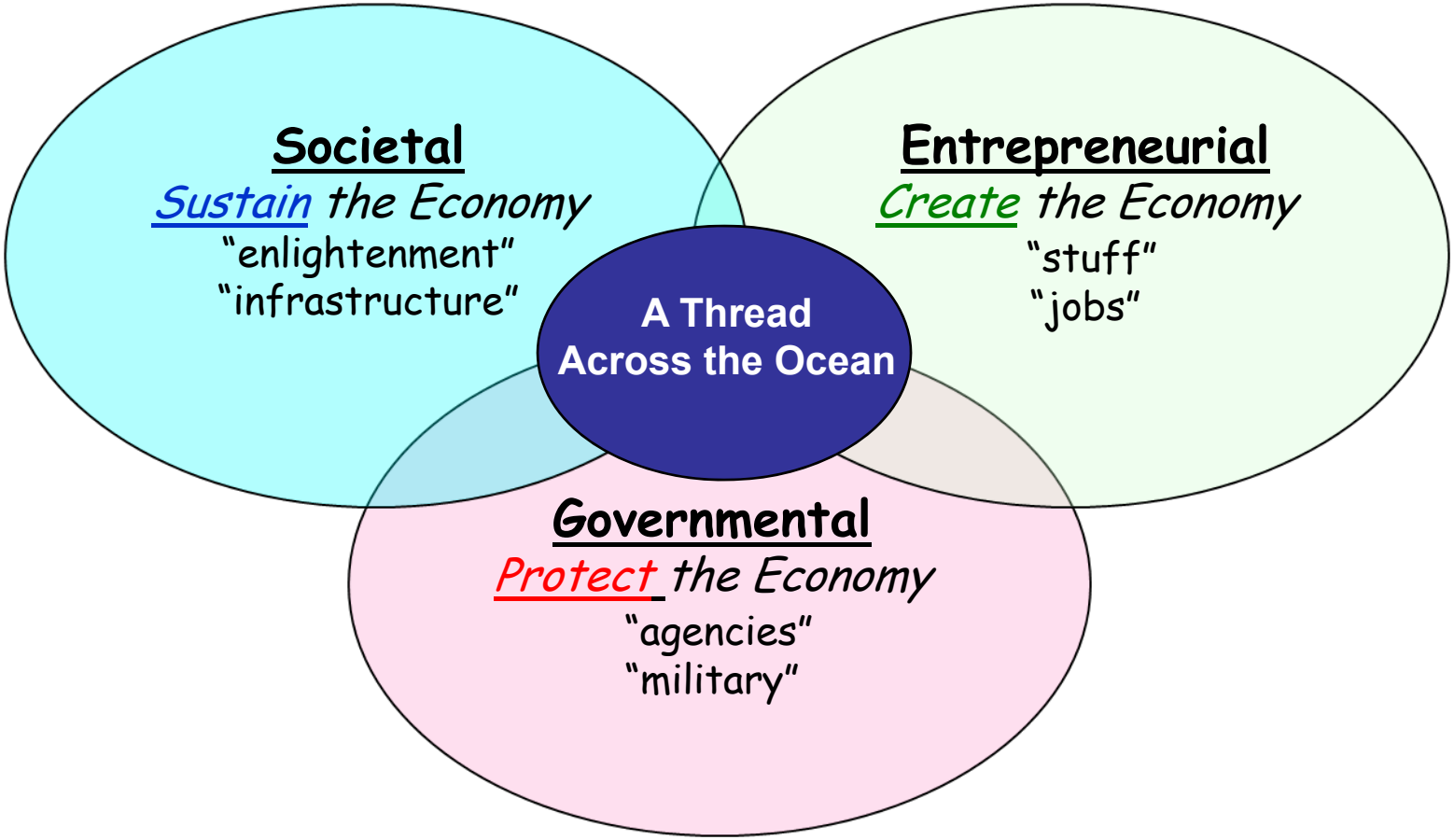
The Morning After

Viva New York!

Can “New” Transmission Technology Help?

- Yes, but probably not superconductivity in a big way, at least for a while.
- More likely, “smart” grid stuff will come first
  - HVDC cables and lines
  - FACTS to increase present corridor capacity by 30%
  - IT and communications plus an “OS/360” to more effectively and efficiently management power flows

The Economic Troika That Drives and Exploits Technology Innovation



“A Thread Across the Ocean”

Cyrus Field
American Capitalist

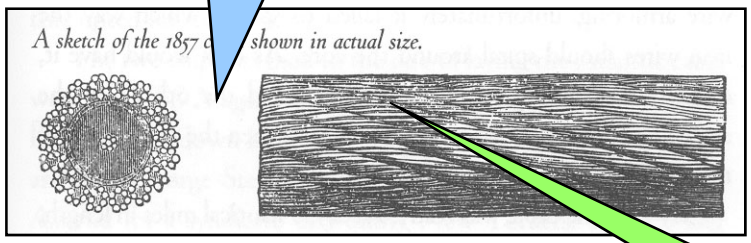
Isambard Kingdom Brunel
English Engineer

William Thomson
Irish Physicist

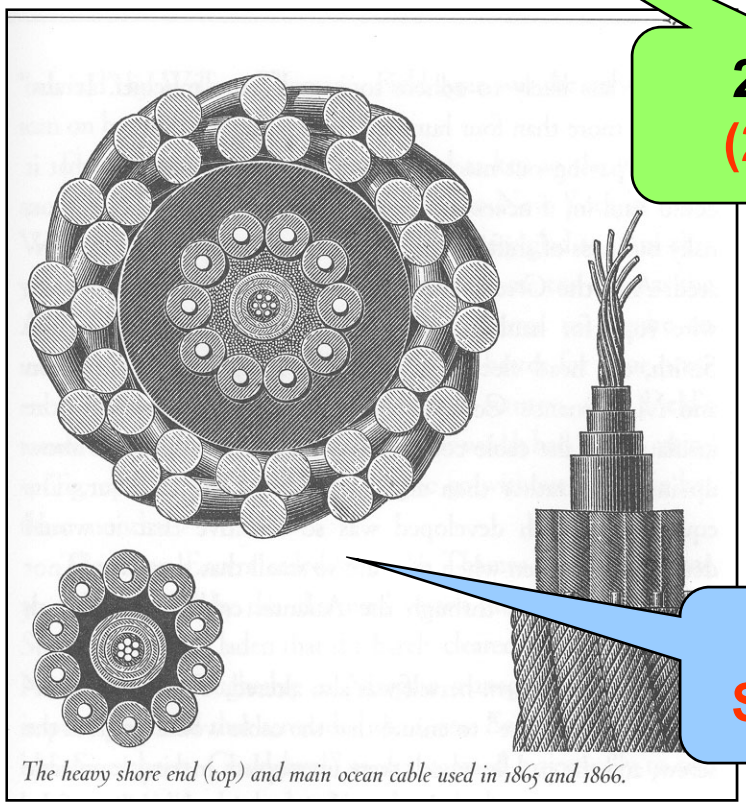
John Steele Gordon

Atlantic Cable Timeline & Designs

1857
"Broke"

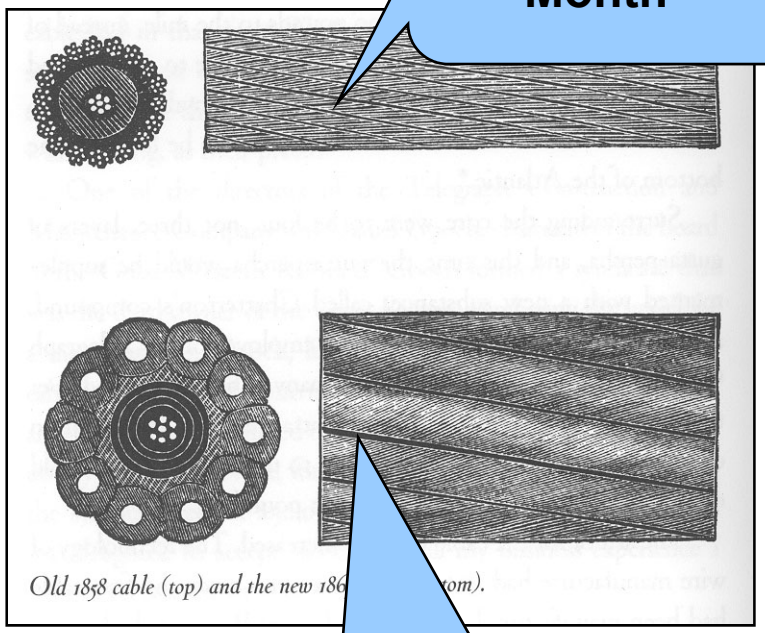


2 $/m
(2005)



