Setup

Plugged Into the Matrix

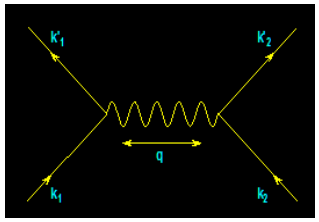
The North American Power Grid: Past, Present and Future

Paul M. Grant

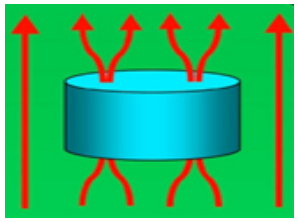
Principal, W2AGZ Technologies
Visiting Scholar, Stanford (2005-2008)
EPRI Science Fellow (*retired*)
IBM Research Staff Member Emeritus
w2agz@w2agz.com
www.w2agz.com

IEEE OEB Life Member Meeting
18 April 2018
Livermore, CA

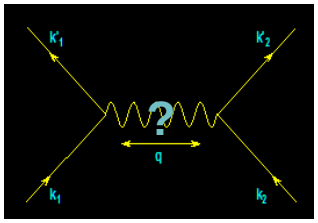
From Electrons Paired



To Electric Power Delivered



…And… Back Again



-- A Personal Journey in Applied Physics --
-- IBM, EPRI, and Beyond --

Paul M. Grant

IBM (1953-1993)

- Joined 1953 (age 17)
- SAGE/NORAD (MIT)
- Clarkson/Harvard
- Magneto-optics
- Displays/Printers
- Organic Conductors
- DFT
- Superconductivity
- High-Tc
- Sabbatical (UNAM)

EPRI (1993-2005)

- High-Tc Power Apps
- Wide Bandgap SCs
- Power Electronics
- "Hot" Fusion
- "Smart Grid"
- "SuperGrid"
- "Climate Change"
- Visionary Energy Societies

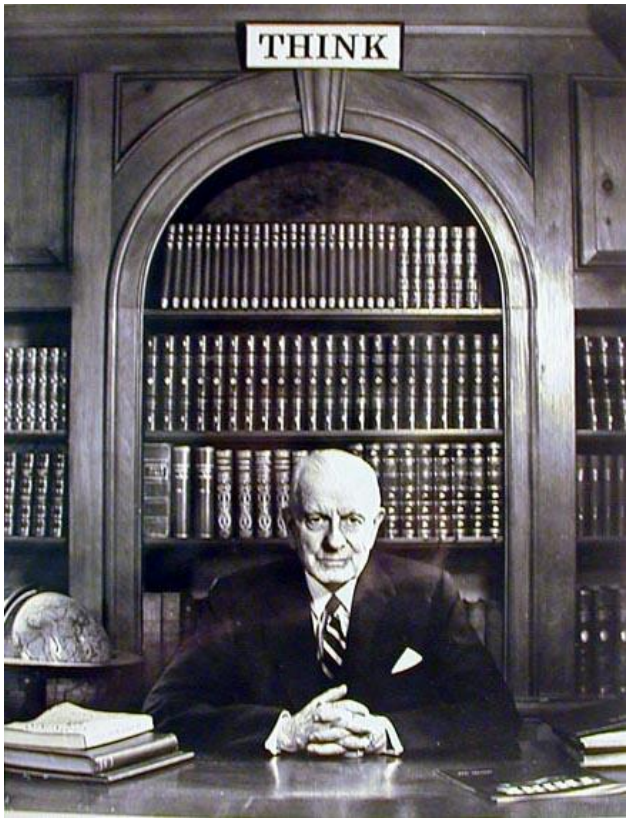
W2AGZ (2005-?)

- Due Diligence
- Tet-CuO (Stanford)
- "Proxy" DFT
- RTSC via DFT
- IASS Potsdam
- *Dual Use of NG Pipeline ROWs for Co-transport of Electricity via HTSC Cables (e.g., Keystone)*

…in their shoes…

- Paul Archibald Grant
  - W2AGZ
  - US Navy, WWII
  - IBM, 1948-1974
  - Ski Patrol, 1948-1970
- Mary Ann Whalen Grant
  - CYO BB Champ, 1921
  - NYS Bowling Champ, 1939
  - Women's Baseball, '33-'47
  - CHG&E, 1927-1965

IBM Poughkeepsie - 1952

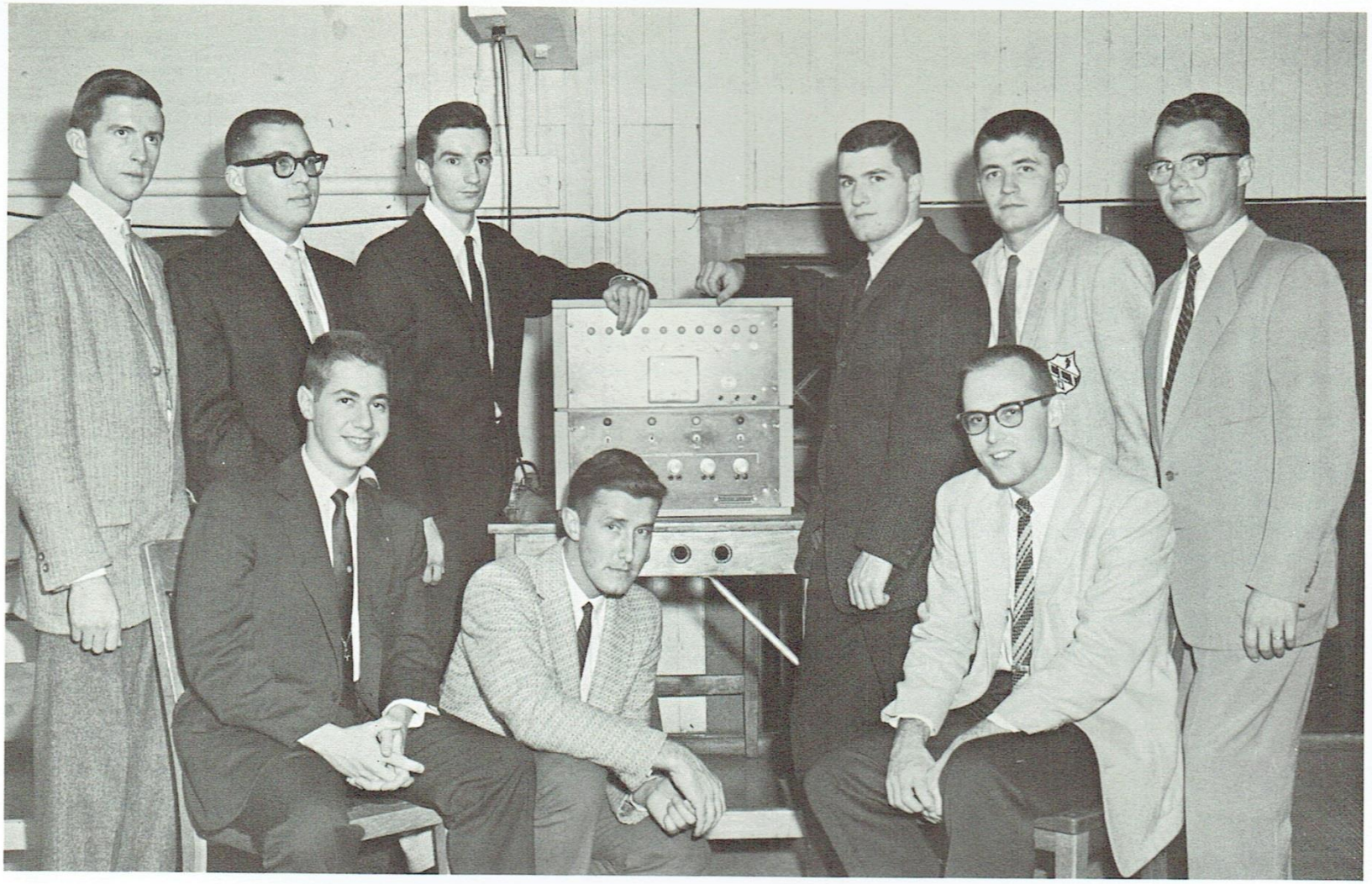


Visit www.w2agz.com for the whole story

1953

Project Sage – IBM/MIT

Eta Kappa Nu, '60



First Row: S. Katz, B. Kleen, D. Wells. *Second Row:* J. Blair, M. Buchholtz, P. Grant, G. Mayo, F. Wellin, R. Jordan.

CLARKSON COLLEGE OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING

A STUDY OF THE ELECTRONIC PROCESSES IN EXTRINSIC GERMANIUM AS EXHIBITED BY THE HALL AND MAGNETORESISTANCE EFFECTS

A SENIOR THESIS

by

PAUL M. GRANT

Submitted in partial fulfillment of the requirements

for the degree of

Bachelor of Electrical Engineering

January 20, 1960

Approved by Thesis Advisor Date

Albert B. Grantham 26 Jan'60

George W. Reed 26 Jan '60

Department Chairman

Paul M. Grant

My Senior Thesis Morphed Into the GMR Read Head Employed in Hard Drives

My Virtual Grandfather (@ 94)

US
Electric Power 101

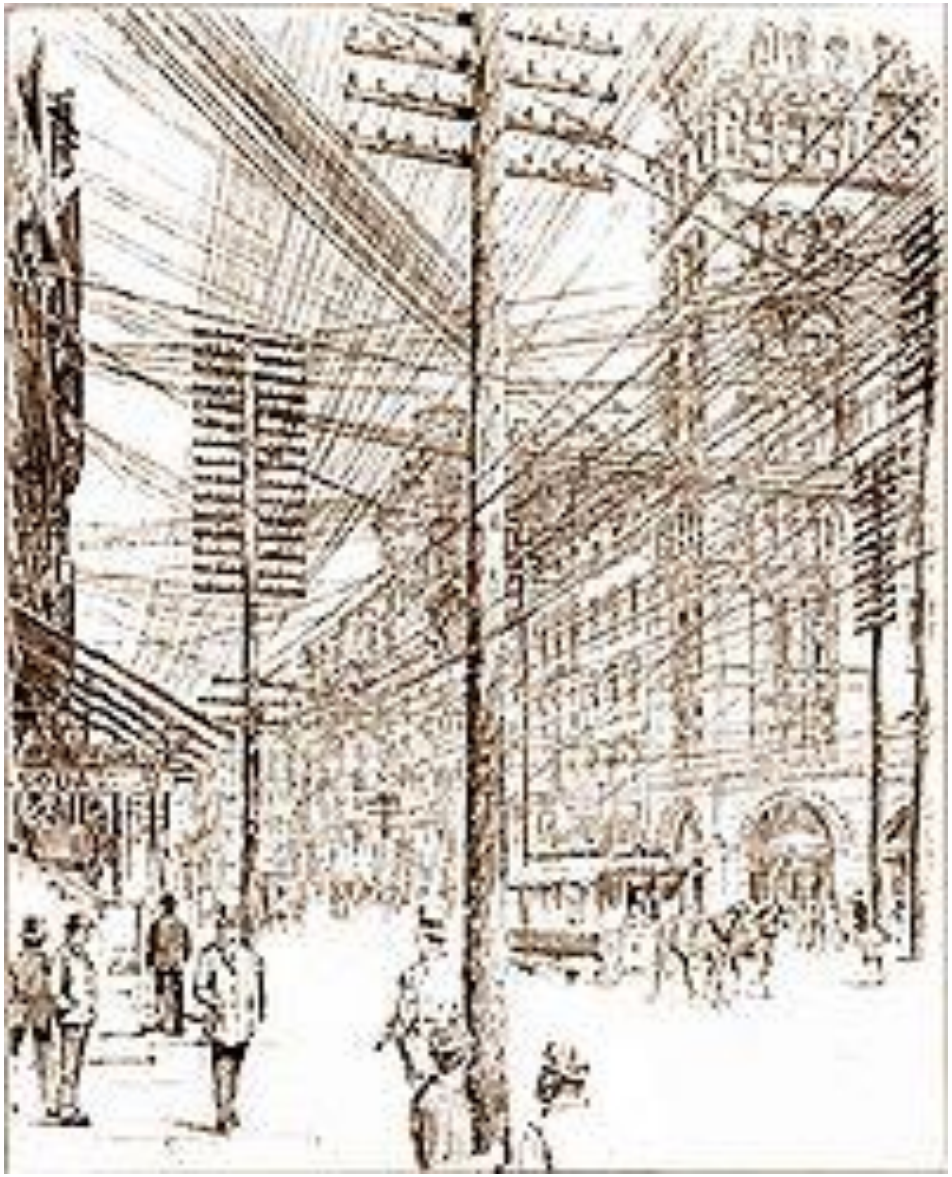
- Electricity Today -

The Crown Jewel of the US Economy

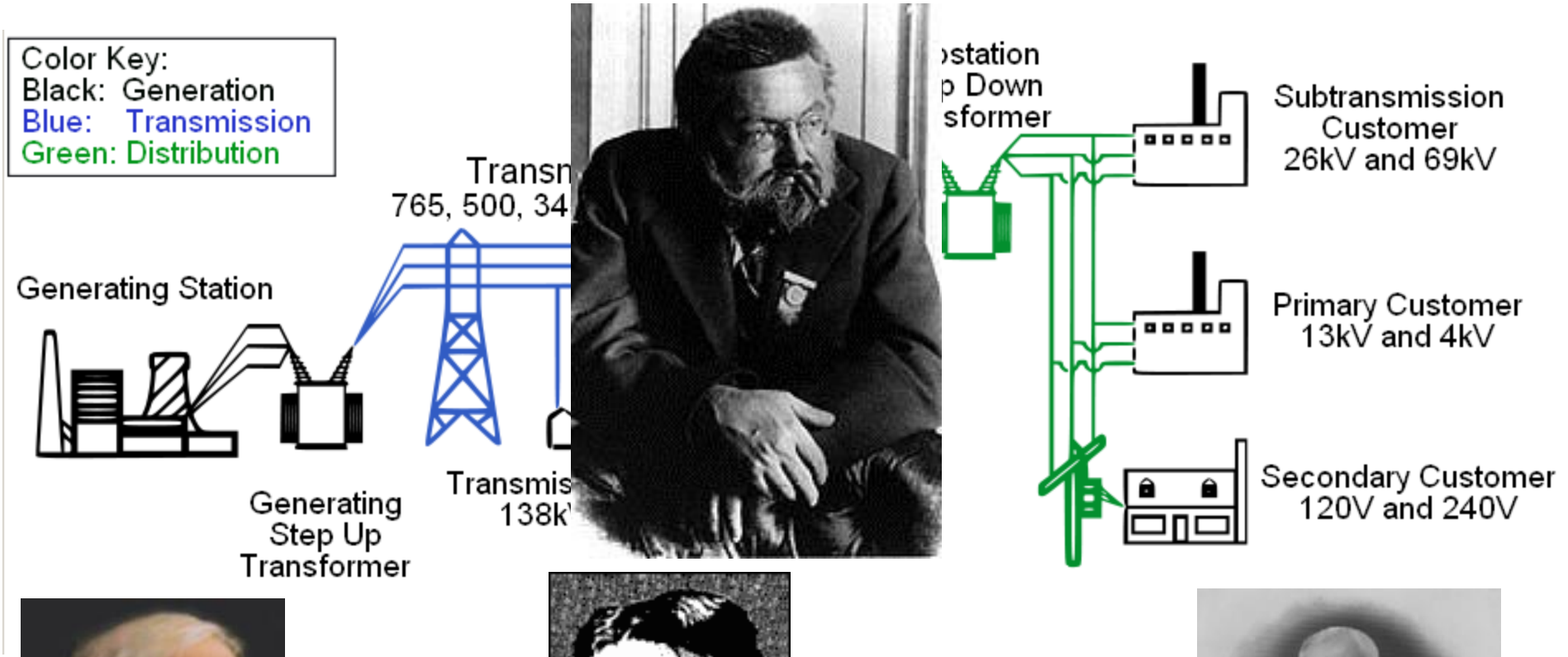
- **~$2 trillion total asset value**
- **$344 billion annual revenues**
- **142 million customers**
- **3273 utilities**

