SPOKANE
CEC/ICMC 2011

Cryogenic Engineering Conference
& International Cryogenic Materials Conference

SPOKANE WASHINGTON
JUNE 13-17, 2011

Superconductivity

Yesterday - Today - Tomorrow

Paul Michael Grant

Aging IBM Pensioner
(research supported under the IBM retirement fund)

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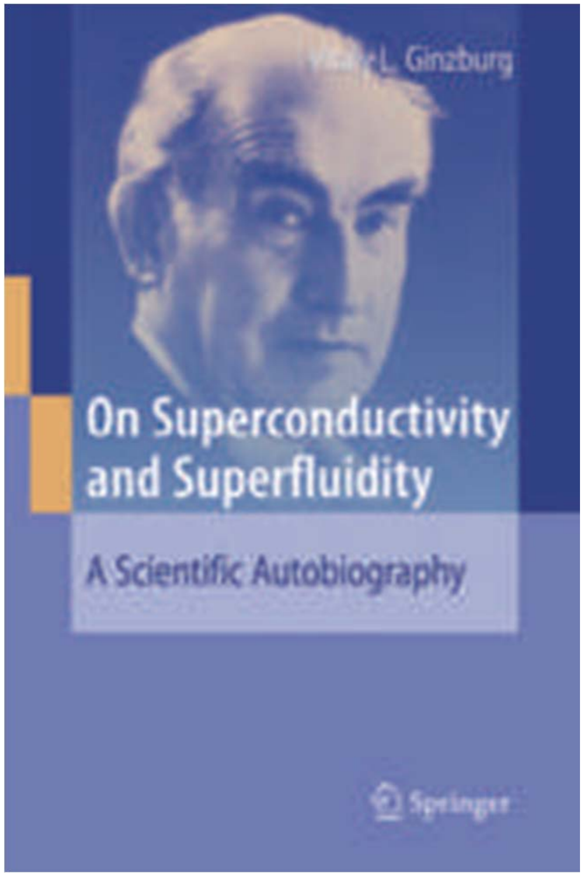
100 Years of Superconducting Materials, Machines, and Cryogenics

Wednesday, 15 June 2011
11:00 AM – 11:30 AM, PL@A-01, Bay 111 B-C, Spokane Convention Center