1866
Success!

1858
"Worked for a Month"

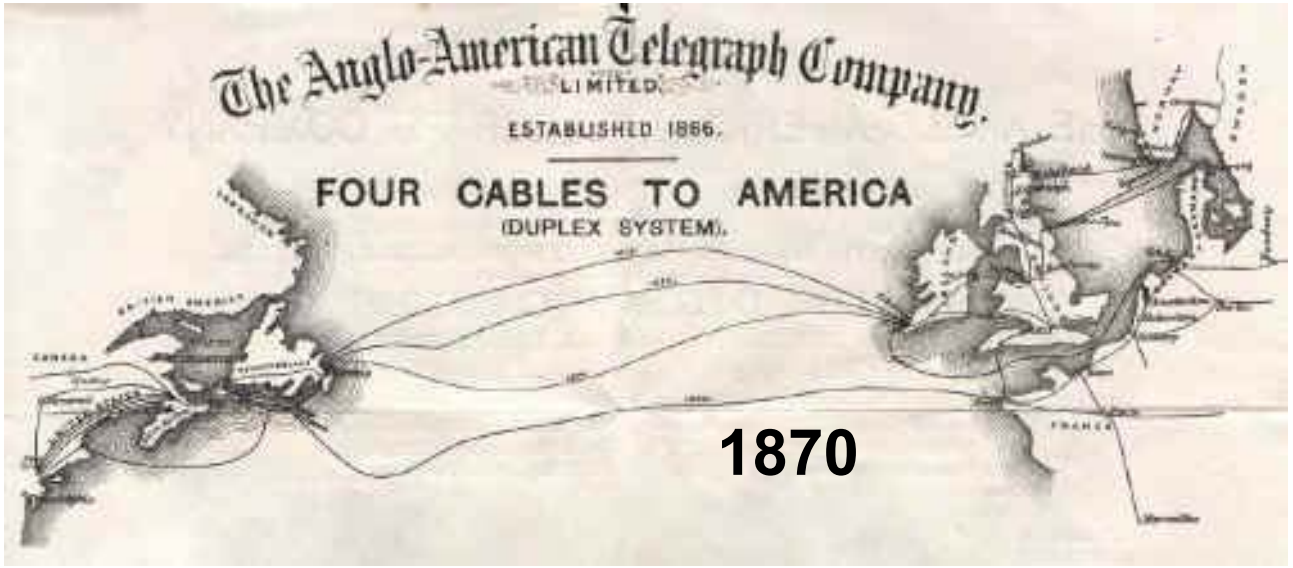


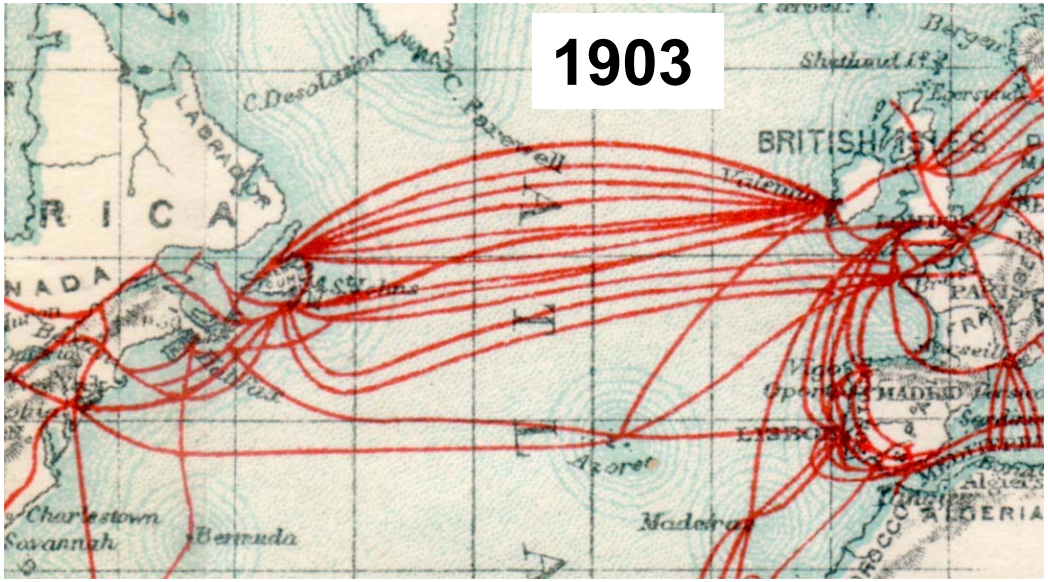
1865
"Parted"
(Recovered in 1866)

What Kept Them Going?

- The investors knew, that if communications with Europe could be cut from 2 weeks to 2 minutes, they'd all get…
- FILTHY RICH!
  - Estimates are that the total cost of the project in 2005 dollars was $100 M
  - First year 1867 revenue in 2005 dollars was $10 M !!

The After-Story





EMPIRE CONNECTION

Specifications

2-1000 MW HVDC Bipolar Circuits

- Circuit 1: 130 miles, Greene County → Bronx County
- Circuit 2: 140 miles, Albany County → New York County
- Each Circuit: +/- 500 kV, 1000 A Bipolar (2 cables ea.)

Financials

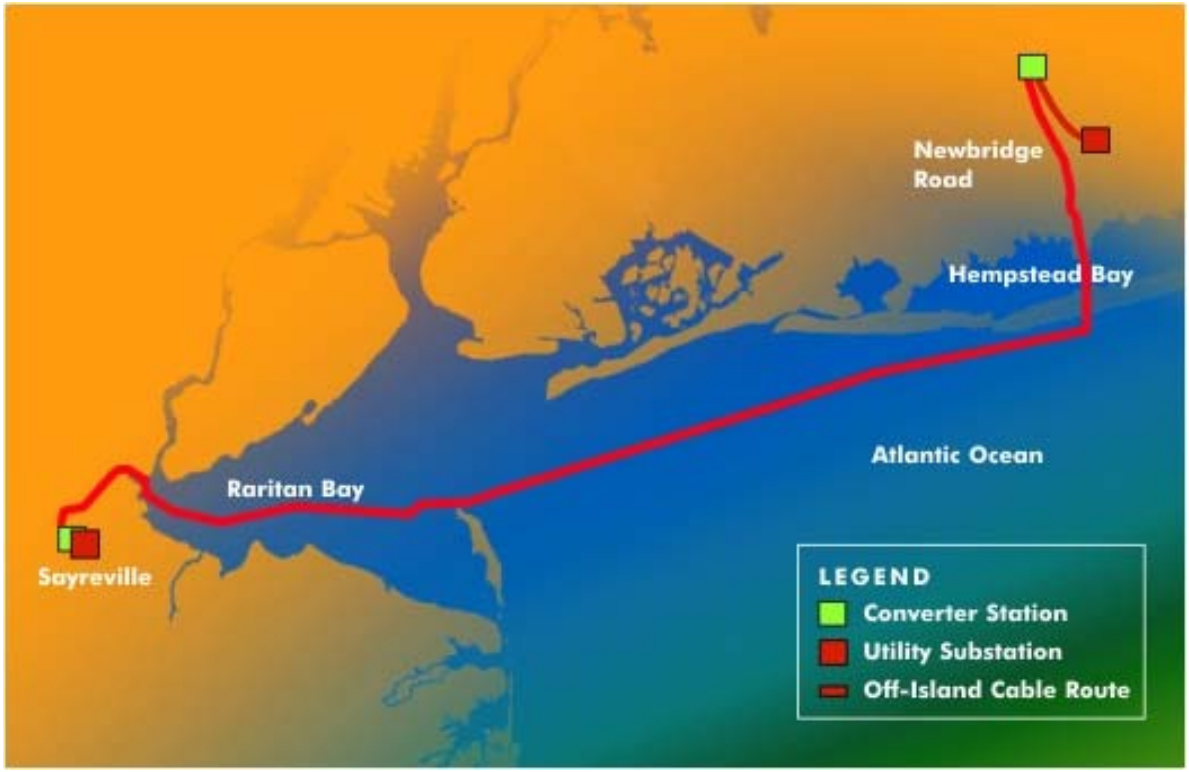
$750 M ($400 M "VC", $350 M "Futures")