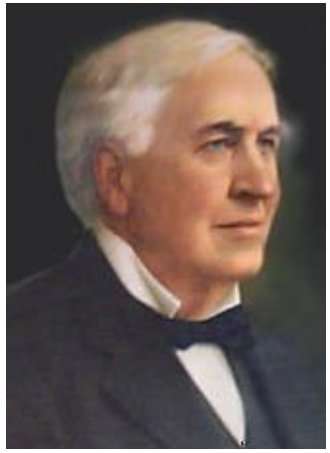
Without electric power the $14.3 trillion U.S. economy would come to a halt

NYC circa 1890s



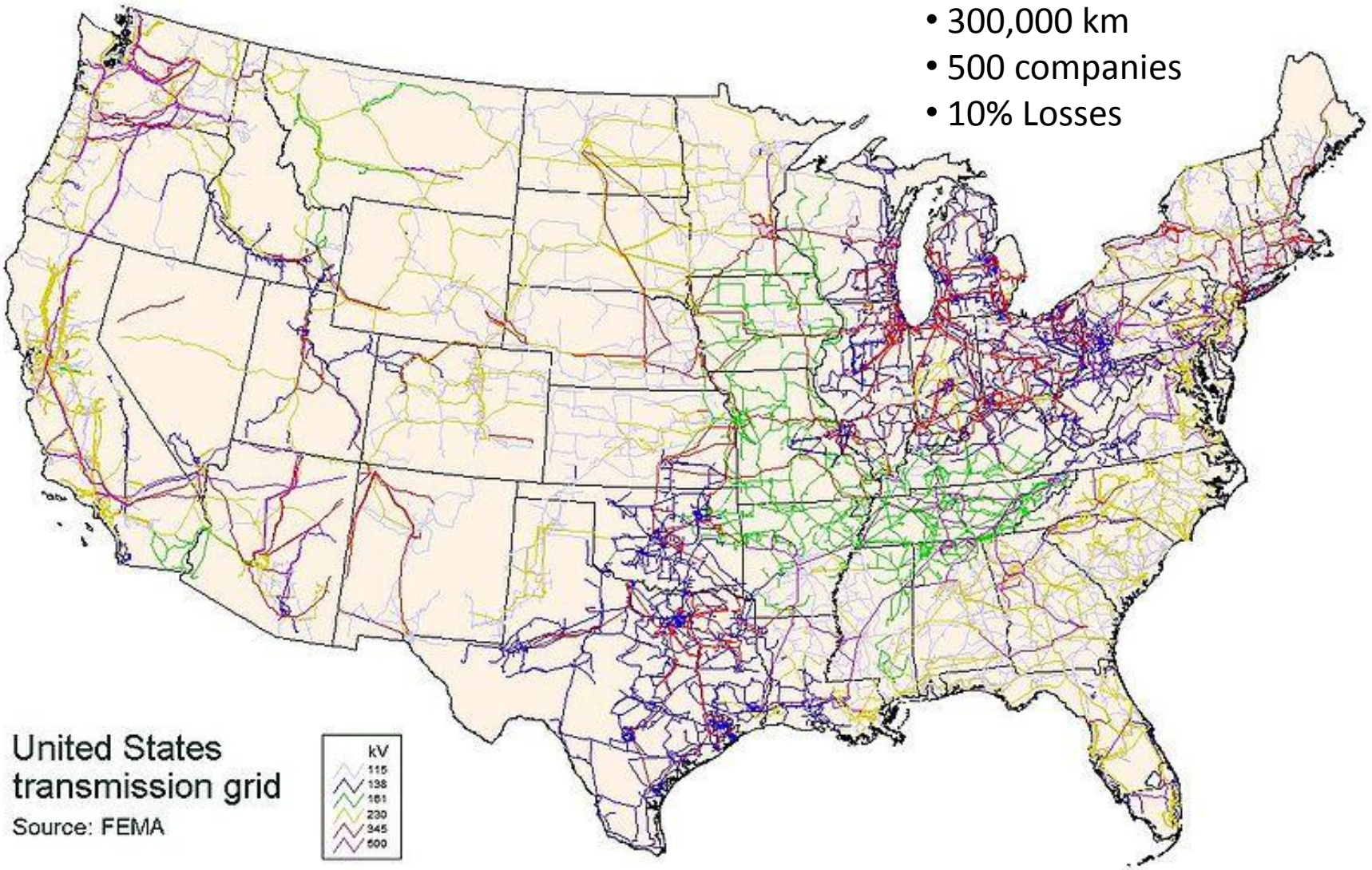
The US Electrical System





The US Transmission Grid(s)

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



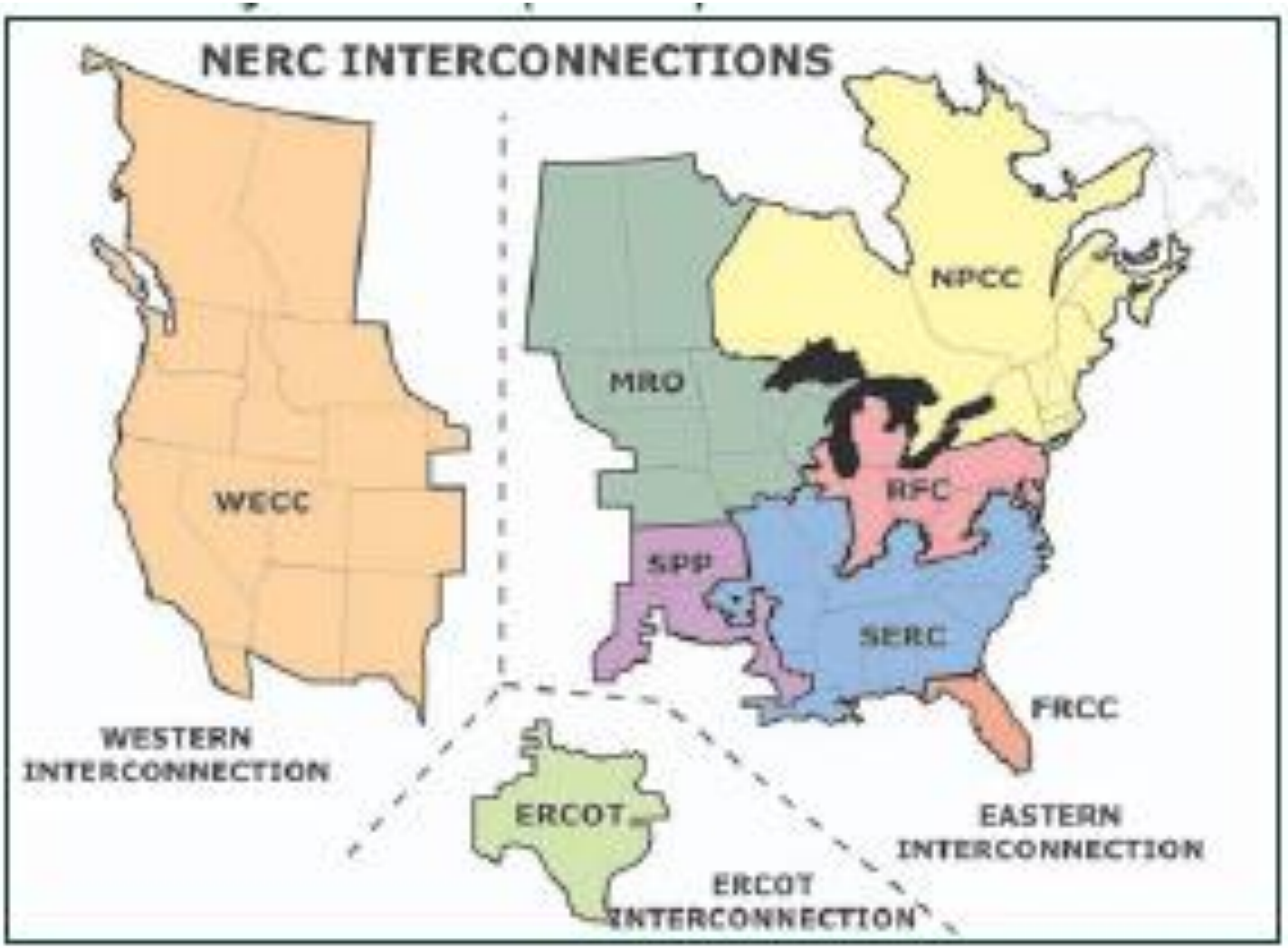
North American HVDC

Pacific Intertie

- HVDC, +/- 500 kV, 3.1 kA, 3.1 GW
- 1,362 km
- ~50% of LA Power Consumption
- Converter/Inverter Losses ~ 5%
- Ohmic Losses ~ 10%

Celilo I/C Station
“A Mountain of Silicon”

NERC Interconnects



Source: DOE 2006 National Electric Transmission Study

The Grid:

A Journey Though the Heart of Our Electrified World

By Phillip F. Schewe
Joseph Henry Press, 2007 (Buy It!)

Reviewed by Paul M. Grant:

Plugged into the matrix

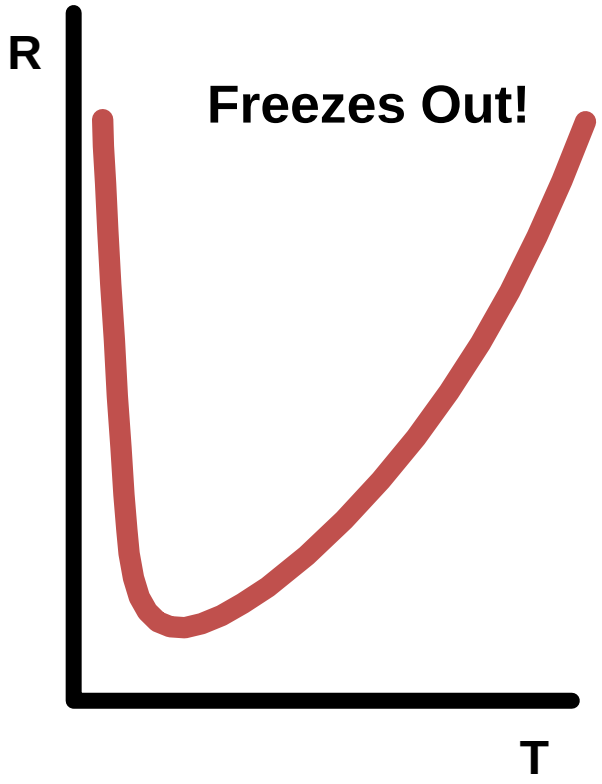
The rise and potential fall of the US electricity grid

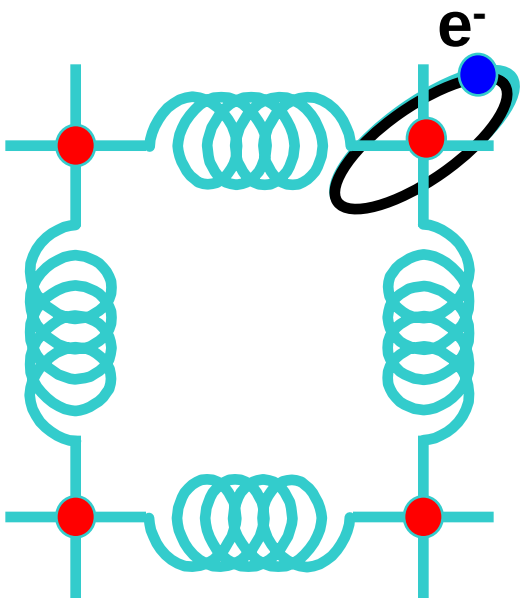
Nature 447, 145 (2007)
http://www.w2agz.com/Publications/Book%20Reviews/06%20%282007%29%20Plugged%20Into%20the%20Matrix.pdf

Superconductivity 101

Models of Electrical Conductivity

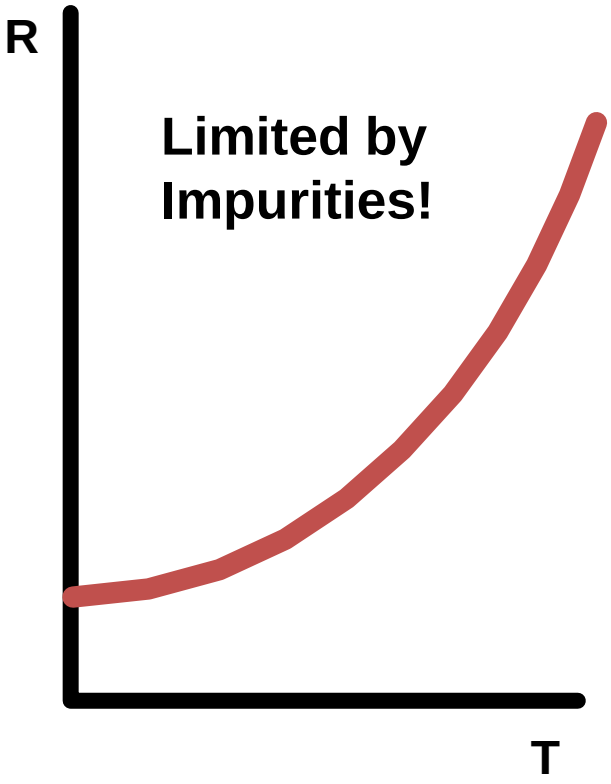
The Most Popular:

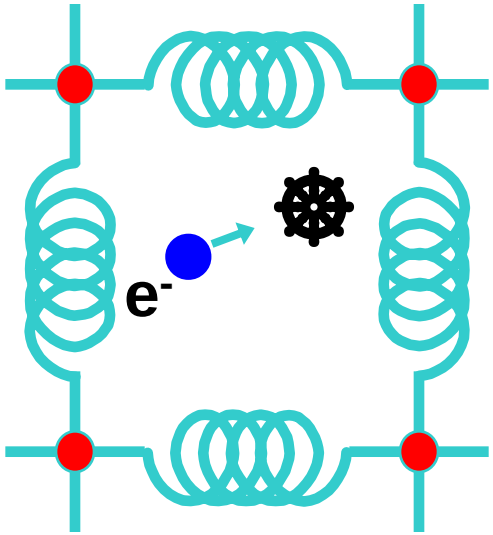




Models of Electrical Conductivity

Reality:

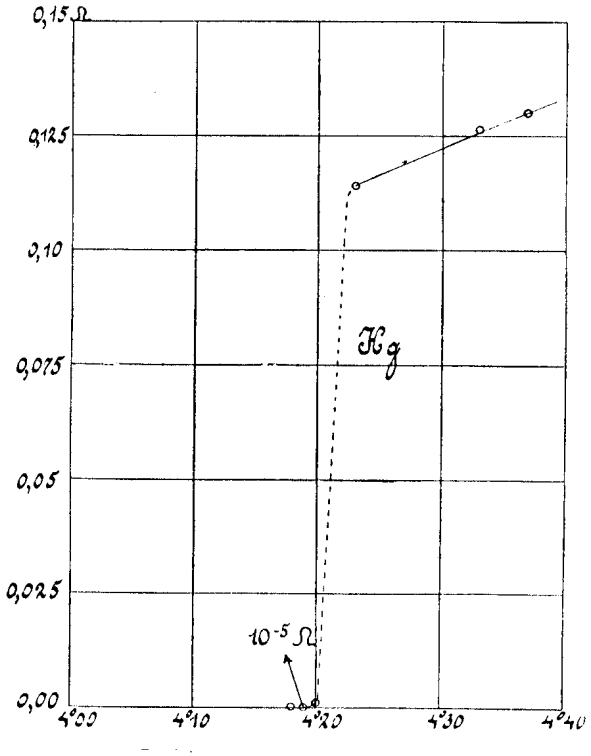




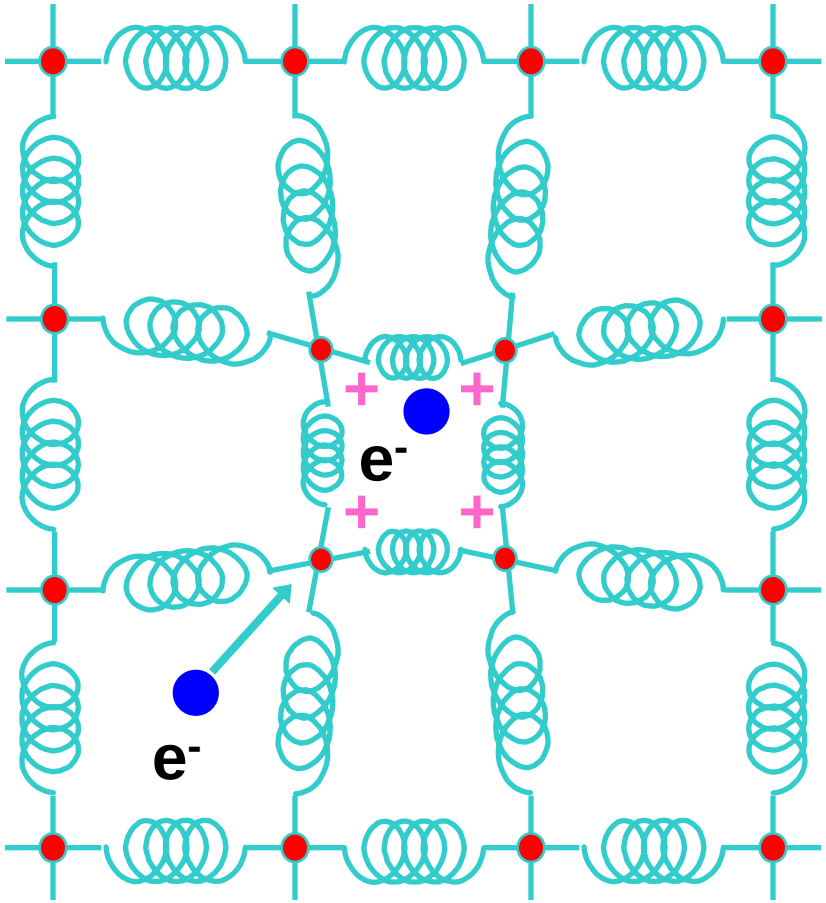
1911
A Big Surprise!

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*

Gilles Holst, H. Kamerlingh-Onnes (1911)



Physics of Superconductivity (1957 – 2006)



Electrons Pair Off!

BCS Equation

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

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

$$\lambda = 0.28,$$

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

It takes two to Tango

conductor

Semiconductor

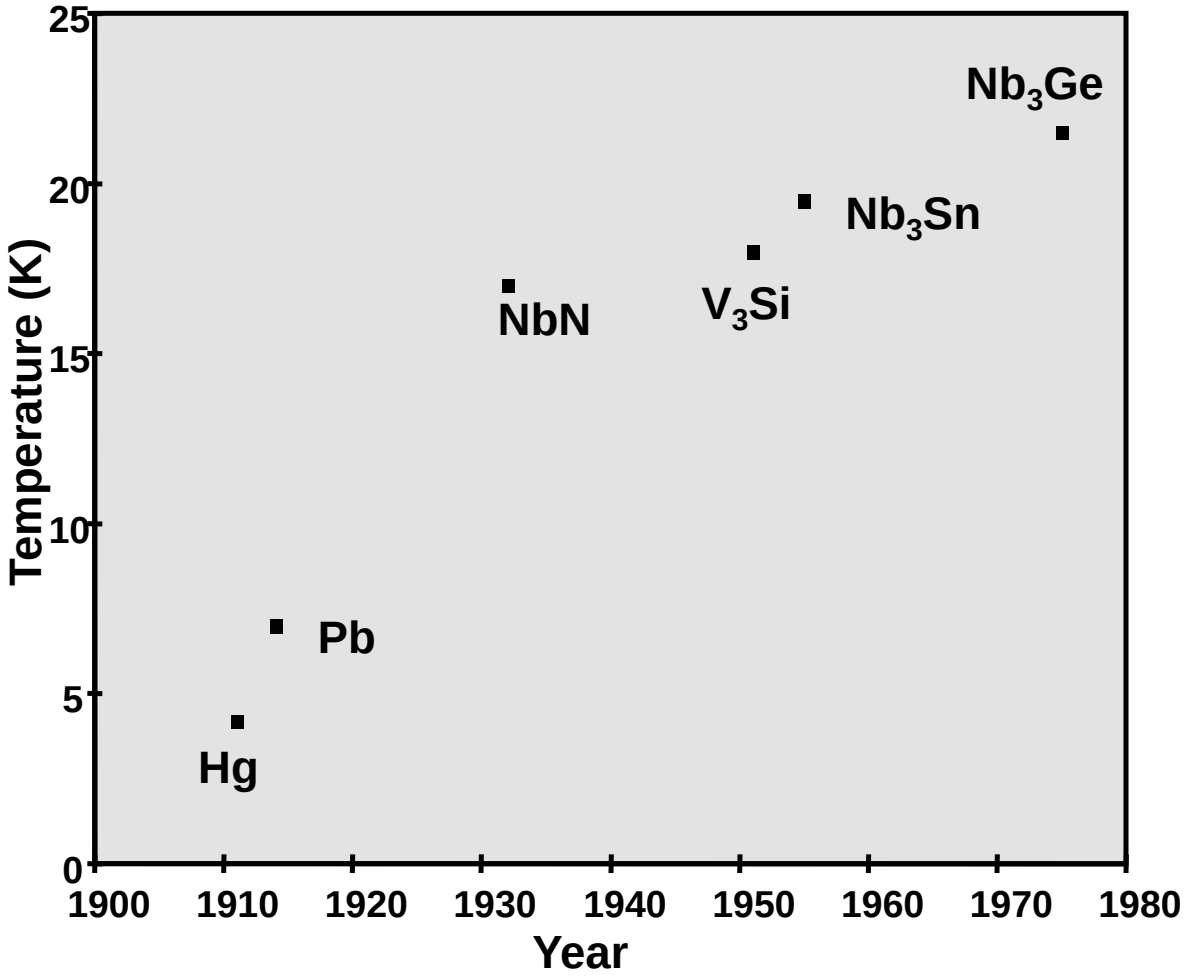
SUPERCONDUCTOR

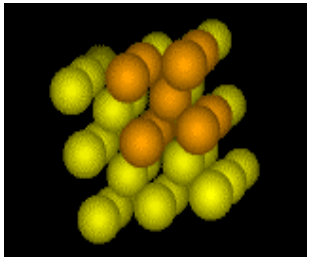
Important Numbers in Superconductivity

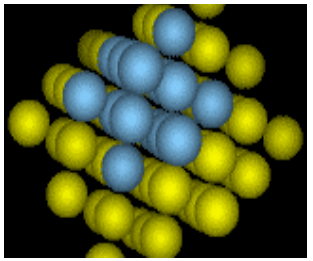
Transition Temperature, T_c	Way below 300 K
Critical Current Density, J_c	10^{-2} - 10^{6} A/cm^2
Critical Magnetic Field, H_c	10^{-4} - 10 T
London Penetration Depth, λ	10 - >1000 Å
Pippard Coherence Length, ξ	10 - >1000 Å
G-L Parameter, $\kappa = \lambda/\xi$	0.01 - 100

NB! All these numbers depend on each other. E.g., $H_c \sim \lambda\, \xi$

T_C vs. Year: 1911 - 1980

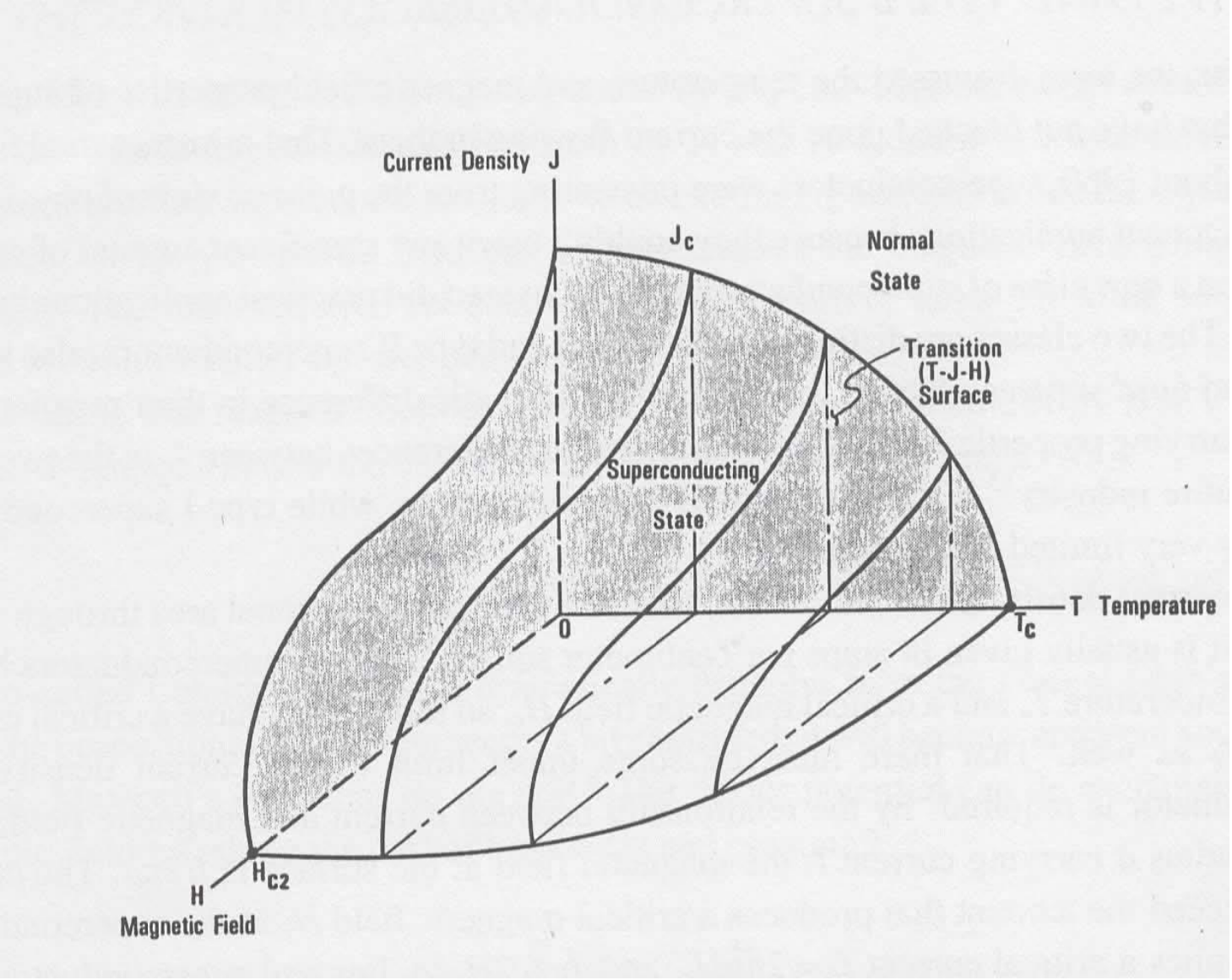






Cubic Metals

Properties

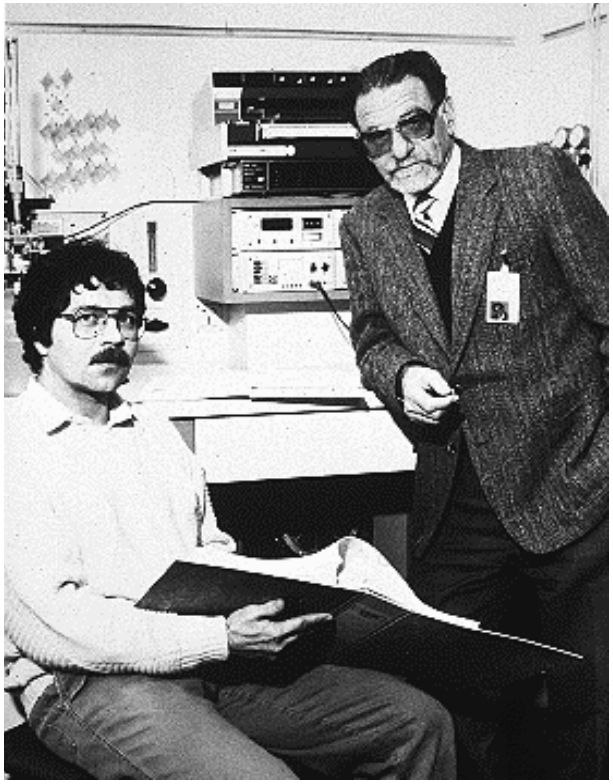

Current Density J
J_c
Normal
State
Transition
(T-J-H)
Surface
Superconducting
State
0
T_c
T Temperature
H_{c2}
H
Magnetic Field