Grandfather of Us All

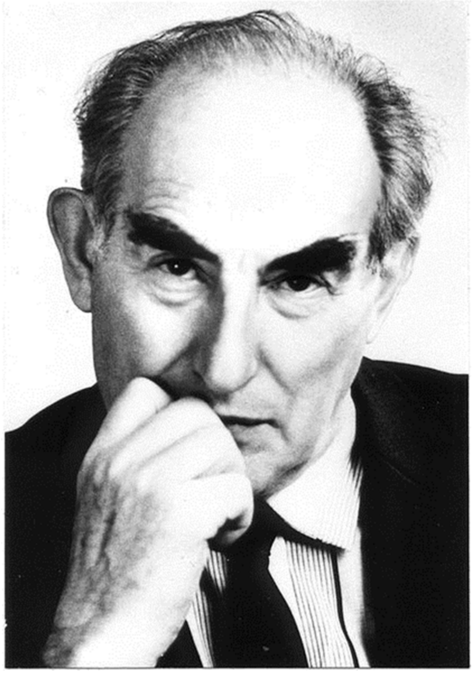


Vitaly L. Ginzburg

On Superconductivity and Superfluidity

A Scientific Autobiography

Springer



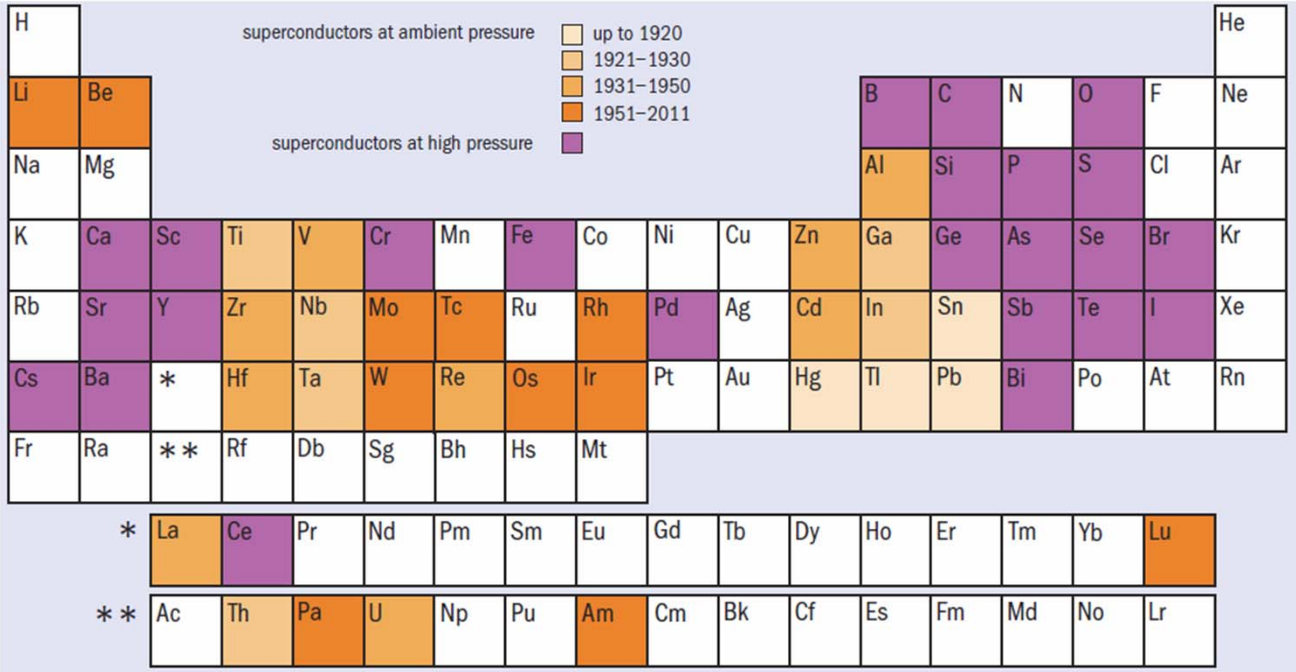
Vitaly Lazarevich “VL” Ginzburg

1916 – 2009

“A Man for All Seasons”

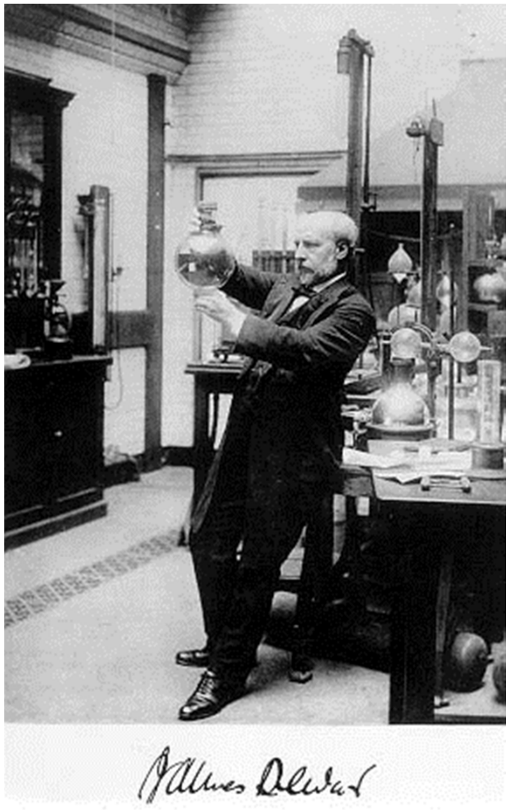
Down the path of least resistance

Since its discovery 100 years ago, our understanding of superconductivity has developed in a far from smooth fashion. **Paul Michael Grant** explains exactly why this beautiful, elegant and profound phenomenon continues to confound and baffle condensed-matter physicists today



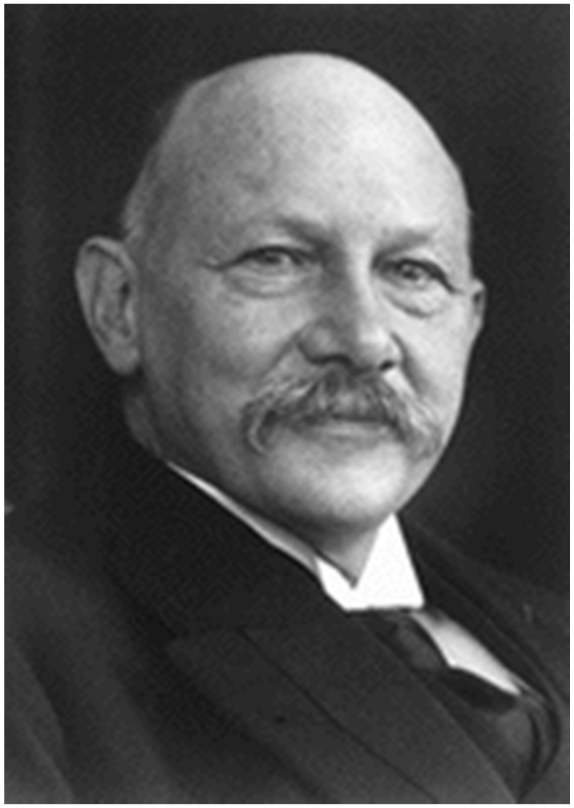
Yesterday

Fathers of Cryogenics



Dewar

CH_4	112 K
O	90
N_2	77
Ne	27
H_2	20
He	4.2



Kammerlingh-Onnes

Discovery Anniversaries

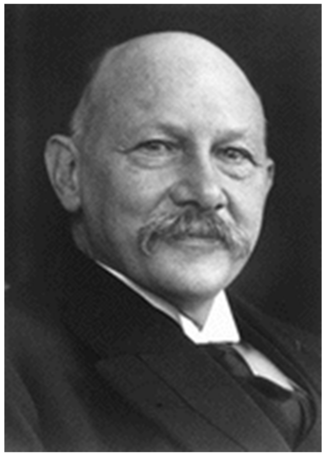
100 25

1911 (4.2 K)