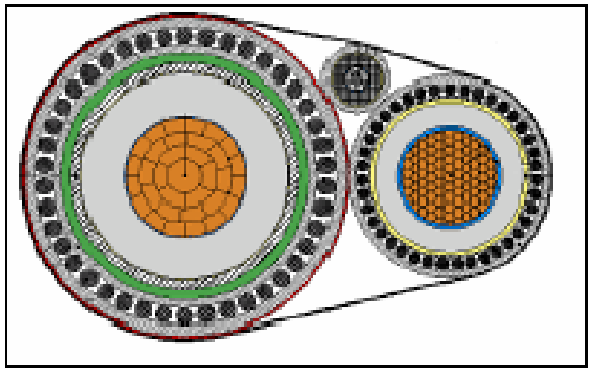
- Loan Payment (4%, 40 yrs, 750 M$) = 35 M$/yr
- Labor, Overhead, Maintenance = 5 M$/yr
- Tariff = 0.5 ¢/kWh
- Profit (NOI) @ 50% Capacity = 4 M$/yr
- Profit (NOI) @ Full Capacity = 48 M$/yr

Why didn't it go forward?

Wire C/P = 100 $/kA×m
HTSC Cost = $87 M

NEPTUNE
Regional Transmission System™





HVDC Cable Cross-Section

Pirelli (Prysmian) Energy Cables

$190 M

Sayerville, NJ → Levittown LI, NY

- 600 MW (+/- 250 kV, 1200 A)
- 65 miles (105 km)
- $400 M
- 2007

Financials

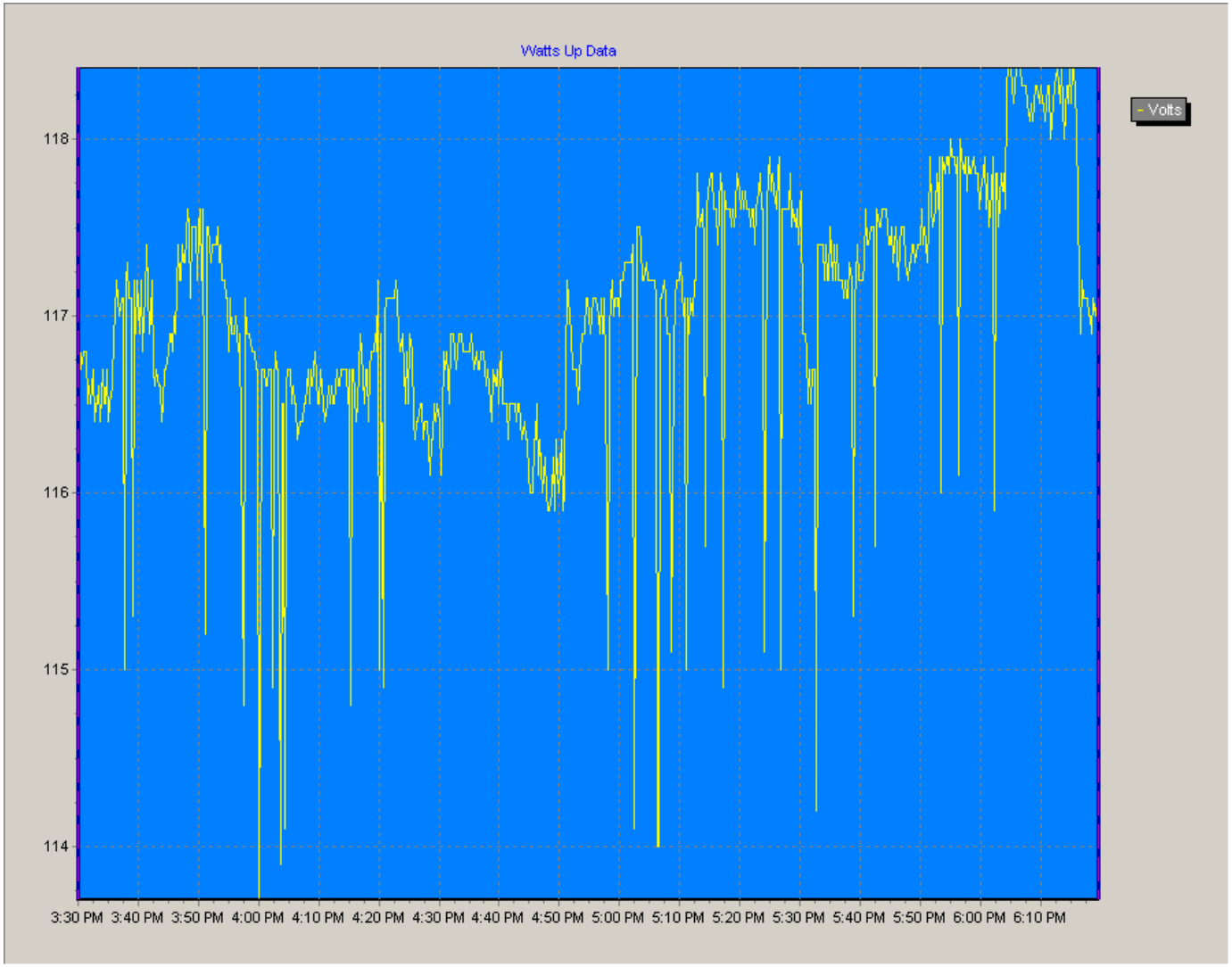
40 yrs @ 4%:	$ 20M
LOM:	1 M
NOI (100%):	5 M

T 77 K	C/P $/kA×m	Cost ($M)
Cu	7	1.8
HTSC	100	25.1

So Where's the "Gold Rush" to Superconductivity?

- What's the analogy to the Erie Canal, Railroads, REA, TVA, Interstate Highways that opened the country to economic development?
  - Capacity? Possibly
  - Reliability? Maybe
  - Power Quality? Nah

How many 9's?



07/25/04

3:30-6:00 PM

Sunday

Voltage

W2AGZ Server

SJ, CA 95120

What Then?

- An Electricity Infrastructure to Sustain and Expand the American Economy for this and the Next Generation.
  - In the absence of crisis or a “Gold Rush” need, to assure this goal will require unusual dedication, leadership and financial over many years.
- How can we maintain and perform the long range R&D this objective will require?

I. Establish a "National Bank" for Transmission R&D

Electricity Consumption	$300 B/yr
Transmission Tariff 10%	$30 B/yr
Investment for Transmission Grid R&D 2%	$600 M/yr

II. Create a "Fannie Mae" for Electricity

- X % of revenue to be administered by DOE for basic and strategic research in the electrical sciences to be carried out by the National Laboratories and the nation's Universities.
- (100-X)% to be divided amongst and administered by the RTOs to underwrite specific R&D interests of the RTO and its member utilities and to be carried out by contracts with private for-profit and non-profit organizations (Bechtel, EPRI, SRI, MRI, etc.)

Carry out demonstration projects!