MRI & “Big Physics”

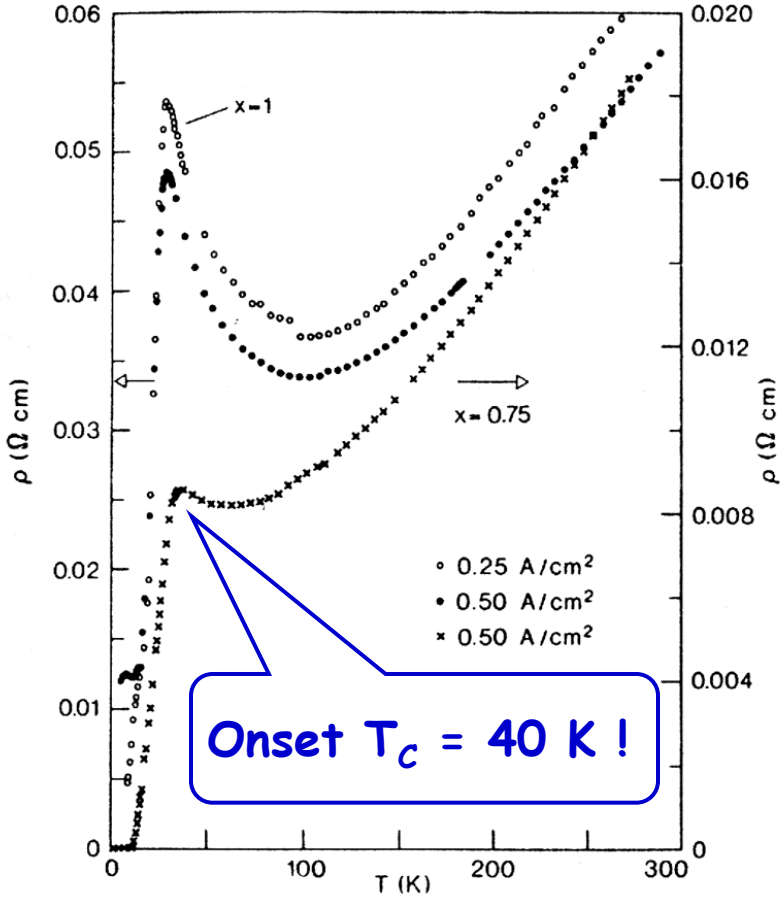
Magnetic Resonance Imaging
Philips

Tevatron
Fermi National Laboratory

1986
Another Big Surprise!



Bednorz and Mueller
IBM Zuerich, 1986



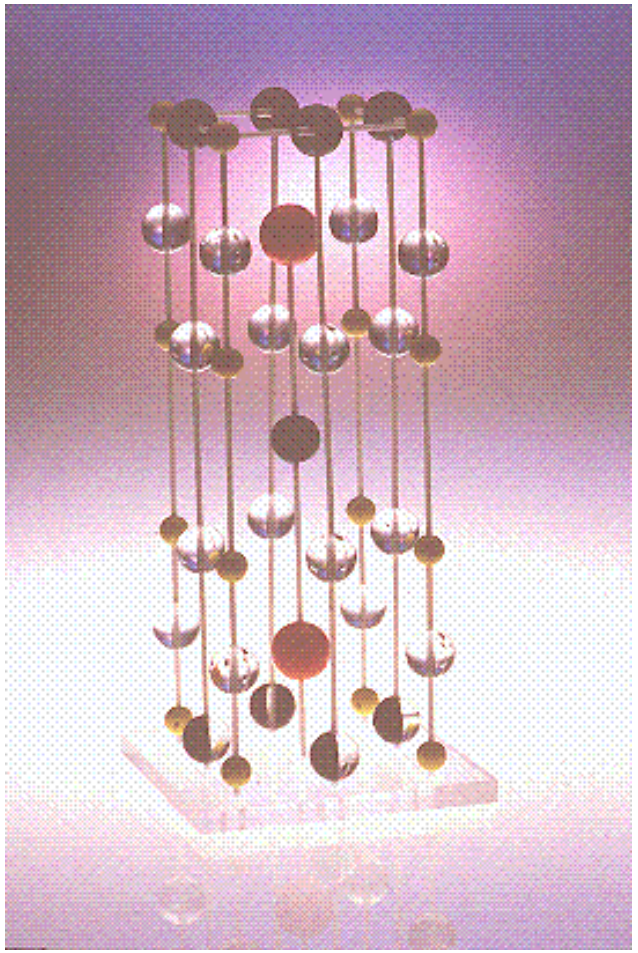
1987
“The Prize!”

Associated Press

J. Georg Bednorz, left, and K. Alex Müller after learning they had won the Nobel Prize in physics.

2 Get Nobel for Unlocking Superconductor Secret

March 3, 1987
“123” Discovered



Woodstock of Physics NYC, 1987

Physicists' Night Out!

Woodstock of physics revisited

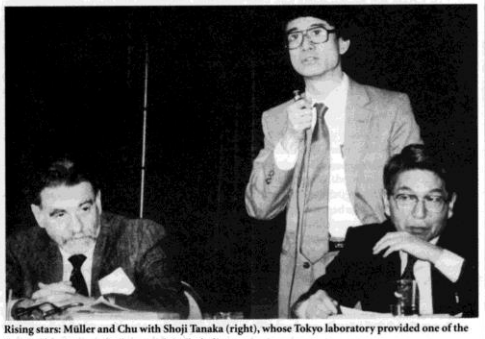
Ten years have passed since the now famous American Physical Society meeting that heard the first breathless accounts of high-temperature superconductivity. Now, in calmer times, practical applications are emerging.

Paul M. Grant

Snap quiz: who can tell me the winner of the 1987 Super Bowl? Not most physicists, I suspect, for whom it was certainly eclipsed by two events of far greater consequence that shared the early months of that year. One, the discovery of Supernova 1987A, perhaps portended the other: the announcement of superconductivity above liquid-nitrogen temperature on planet Earth — a dream fulfilled for many condensed-matter physicists like myself, whose careers had orbited around this elusive star.

The successful sighting[1] fell to W. K. Wu and C. W. (Paul) Chu and their teams of students and postdocs at the Universities of Alabama and Houston, following only five months after the publication in autumn 1986 by Georg Bednorz and Alex Müller[2] at IBM Zürich of their discovery of superconductivity in a previously unexplored class of compounds, the layered copper-oxide perovskites.

The 'inside' story of the hectic interval between the first week in January 1987 — when an announcement of the confirmation of Bednorz and Müller's discovery first brought 'high-temperature superconductivity' to wide public attention — and the week of the American Physical Society's March meeting, remains to be told. Suffice it to say that this period, and the last three months of 1986, were replete with incredulity, credulity, excitement, secrecy and a sense of immediacy in competition with one's peers, all of which resulted in, frankly, a substantial amount of intrigue and suspicion. All who participated surely came to understand, if they had not done so before, that physics is not only a science but, perhaps more significantly, an intensely human pursuit — something they do not teach you in graduate school.



Rising stars: Müller and Chu with Shoji Tanaka (right), whose Tokyo laboratory provided one of the first confirmations of Bednorz and Müller's discovery.

The programme of the March meeting, held each year in a different US city, is 'cast in concrete' early the preceding December; thereafter, an absolute policy of no alterations prevails. By the deadline of 5 December 1986, for the 1987 meeting at the Hilton hotel in New York City, only one abstract had been accepted on the new materials: "Specific heat of Ba–La–Cu–O superconductors" by Rick Greene and his collaborators at IBM Yorktown. But the explosion of results that appeared in the new year prompted the meeting's organizers to take an unprecedented step. Brian Maple of the University of California, San Diego, was asked to put together a special post-deadline evening session devoted entirely to the discovery.

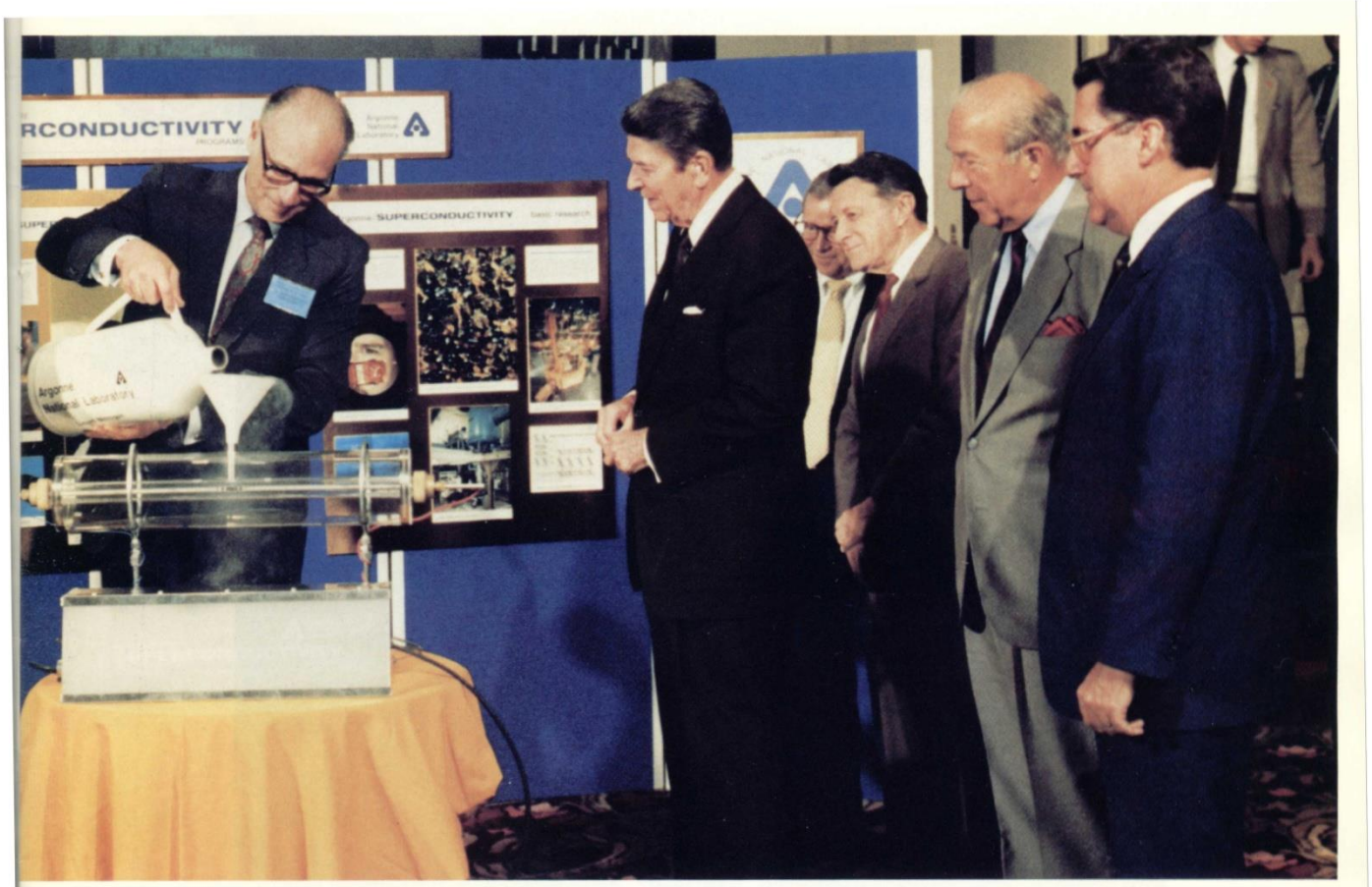
All those wishing to report results would be granted five minutes each, in order of the arrival of their request to take part — and did the requests rain in, reaching a downpour in the two weeks before the meeting, as confirmations of the Wu–Chu measurements were made. All in all, 51 presentations were to be given throughout the evening and early morning of Wednesday and Thursday, 18 and 19 March. That memorable and riotous session was to become our "Woodstock of physics", so named in honour of the village only 50 miles north where, in an obscure farmer's muddy field in 1969, the rock concert occurred that defined a generation of youth the world over.

Fever pitch: the room filled to overflowing with physicists eager for news of superconductivity.