“Superconduct-ress”

Mr. Electric Utility Good Ol' Boy

Miss Same Old Technology

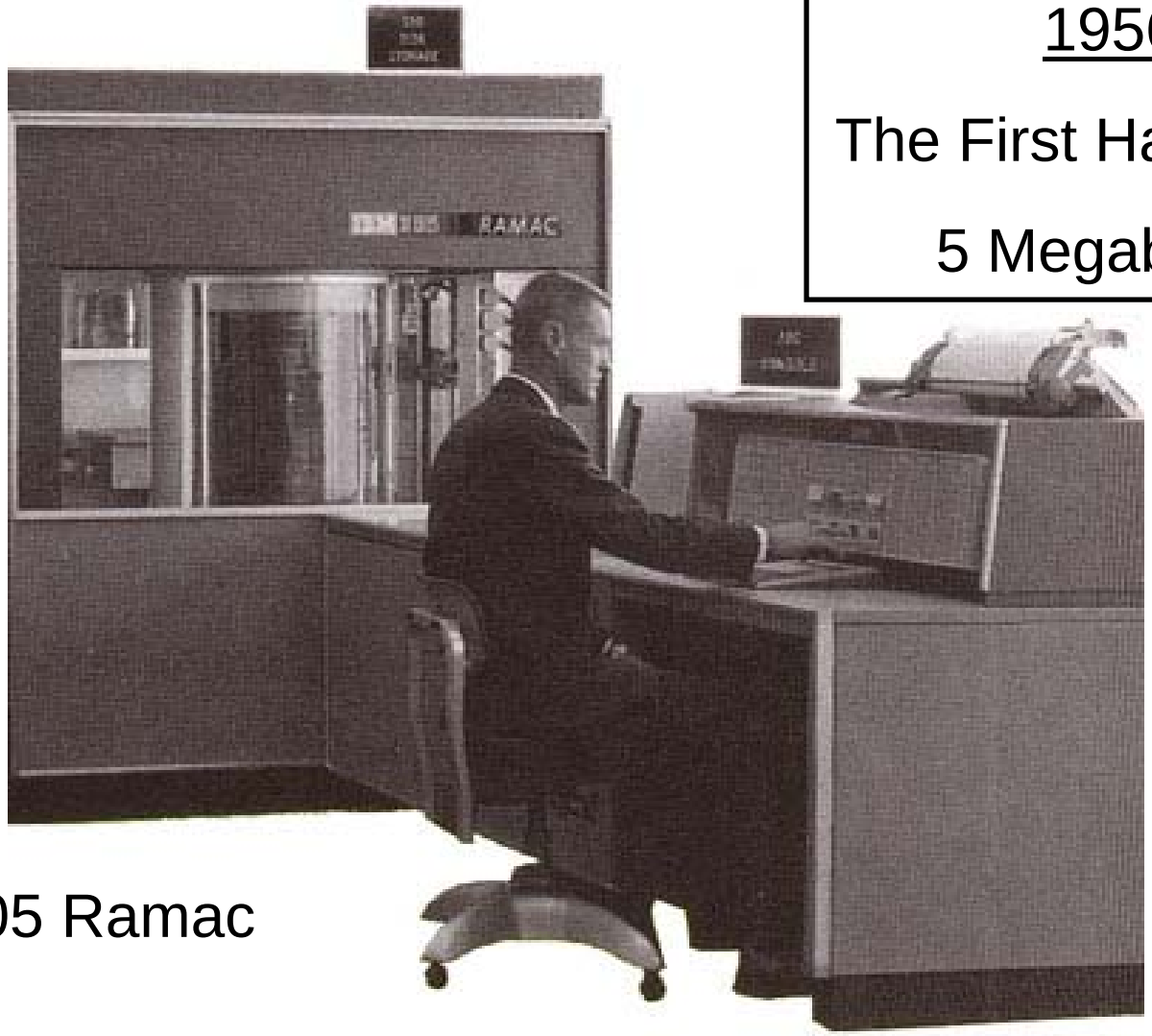
Together Forever?

…an 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

Final Exam

- Higher Temperature Superconductors -

- Novel Power Delivery Systems -

- On Finding New Superconductors - *Guidance from Our Elders*

- *"Don't listen to theoreticians"* (B. Matthias, ca. 1970s).
- *"To make a long story short, searches for high-temperature superconductors, especially with the existing obscurities in the area of theory, may lead to unexpected results and discoveries"* (V. L. Ginzburg, 1984).
- *"At the extreme forefront of research in superconductivity is the empirical search for new materials"* (M. R. Beasley (1983), as communicated by K. A. Mueller and J. G. Bednorz, (1986)).
- "*If you find an old metal laying around in the literature, try cooling it down,"* (P. M. Grant, 1976).

Materials Synthesis Pathways

- Light Elements
- Heavy Elements
- Many Elements
- All Elements

- *COMBINATORIAL !*

Bob Laughlin's "Theory of Everything" (that matters)

Theory of Everything

$$\mathcal{H} = -\sum_j \frac{\hbar^2}{2m}\nabla_j^2 - \sum_\alpha \frac{\hbar^2}{2M_\alpha}\nabla_\alpha^2 - \sum_{j,\alpha} \frac{Z_\alpha e^2}{|r_j - R_\alpha|} + \sum_{j<k} \frac{e^2}{|r_j - r_k|} + \sum_{\alpha<\beta} \frac{Z_\alpha Z_\beta e^2}{|R_\alpha - R_\beta|}$$

- Hydrogen atom
- Methane molecule
- water
- Air
- Rocks
- Concrete
- Steel
- Glass
- Plastic
- Buildings
- Cities
- Continents

- Proteins
- DNA
- Viruses
- Bacteria
- Yeast
- Slime mold
- Butterflies
- Sharks
- Rats
- Lawyers
- Ebola virus
- Legislatures
- Civilizations

- Flowers
- Trees
- Cows
- Cheese
- Sauce Bernais
- Computers
- Television
- Cars
- Jets
- Lawnmowers
- Sewage
- Spotted Owls
- ...

Where's spin, Pauli and Darwin? Ya screwed up, Bob…should'a used the many body Dirac equation! Oh yeah, and maybe Maxwell, Boltzman and Gibbs, too…and Newton's Apple.

The crunch comes when Σ_i with i >= 3 -> "thermodynamic limit."

"Size Matters !"

Electron-Phonon Coupling a la Migdal-Eliashberg-McMillan

(plus Allen & Dynes)

$$H_{el-ph} = \sum_{\mathbf{k}\mathbf{q}\nu} g^{\mathbf{q}\nu,mn}_{\mathbf{k}+\mathbf{q},\mathbf{k}}\, c^{\dagger m}_{\mathbf{k}+\mathbf{q}}\, c^{n}_{\mathbf{k}}\, (b^{\dagger}_{-\mathbf{q}\nu} + b_{\mathbf{q}\nu}) \qquad (1)$$

First compute this via DFT…

$$\alpha^2 F(\omega) = \frac{1}{N(\varepsilon_F)} \sum_{mn} \sum_{\mathbf{q}\nu} \delta(\omega - \omega_{\mathbf{q}\nu}) \sum_{\mathbf{k}} |g^{\mathbf{q}\nu,mn}_{\mathbf{k}+\mathbf{q},\mathbf{k}}|^2 \times \delta(\varepsilon_{\mathbf{k}+\mathbf{q},m} - \varepsilon_F)\delta(\varepsilon_{\mathbf{k},n} - \varepsilon_F), \qquad (2)$$

$$\lambda = 2\int \frac{\alpha^2 F(\omega)}{\omega} d\omega = \sum_{\mathbf{q}\nu} \lambda_{\mathbf{q}\nu}, \qquad (3)$$

$$\lambda_{\mathbf{q}\nu} = \frac{2}{N(\varepsilon_F)\omega_{\mathbf{q}\nu}} \sum_{mn} \sum_{\mathbf{k}} |g^{\mathbf{q}\nu,mn}_{\mathbf{k}+\mathbf{q},\mathbf{k}}|^2 \times \delta(\varepsilon_{\mathbf{k}+\mathbf{q},m} - \varepsilon_F)\delta(\varepsilon_{\mathbf{k},n} - \varepsilon_F). \qquad (4)$$

Then this…

Quantum-Espresso (Democritos-ISSA-CNR)

http://www.pwscf.org Grazie!

So…

- Now we can compute the sc phase diagram of Al, Nb, MgB_2, etc., as accurately as can be measured.
- Then has phonon-mediated superconductivity in s-p (light elements…some not so light) systems become "solved science?"
- Maybe…but...
- Unresolved: ultra-strong λ and flux dynamics.
  - Will this lead to a BEC instead?
  - Will we get a superconductor that's not a perfect conductor?

$$\xi \propto 1/\lambda T_C$$

What to do next?

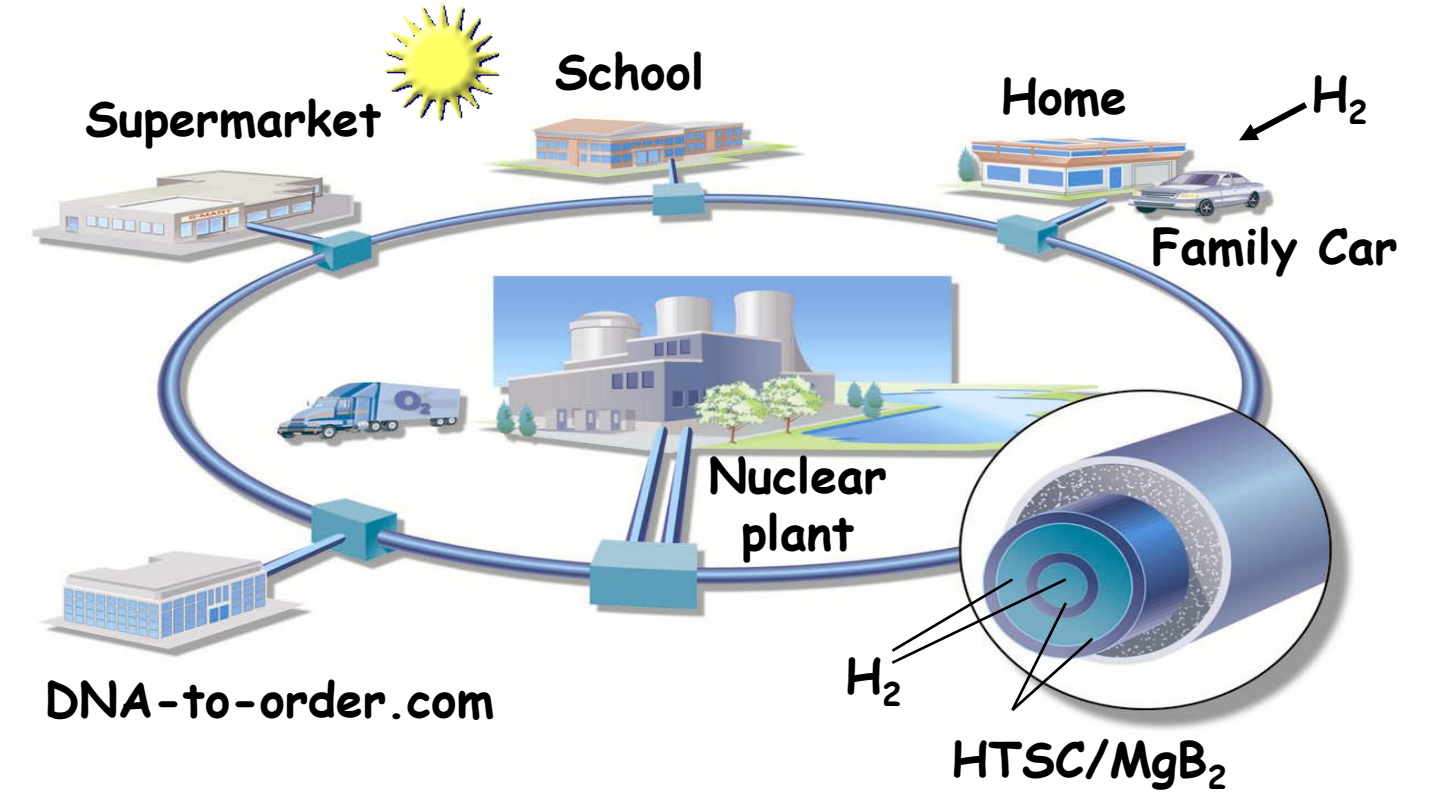
- Develop DFT algorithms to compute “exotic” pairing mechanisms, analogous to e-p.
- Especially polarization (“exciton”) and magnetic (“all flavors,” particularly “negative-U”).
- If I were a big-shot superconductivity professor, I’d assign, as a doctoral project, coding the Kirshnitz, Maximov and Khomskii alternative to Eliashberg-MacMillan, including LDA+U and phonons, within the formalism of a plane-wave pseudopotential DFT framework…and then give it away!