Opening act

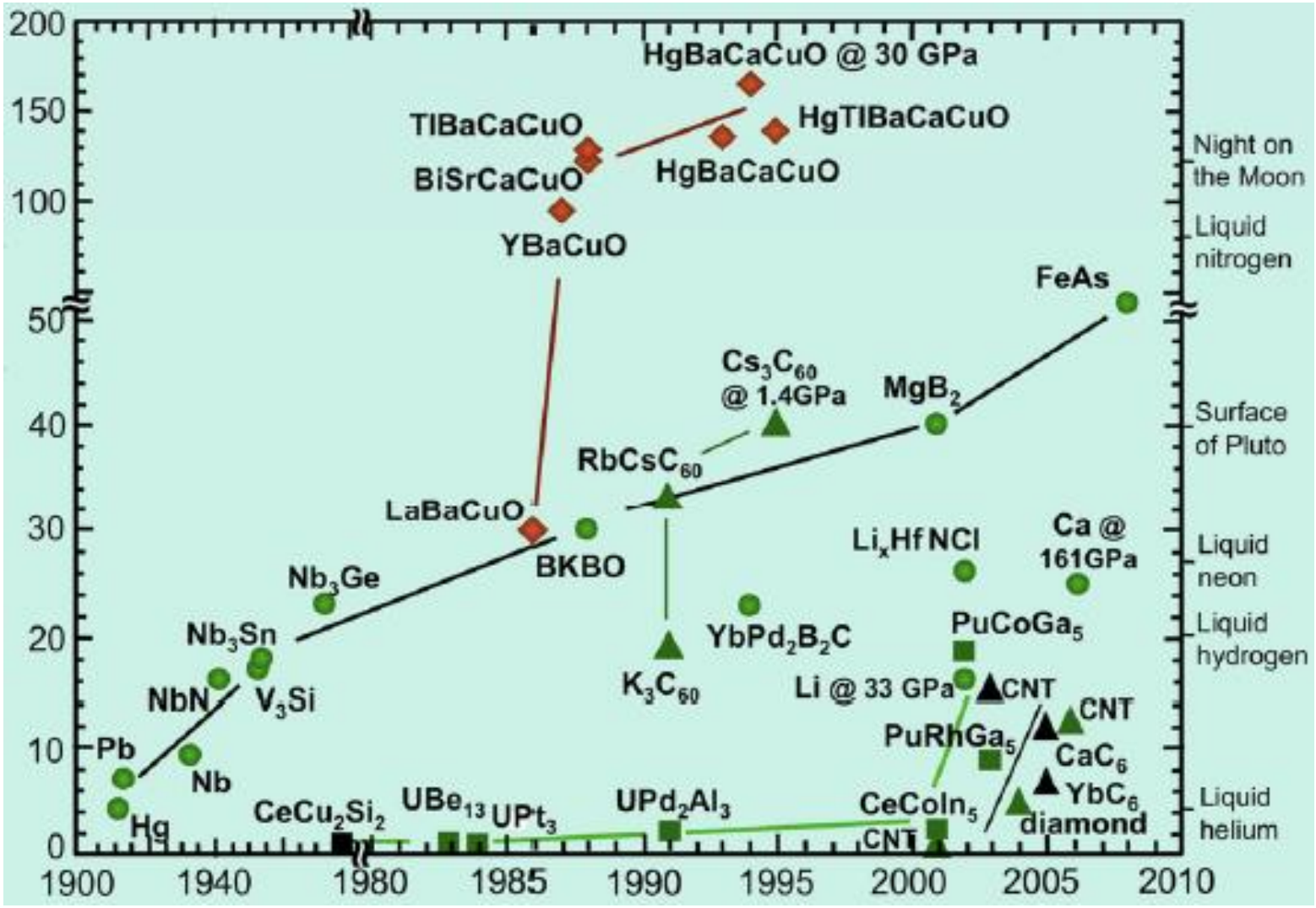
A few personal observations and anecdotes may help to convey the colour of that week in midtown Manhattan. Excitement was running high even before Wednesday night. On Monday, the opening day, the press were already beginning to catch some of us to be interviewed. That noon my colleague Ed Engler and I went to lunch at a nearby Brew 'n' Burger and found Alex Müller sitting by himself in a corner booth, attempting to escape the turmoil at the Hilton. At the time he was not yet widely recognizable to those attending the meeting or to the press — a situation that would soon change.

“The Great Communicator”

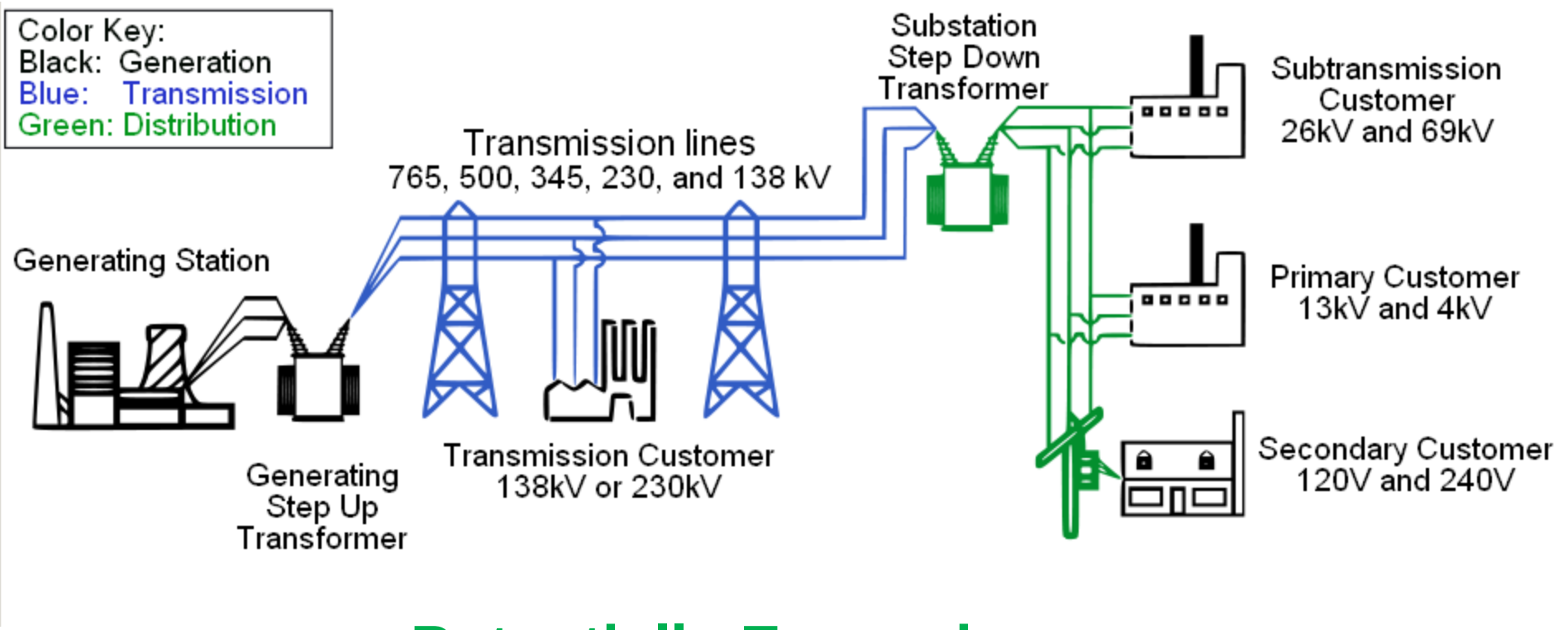


Alan Schriesheim, Director of Argonne National Laboratory, demonstrates superconductivity to the President, Chief of Staff Howard Baker, Secretary of Defense Caspar Weinberger, Secretary of State George Shultz and Secretary Herrington.

Today

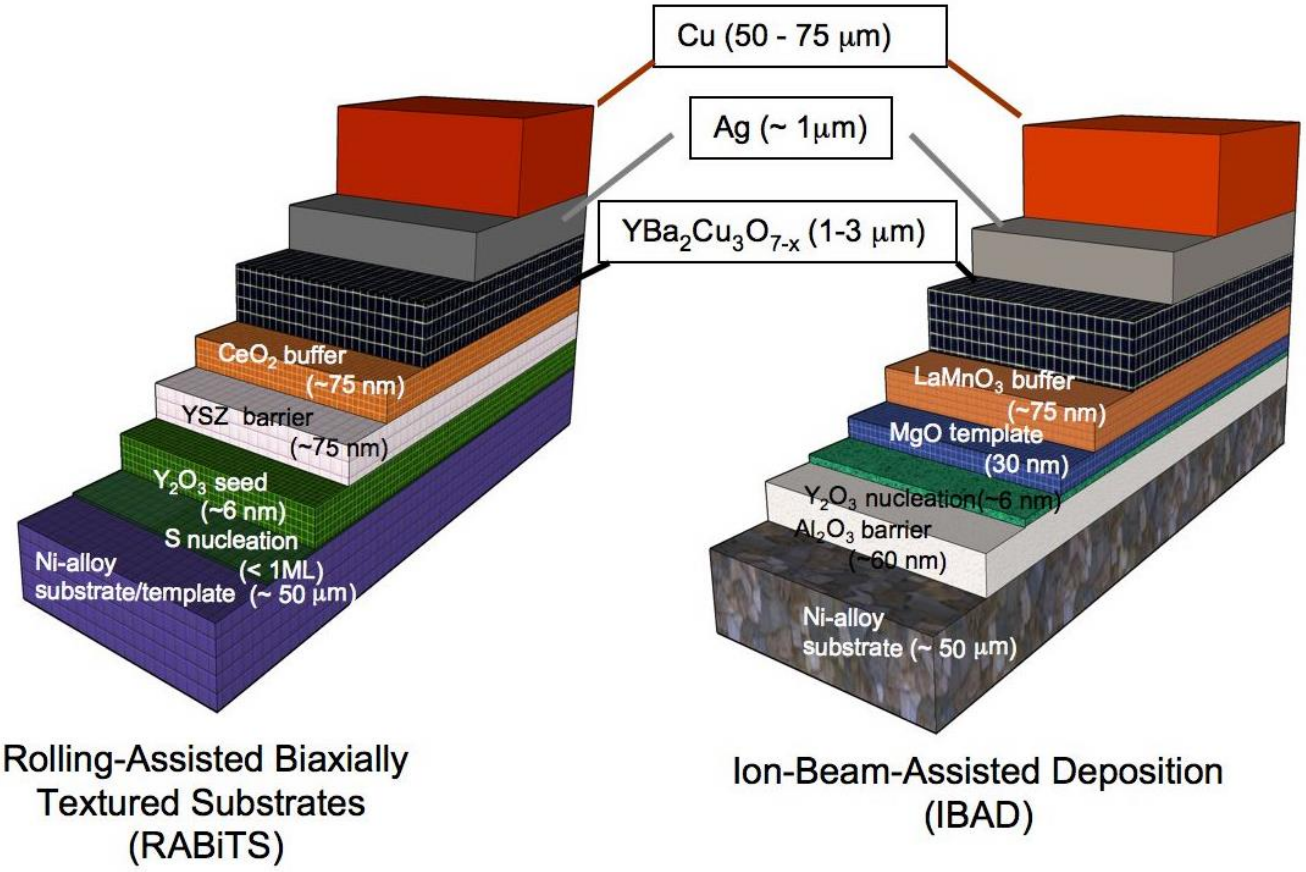

Tc (K)
Year
HgBaCaCuO @ 30 GPa
TlBaCaCuO
HgTlBaCaCuO
BiSrCaCuO
HgBaCaCuO
YBaCuO
FeAs
Cs_3C_{60} @ 1.4GPa
MgB_2
$RbCsC_{60}$
LaBaCuO
BKBO
Li_xHfNCl
Ca @ 161GPa
Nb_3Ge
Nb_3Sn
$YbPd_2B_2C$
$PuCoGa_5$
K_3C_{60}
Li @ 33 GPa
CNT
CNT
NbN
V_3Si
$PuRhGa_5$
CaC_6
Pb
Nb
YbC_6
$CeCu_2Si_2$
UBe_{13}
UPt_3
UPd_2Al_3
$CeCoIn_5$
diamond
CNT
Hg
Night on the Moon
Liquid nitrogen
Surface of Pluto
Liquid neon
Liquid hydrogen
Liquid helium
200
150
100
50
40
30
20
10
0
1900
1940
1980
1985
1990
1995
2000
2005
2010

Where Can We Apply Superconductivity to Electric Power?



Potentially Everywhere

Gen II Coated Conductor



Rolling-Assisted Biaxially Textured Substrates (RABiTS)

Ion-Beam-Assisted Deposition (IBAD)

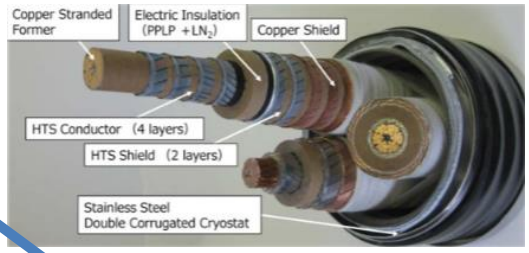
American Superconductor

SuperPower

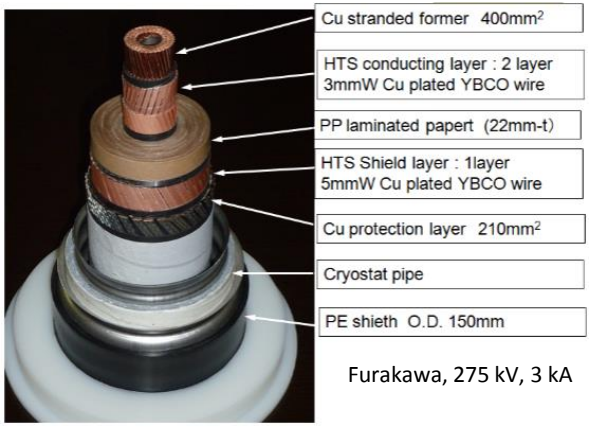
~ 1997

HTSC SuperCables: Brief History

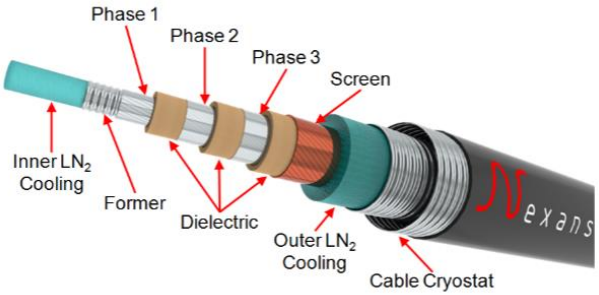
Pirelli

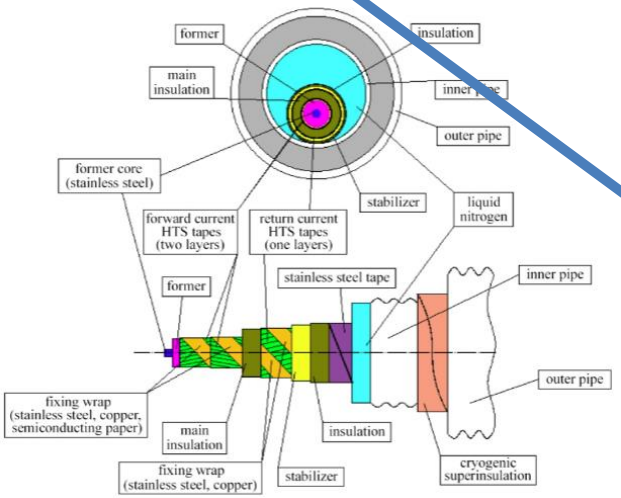


Sumitomo 66 kV 3-in-1

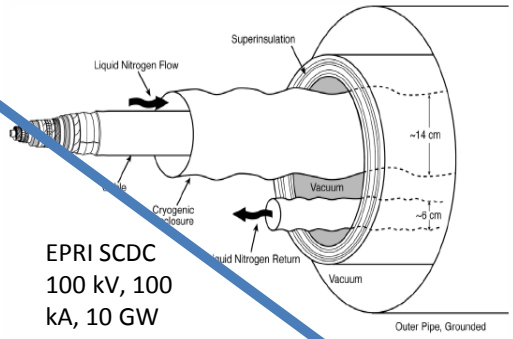


Furakawa, 275 kV, 3 kA





St. Petersburg, Russia



EPRI SCDC
100 kV, 100 kA, 10 GW

~ 2014

Pacific Intertie

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

Tear down the PI and replace with HTSC underground cables to capture this saving?