Final Exam

- Higher Temperature Superconductors -

- Novel Power Delivery Systems -

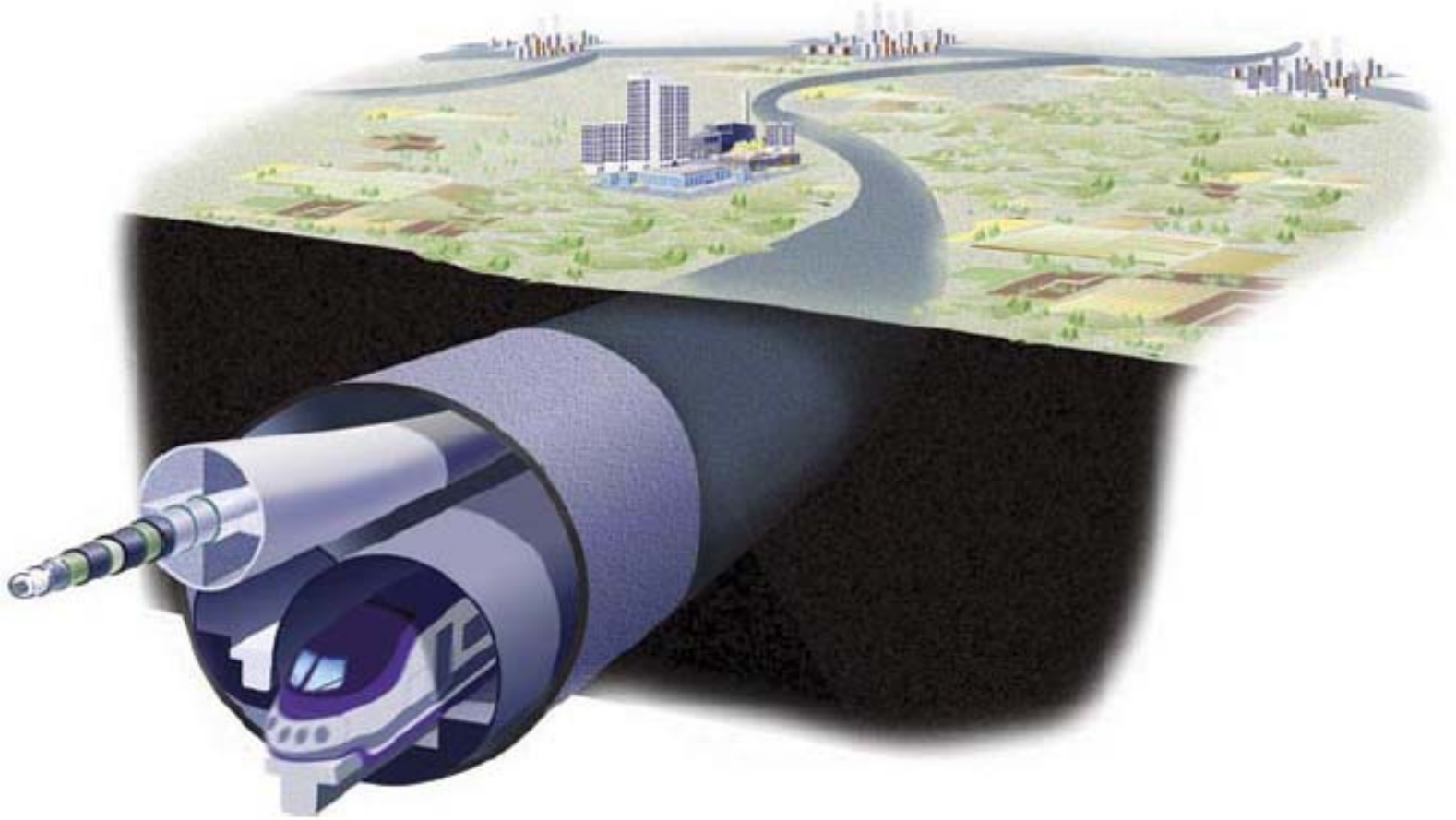
SuperCity



P.M. Grant, The Industrial Physicist, Feb/March Issue, 2002

SuperGrid

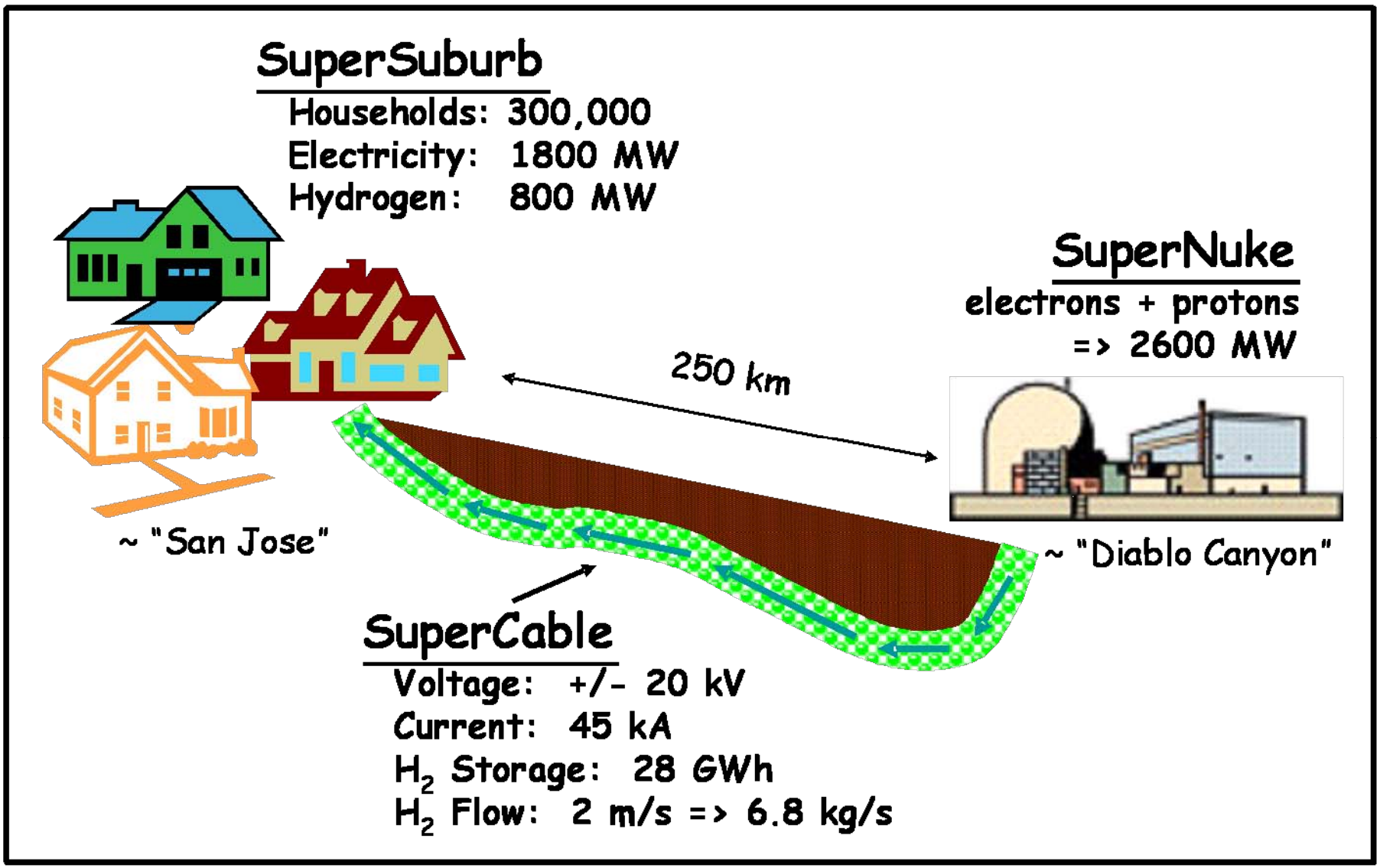
Grant, Starr & Overbye, Scientific American, July 2006, p. 78



http://www.w2agz.com/ucdpc08.htm

EPRI White Paper, 2006

SuperSuburb



A Canadian's View of the World

The Mackenzie Valley Pipeline

http://www.mackenziegasproject.com

1220 km

18 GW-thermal

2006 - 2009

Powering the Middle East

- *"The e-Pipe"* -

Concept:

- Wellhead generation by natural gas in Qatar
- Transport power via HTSC cable to the Levant

Specifications:

- 1610 km
- 50 kA, +/- 50 kV
- 5 GW
- 1.3 x Pacific Intertie !

Utility Spec for an “RTSC”

- σ >= 200x Cu @ 300 K @ 20 kA/cm^2 @ 1000 Hz
- ρ_{RTSC}/ρ_{Cu} <= 2
- Tensile Strength ~ Al
- Not Obnoxiously Toxic
- Cost <= 5x Cu
  - Related to cost of electricity

Could possibly enable a hydrogen economy!

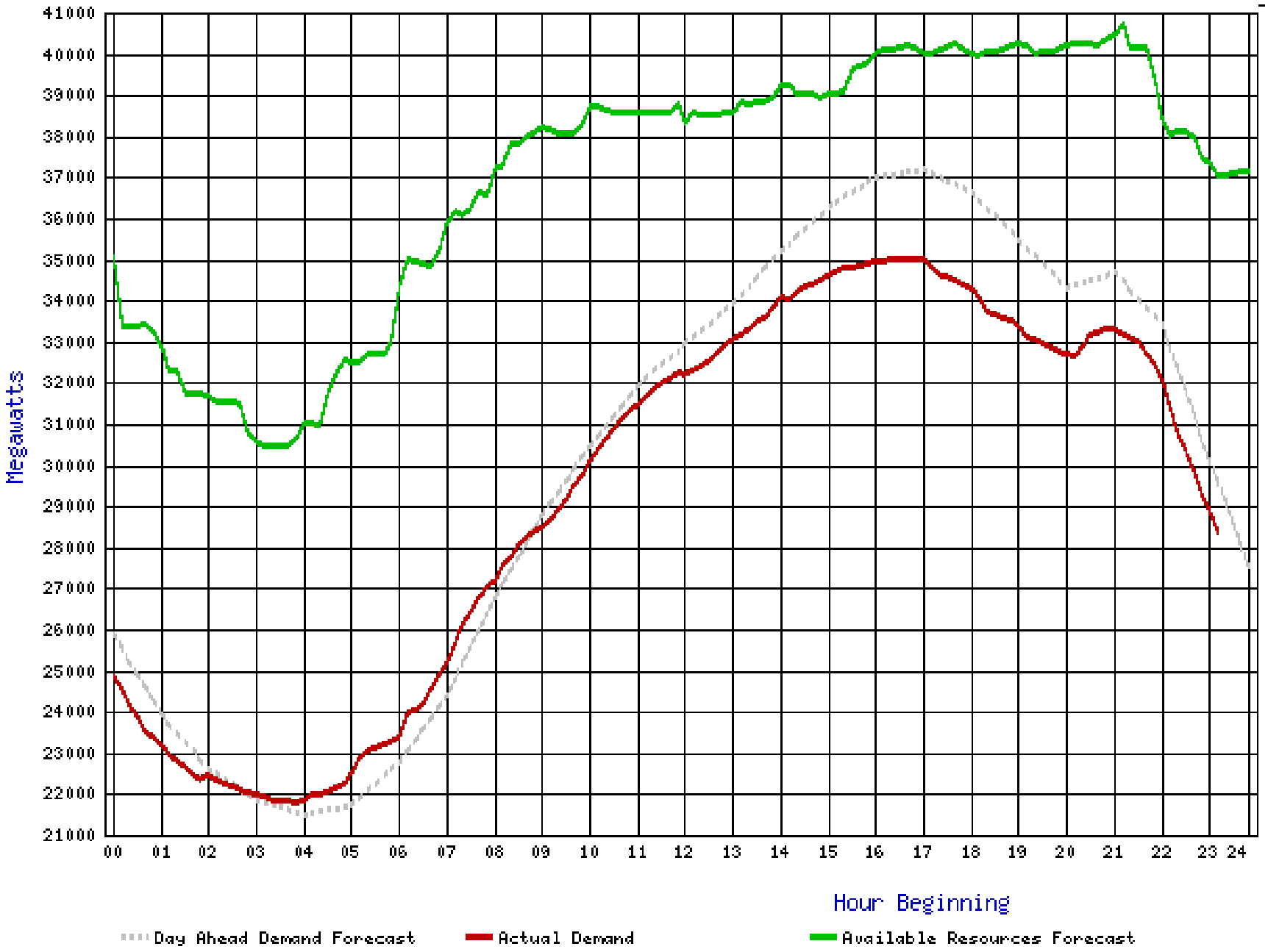
Hydrogen Transport & Delivery (Current DOE OH Plan)

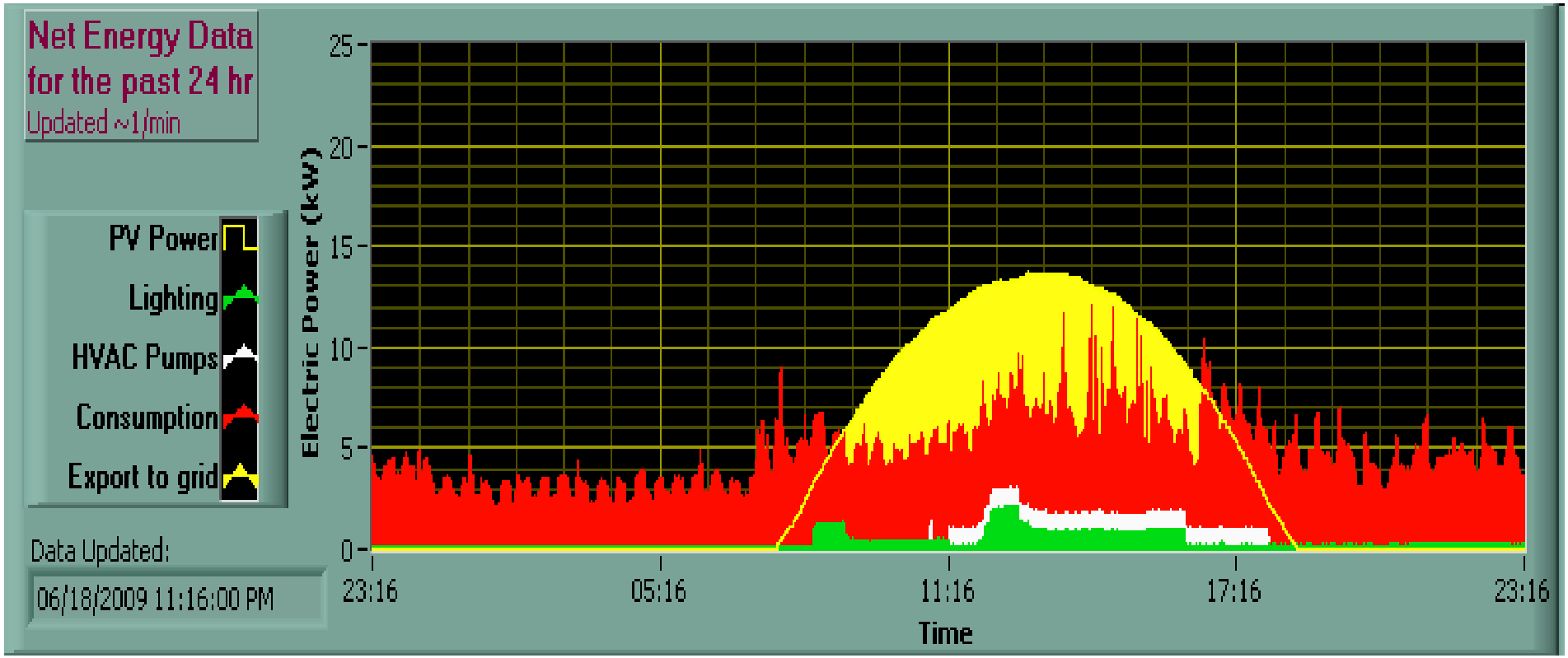
“You can’t always get what you want…”

“…you get what you need!”

Where there is no vision, the people perish…

Proverbs 29:18


Megawatts
41000
40000
39000
38000
37000
36000
35000
34000
33000
32000
31000
30000
29000
28000
27000
26000
25000
24000
23000
22000
21000
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour Beginning
Day Ahead Demand Forecast
Actual Demand
Available Resources Forecast


Net Energy Data
for the past 24 hr
Updated ~1/min
PV Power
Lighting
HVAC Pumps
Consumption
Export to grid
Data Updated:
06/18/2009 11:16:00 PM
Electric Power (kW)
25
20
15
10
5
0
23:16
05:16
11:16
17:16
23:16
Time