Ain't gonna happen, baby!
Not a "compelling need!"

Even should the cost of the wire be zero!

Required Reading!
(Thanks to Steve Eckroad, EPRI)

- Two EPRI Reports (available free from epri.com or w2agz.com)
  - (2012) Superconducting Power Equipment; Technology Watch 2012 (1024190)
  - (2013) SIU: Superconductivity for PDA (03002001)
- Bottom Lines:
  - Work continues on wire improvement and power application demonstration, although not at the pace of a decade ago.
  - HTSC materials performance and costs have matured.
  - What's needed is a strong business case for HTSC power applications.
  - Does there exist a "compelling need," now or in the next decade, to effect a major and continuing deployment of HTSC in the electricity enterprise?

"The Short Story"

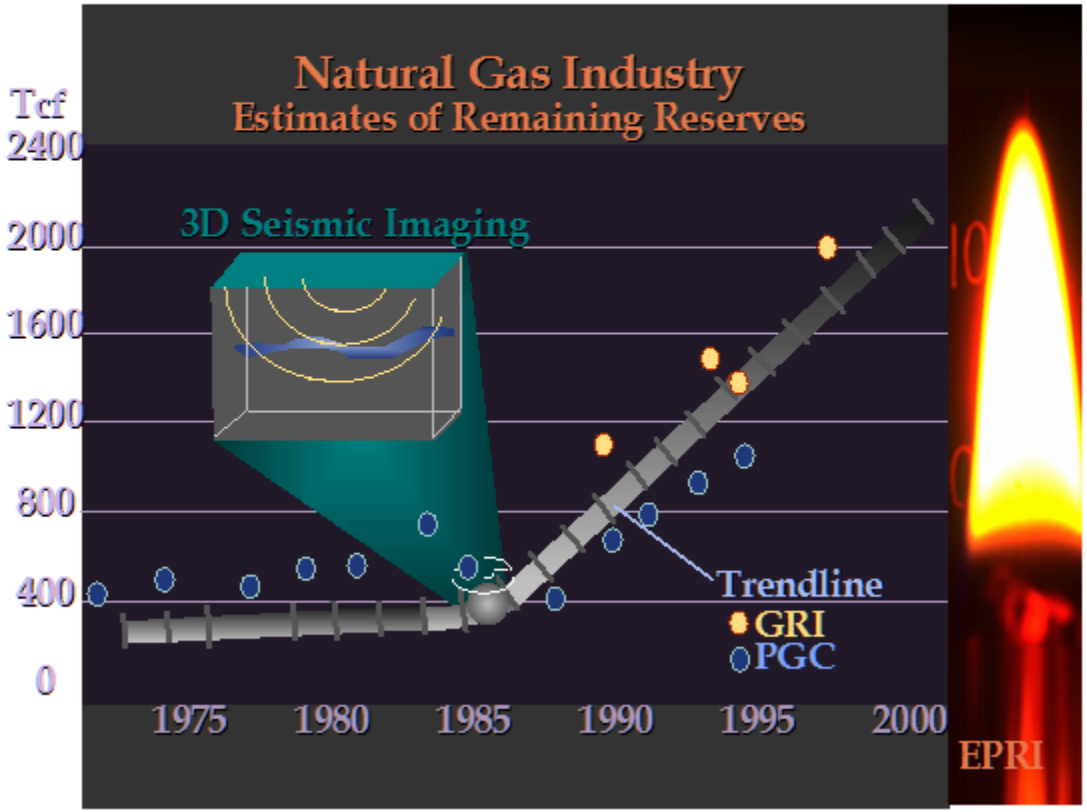
- Following the 1911 discovery, Kamerlingh Onnes attempted the construction of an electromagnet...unsuccessfully.
- Throughout the second half of the 20th Century and up to the present, many successful demonstrations of superconducting cables, transformers, current limiters, storage units, rotating machinery, etc., have been carried out. Yet, to date, no significant markets (> 10^8 USD/yr) have emerged for deployment worldwide in the Electricity Enterprise.
  - For a 1997 review, see *"Superconductivity and Electric Power: Promises, Promises...Past, Present and Future,"* P. M. Grant, IEEE Trans. Appl. Supercon. 7, 112 (1997). Available on request from www.w2agz.com.
  - Today, the principal "power" applications of superconductivity remain cabling and deflection magnets for hadron colliders and solenoids for medical MRI.
- *As of today, all US HTSC power app demos have been concluded or are "on hold."*
- What might constitute a "Longer Story?"
  - Advancing a current "technology addiction."
  - Satisfying a compelling social need.
  - Identifying a new opportunity.

Energy Fraternal Twins

However, we do indeed have a "compelling new opportunity!"

P.M. Grant, EPRI, 1998

North American CH_4
There's Lots of It



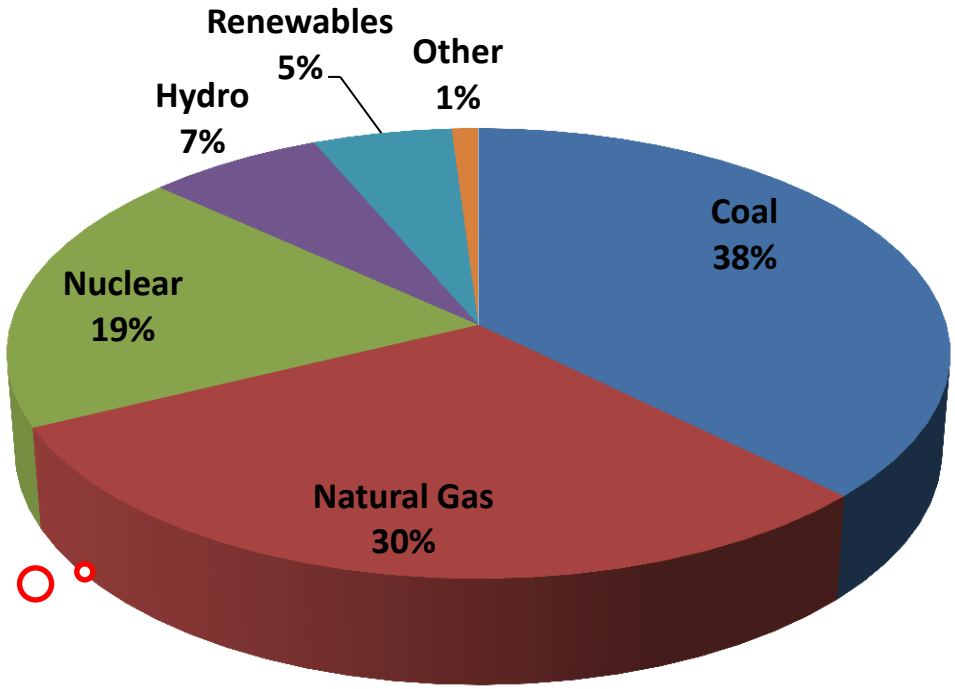
3D Seismic Imaging Plus Directional Drilling

50 Years at '97 Prices!

...& hydraulic fracturing , aka "fracking"

Natural Gas & Electricity

"Fraternal Twins,"
Smart Grid News
16 April 2013

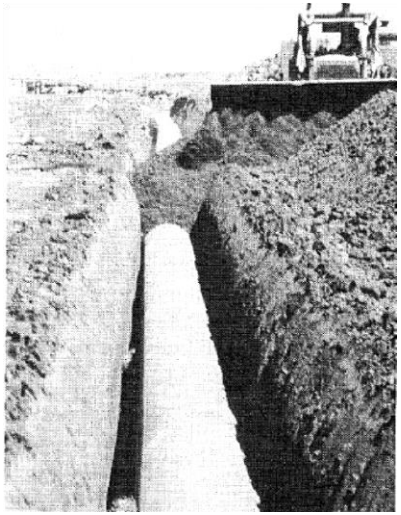


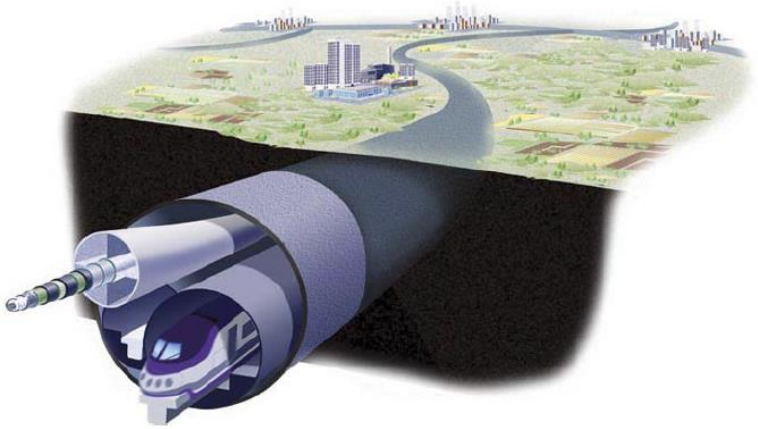
Wow!

2012 USA Electricity Generation by Primary Fuel Source

The “Dual Use” Concept Embodied

- Almost all NG used for electricity generation is “combusted” at a “local” delivery point using modern, efficient, combined cycle gas turbine (CCGT) technology.
- Why not “combust” that gas portion so-used at the “well-head” instead and deliver the “electrons” over a low-loss HTSC dc cable? As well as reducing volume...and...frictional loss due to NG transported by pipeline.
- ...and...consider “recycling” well-head generated CO_2 emissions into alcohols...and “pipe” those down the same ROW!



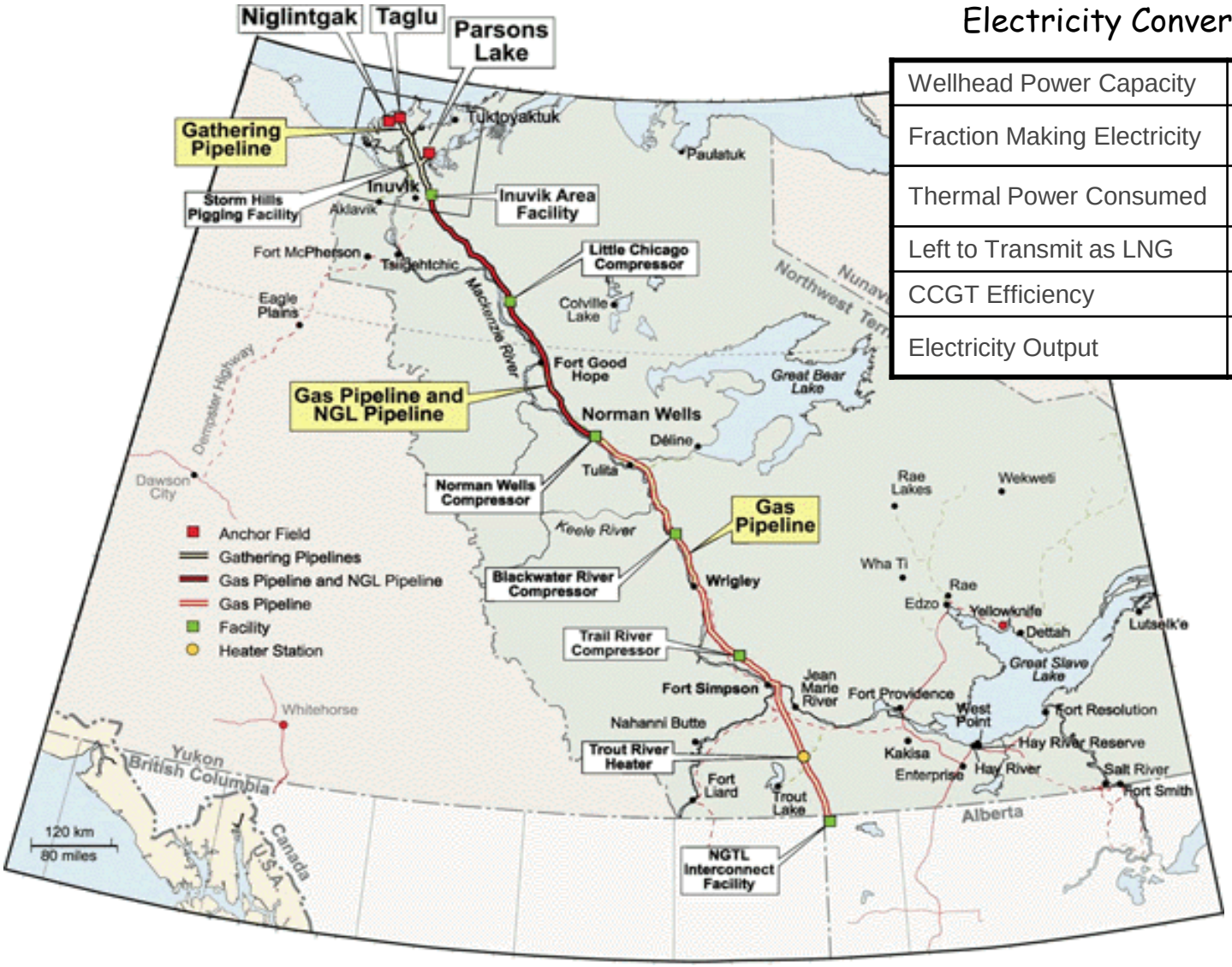


The ROW Dual Use concept has been documented in several peer reviewed journals as well as member magazines of the APS, IOP, IEEE, and Nature...contact the author/speaker for a linkable anthology.

Does "Keystone XL" Provide a "Compelling Opportunity" to "Raise Our Fraternal Twins?"

Let's encourage DOE to enlist EPRI, GTI, EIPC, INGAA,...in a collaboration to conduct an "engineering economy" study focused on the dual-use ROW concept.

...and in the long term...