U.S. Electricity Production/Loss Summary

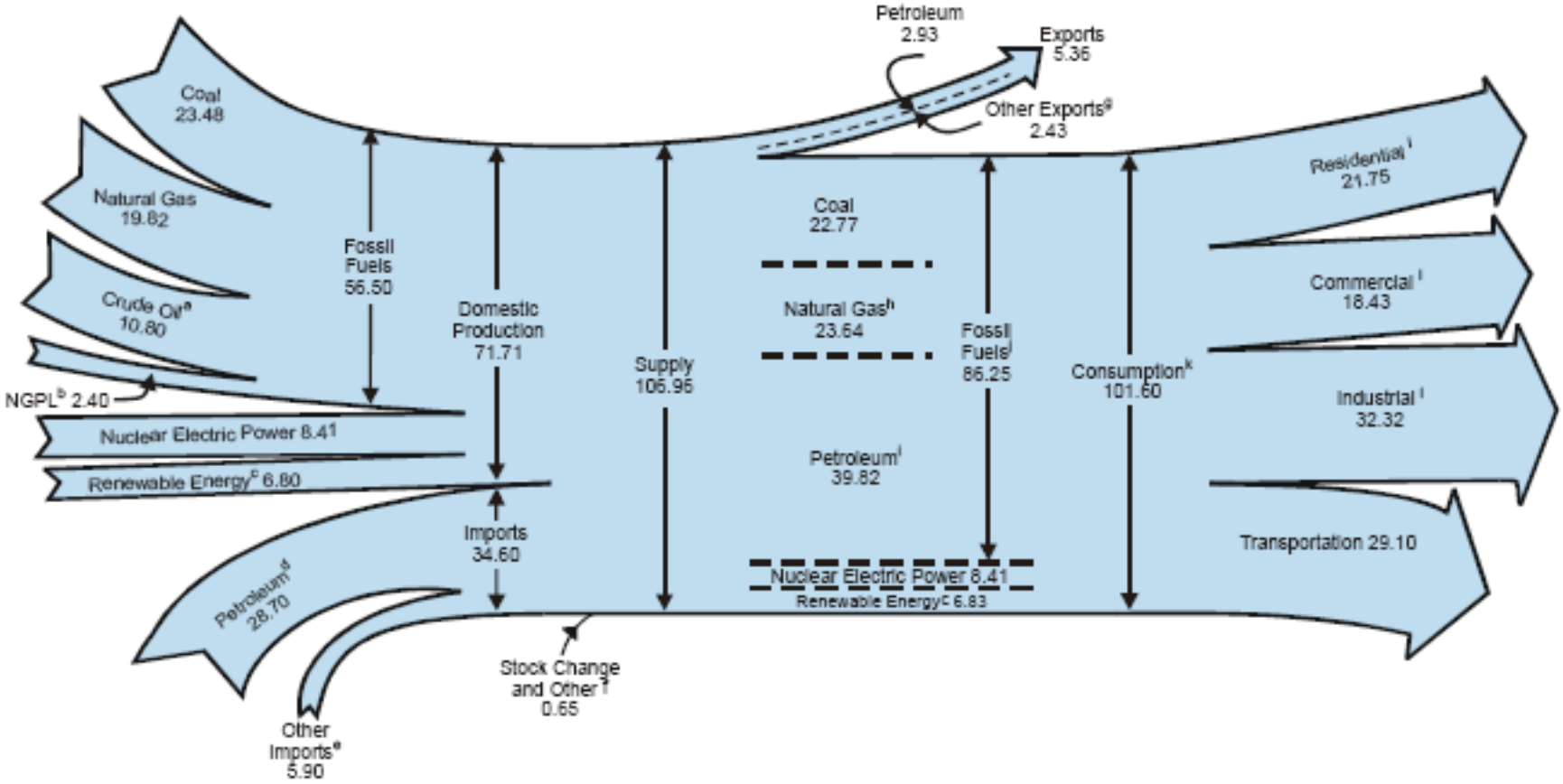
	TkWh	% in T&D Loss and In-Plant Use	Revenue @ $0.10/kWh (B$)	No. of 500 MW Power Plant Equivalents	Capital Cost @ $800/kW (B$)
Total	3.24		324	740	296
T&D Losses	0.28	8%	28	63	25
In-Plant Used	0.15	5%	15	35	14

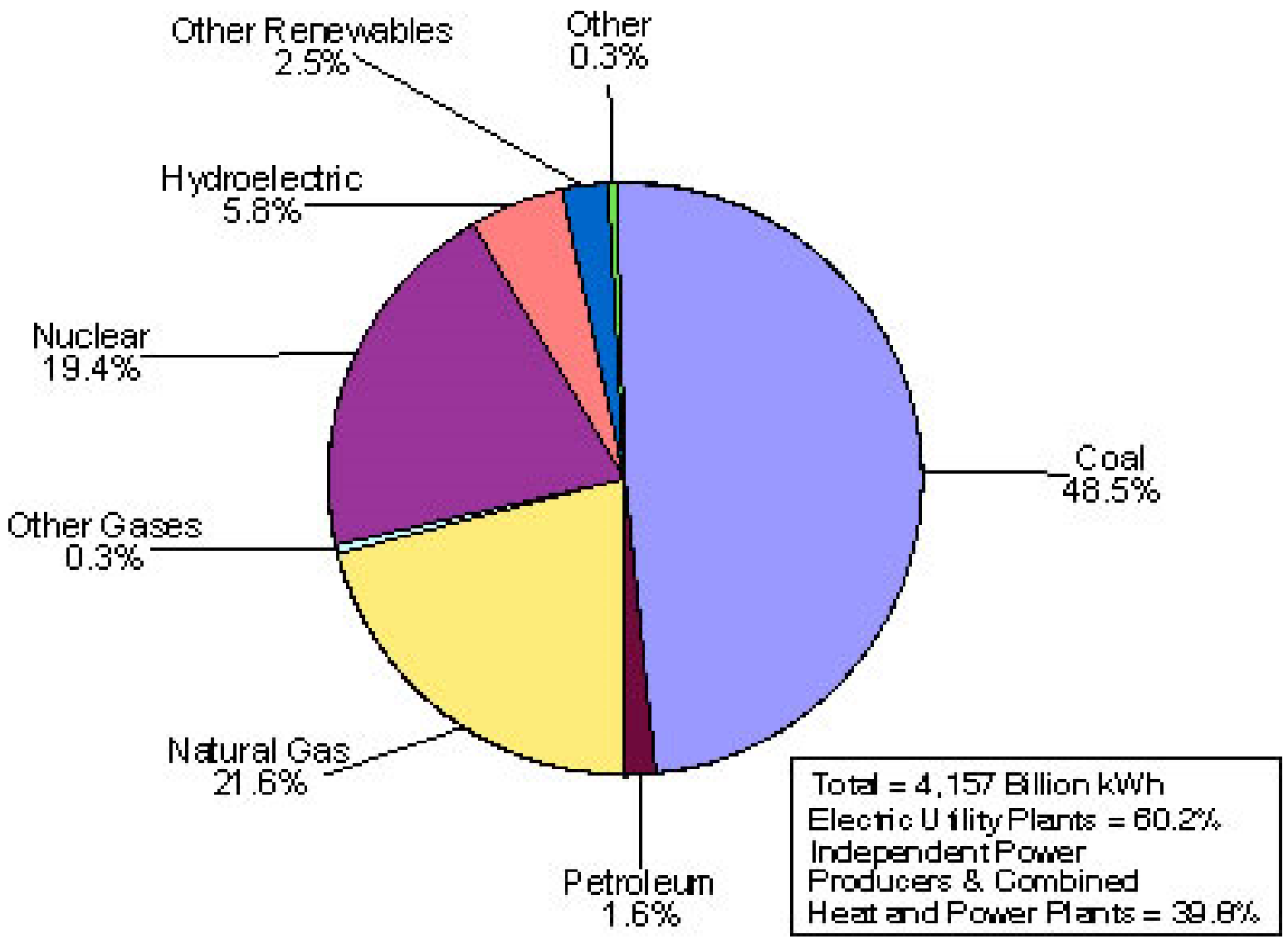
Superconductivity and Efficiency

	1994	2014 @ 2%/yr	2014 Plants Saved 0.2% Penetration 4× Efficiency
Total	740	360	
T&D Losses	63	31	11
In-House Use	35	17	6

Operating Parameters

Capacity	**50 kA, ±50 kV; %GMW**
Length	**1610 km**
Temperature Rise, 1 K every 10 km, 65 K, 1 W/m heat input	**21,600 liters LN_2/hr, 100 kW coolers, 120 gal/min**
Vacuum 10^{-5}-10^{-4} torr	**10 stations/10 km need 200 kW**


Petroleum
2.93
Exports
5.36
Other Exports[g]
2.43
Coal
23.48
Natural Gas
19.82
Crude Oil[a]
10.80
NGPL[b] 2.40
Nuclear Electric Power 8.41
Renewable Energy[c] 6.80
Fossil
Fuels
56.50
Domestic
Production
71.71
Imports
34.60
Petroleum[d]
28.70
Other
Imports[e]
5.90
Stock Change
and Other[f]
0.65
Supply
105.96
Coal
22.77
Natural Gas[h]
23.64
Petroleum[i]
39.82
Fossil
Fuels[j]
86.25
Nuclear Electric Power 8.41
Renewable Energy[c] 6.83
Consumption[k]
101.60
Residential[l]
21.75
Commercial[l]
18.43
Industrial[l]
32.32
Transportation 29.10


Other Renewables
2.5%
Other
0.3%
Hydroelectric
5.8%
Nuclear
19.4%
Coal
48.5%
Other Gases
0.3%
Natural Gas
21.6%
Petroleum
1.6%
Total = 4,157 Billion kWh
Electric Utility Plants = 60.2%
Independent Power
Producers & Combined
Heat and Power Plants = 39.8%