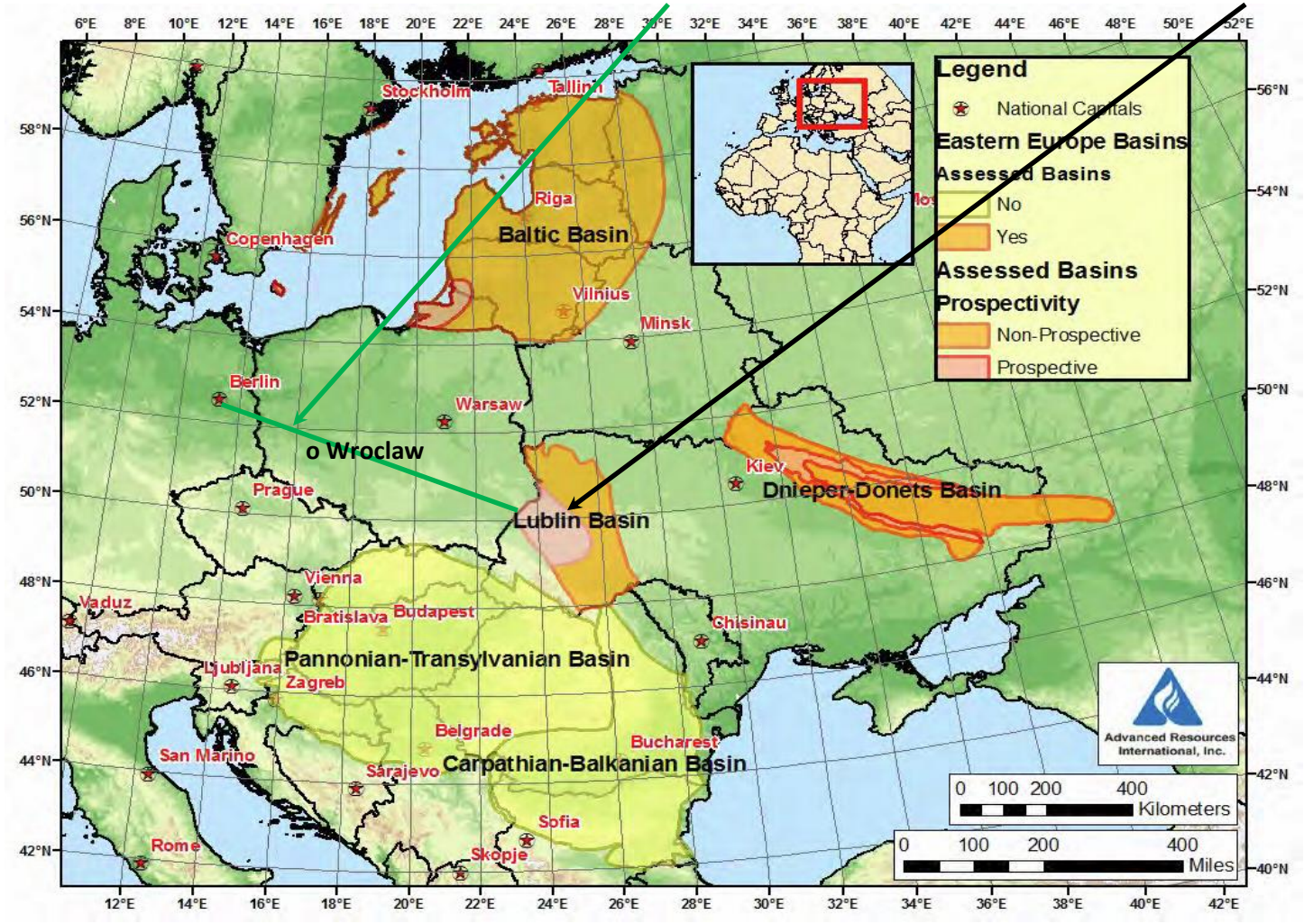
Electricity Conversion Assumptions

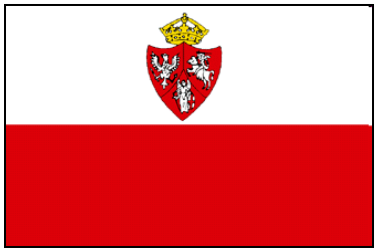
Wellhead Power Capacity	18 GW (HHV)
Fraction Making Electricity	33%
Thermal Power Consumed	6 GW (HHV)
Left to Transmit as LNG	12 GW (HHV)
CCGT Efficiency	60%
Electricity Output	3.6 GW (+/- 18 kV, 100 kA)

"Cryodelivery Systems for the Cotransmission of Chemical and Electric Power," *P.M. Grant, AIP Conf. Proc. 823, 291 (2006).*

Let's Not Forget Europe!

The Wola Obszańska (Lublin) gas field in Poland/Ukraine was discovered in 1989. It began production in 1992 and produces natural gas. The total proven reserves of the Wola Obszańska gas field are around 37 billion cubic feet ($1 \times 10^9 m^3$). "Dual-Pipe" to Berlin?





2100: The World Runs Out of CH_4

- The Dual Use ROWs Remain
- Replace the CCGTs with 1-2 GW Nukes
- Use Half the Power to Electrolyze (Frack) Nearby H_2O Reserves to Release H_2 ,
- Then Liquify and Use to Refridgerate Upgraded HTSC Cables (If Necessary!)

The Energy SuperGrid

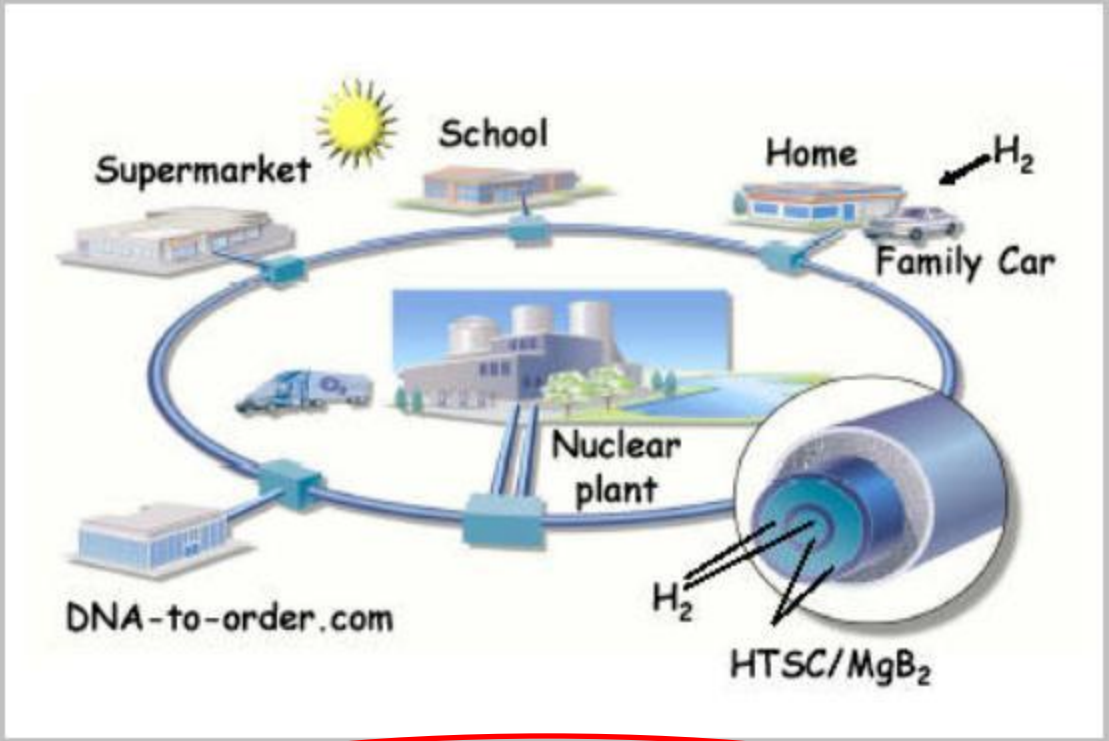
http://w2agz.com/PMG%20SuperGrid%20Home.htm

W2AGZ Technologies

The Energy SuperGrid

W2AGZ Technologies

SG Home
The Vision
Tech Stuff
SuperGrid 2
Press Coverage
Bibliography



Chauncey Starr
Paul Grant
Jesse Ausubel
Tom Overbye
Contact Me

A Symbiosis of

Nuclear/Hydrogen/Superconductivity/Solar/Biomass
Technologies supplying Carbon-free, Non-Intrusive Green Energy
for all Inhabitants of Planet Earth

W2AGZ Technologies

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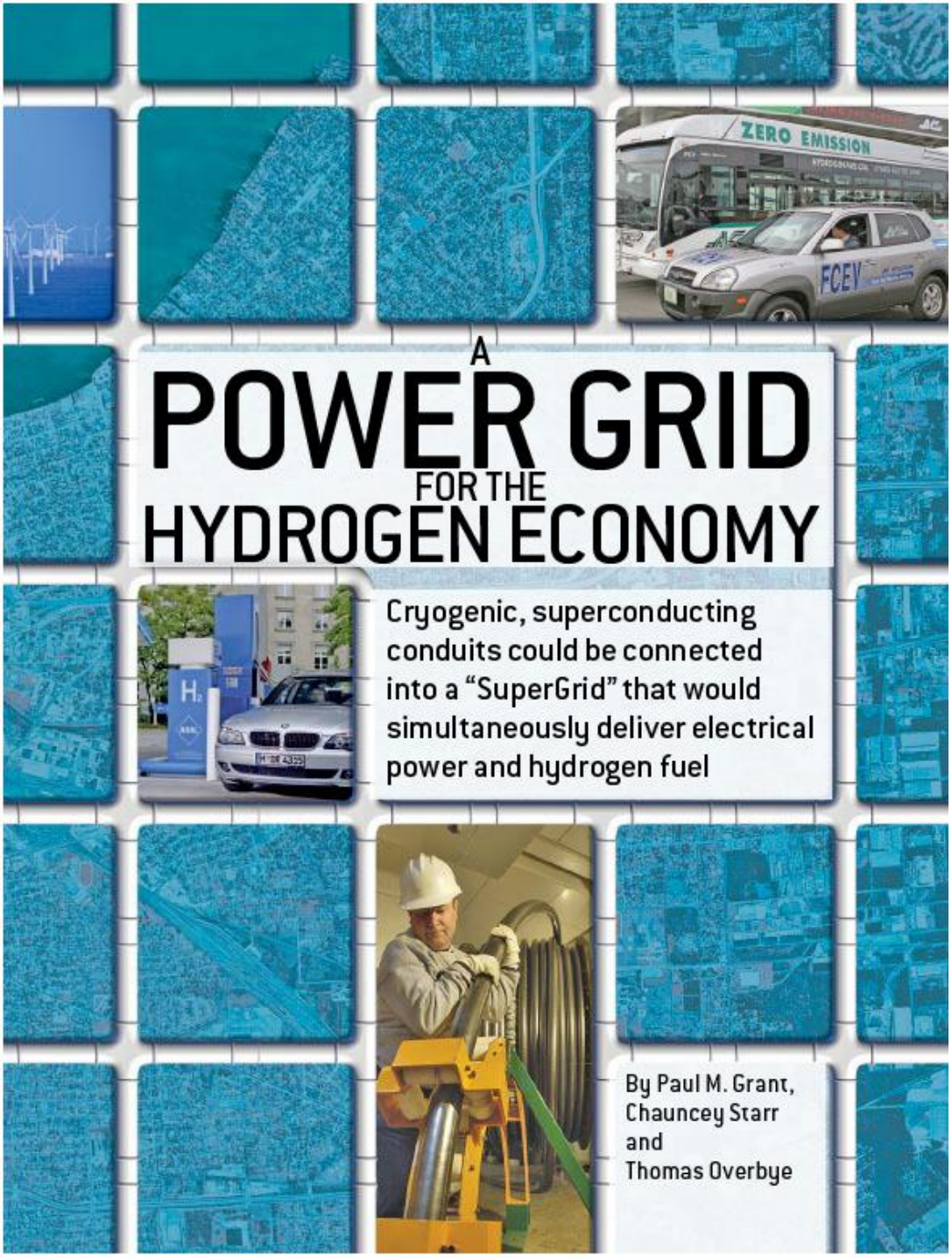


On the afternoon of August 14, 2003, electricity failed to arrive in New York City, plunging the 10 million inhabitants of the Big Apple—along with 40 million other people throughout the northeastern U.S. and Ontario—into a tense night of darkness. After one power plant in

Published in

SCIENTIFIC AMERICAN

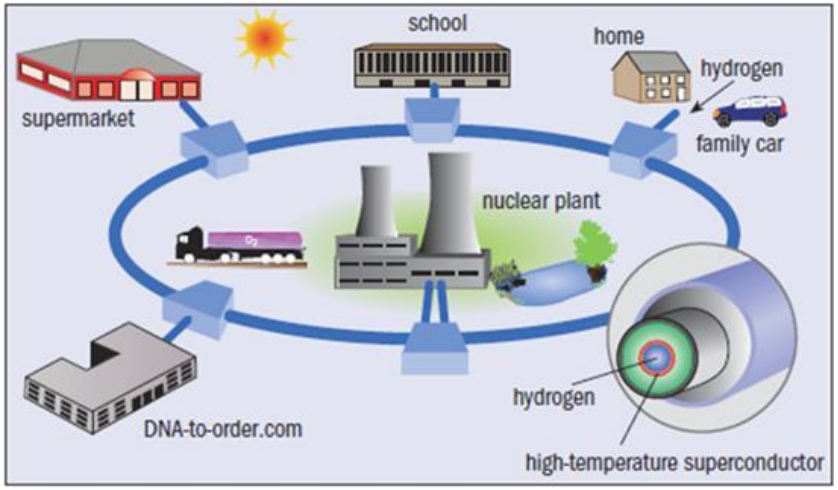
July, 2006

"System Crash"

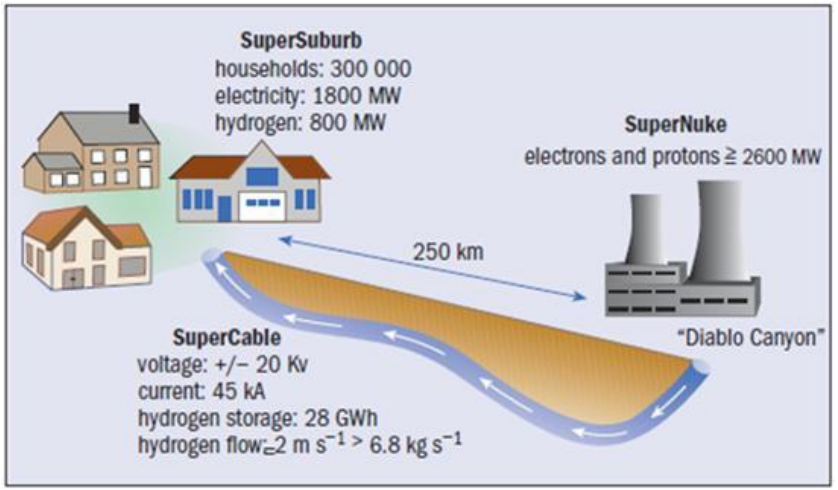
Omni Productions, Vancouver, BC

CBC Broadcast October, 2008

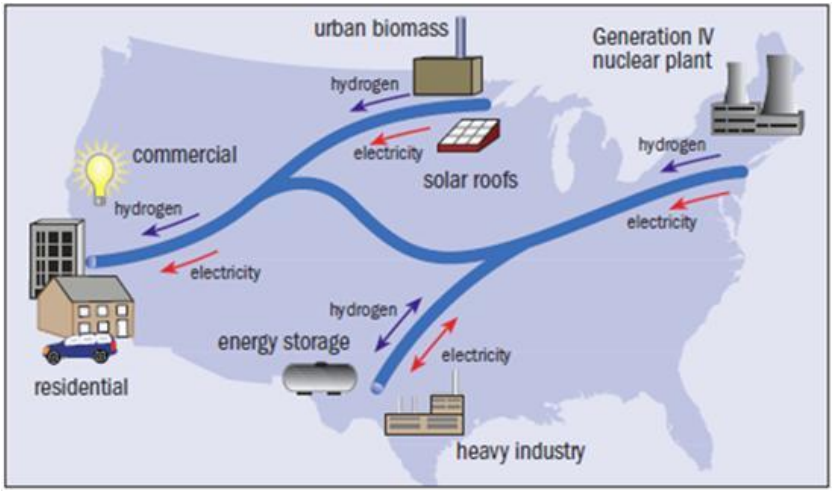
Exascale Energy for Our Great-Great GrandKids!



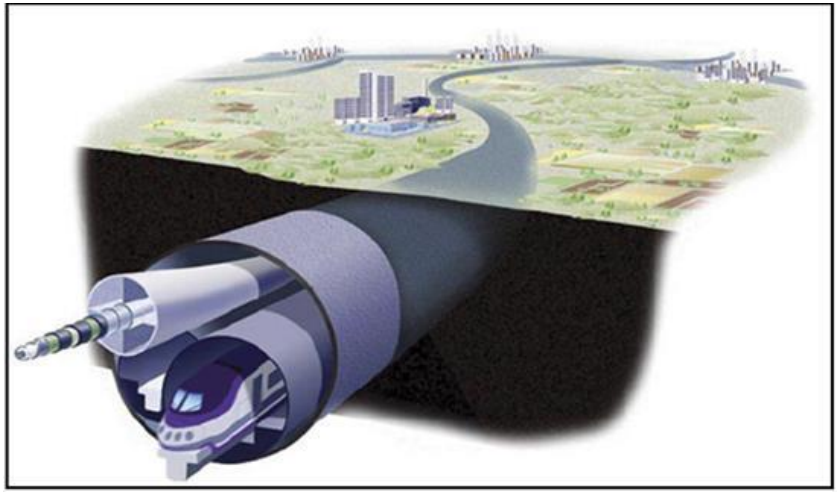
SuperCity



SuperSuburb

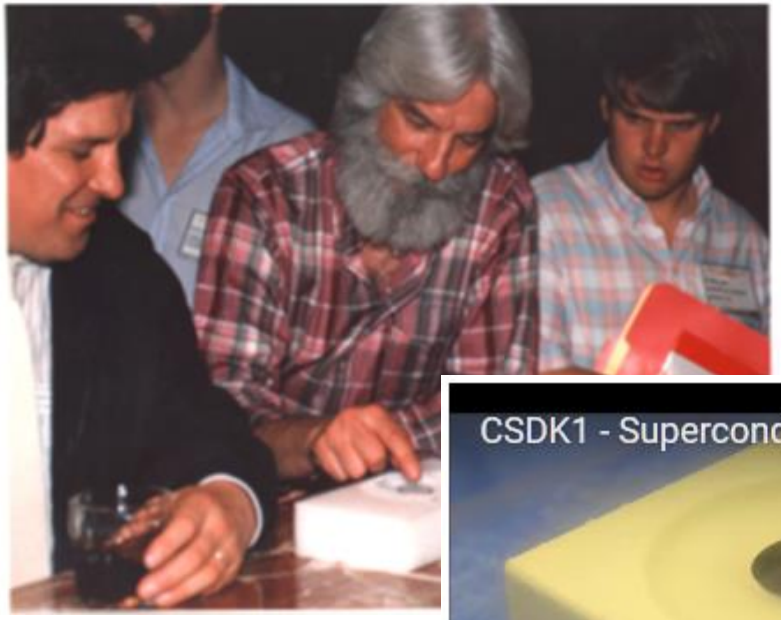


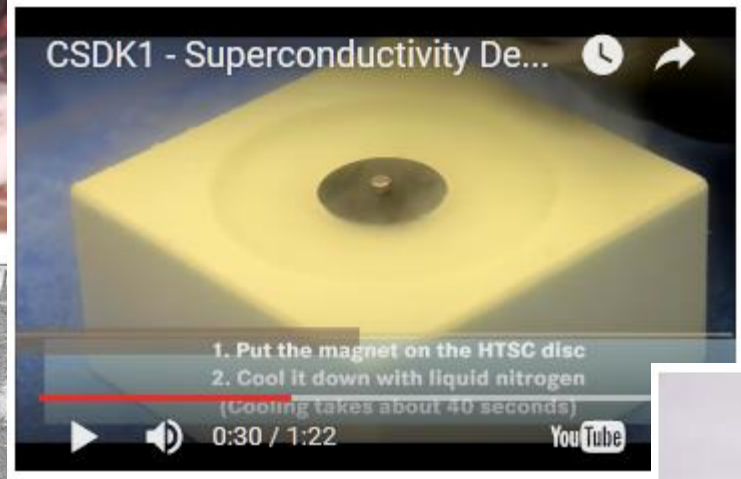
SuperGrid

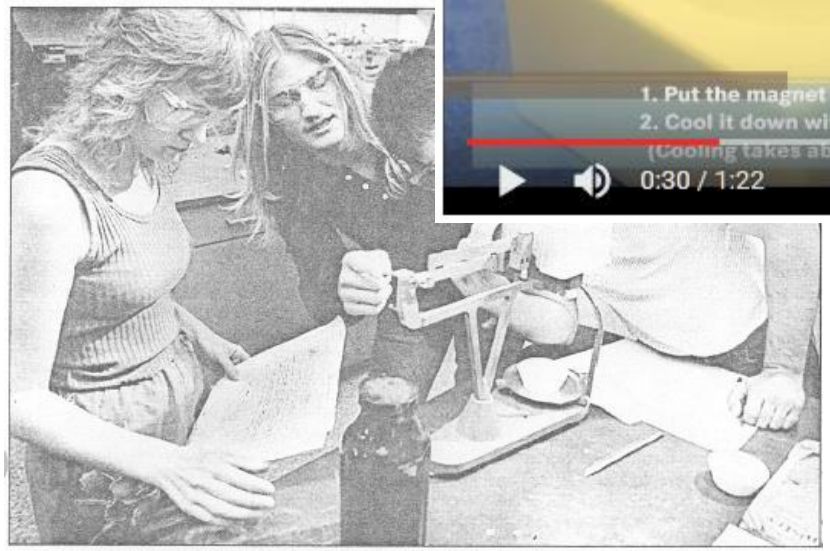


SuperTrain

"The Only Commercial Application of HTSC"







Pupils at Gilroy High School in California make their own high-temperature superconductor

Now it's graphene!

A Model For the Future

“A Thread Across the Ocean”

Cyrus Field
American Capitalist

Isambard Kingdom Brunel
English Engineer

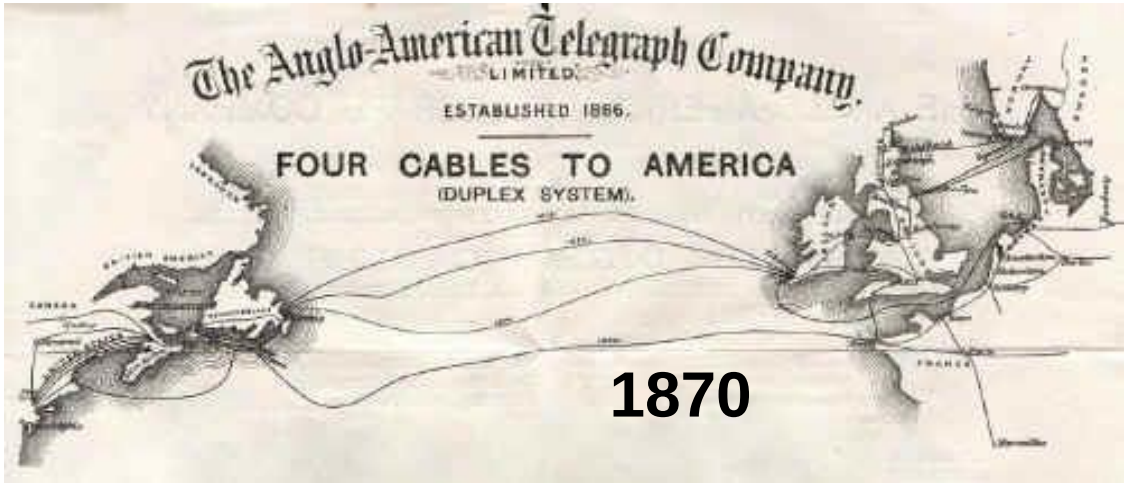
William Thomson
Irish Physicist

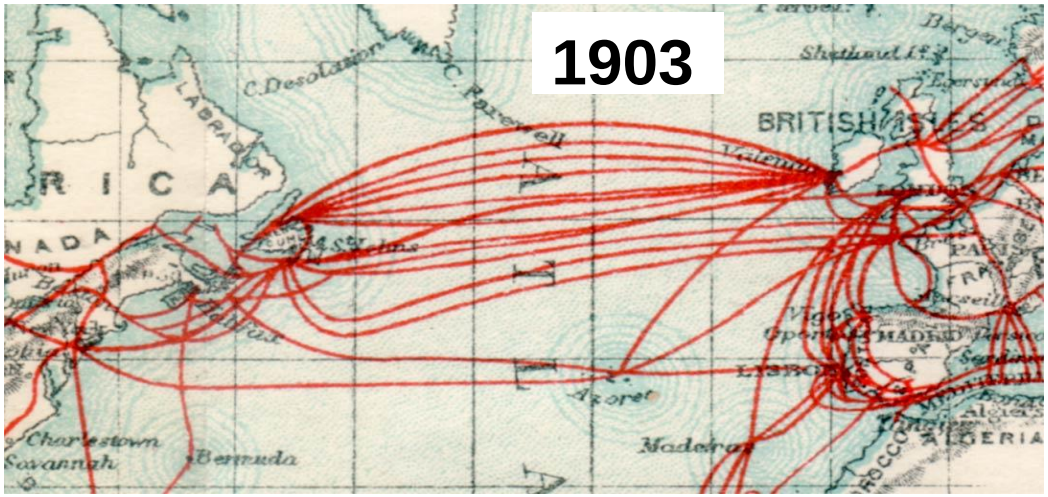
John Steele Gordon

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 as $10 M !

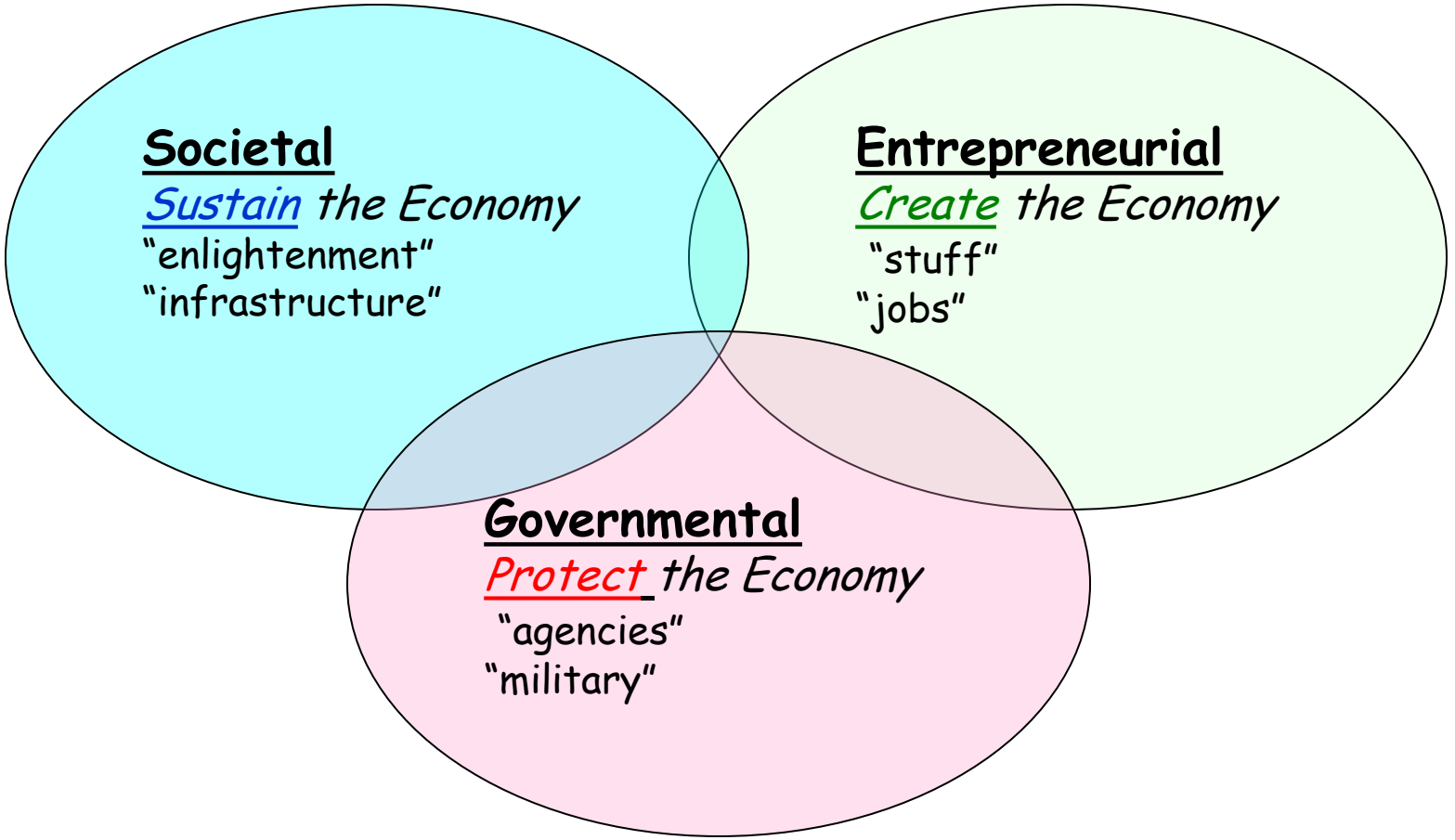
The After-Story





The First Links in the World Wide Web!

The Economic (Venn)Troika That Drives and Exploits Technology Innovation



Finale

Superconductors
- The Long Road Ahead –
Foner & Orlando (1988)

"Widespread use of these [high temperature] superconducting technologies will have far more to do with *questions of public policy and economics* than with the nature of the new materials."

“You can’t always get what you want…”

“…you get what you need!”