Gilles Holst

1986 (20-40 K)

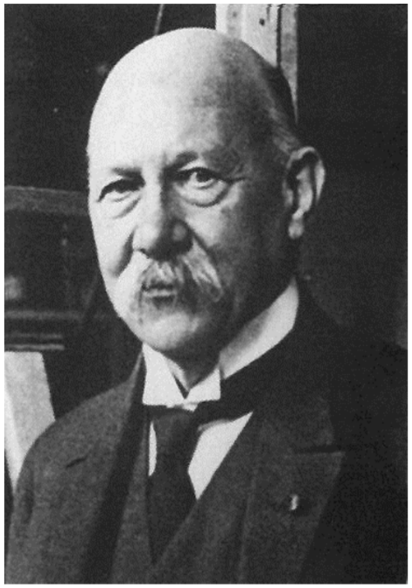
Georg Bednorz



H. Kammerlingh-Onnes

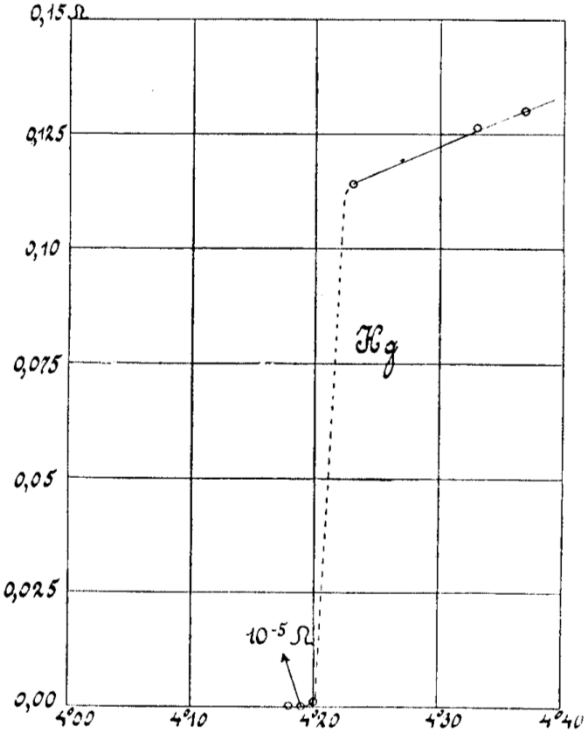
Alex Mueller

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)



Interlude
1914 - 1986

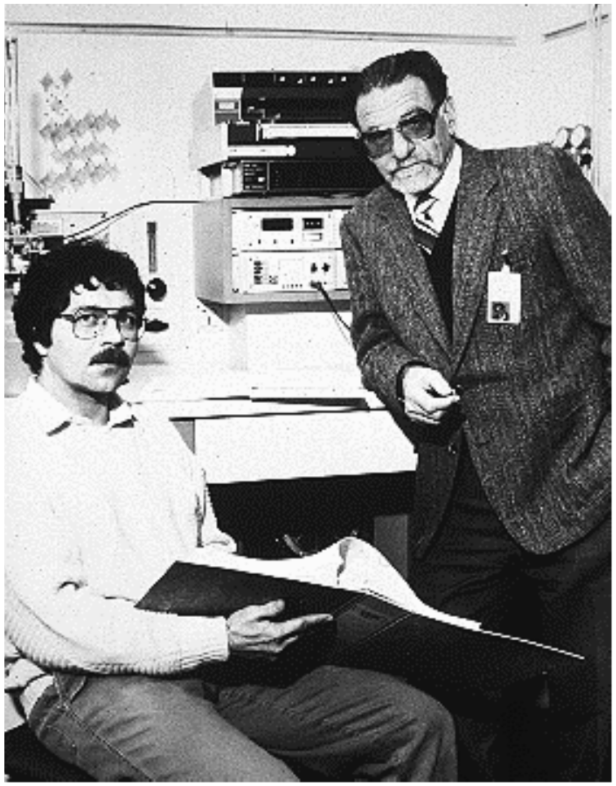
- 1914 - Persistent Currents (*Ehrenfest*)
- 1933 - Flux Expulsion (*Meissner/Ochsenfeld*)
- 1934 - Specific Heat Jump (*Keesom/Kok/Gorter/Casimir*)
- 1935 - “Super-Maxwell” (*London Bros*.)
- 1936 - “Type II” (*Schubnikov, et al*.)
- 1950(-59) - “GLAG” (*Ginzburg, Landau, Abrikosov, Gorkov*)
- 1950 - Isotope Effect (*Maxwell*)
- 1950 - “Electron-Phonon” (*Froehlich*)
- 1953 - Coherence (*Pippard*)
- 1956(-7) - “BCS” (*Bardeen, Cooper, Schreiffer*)
- 1958(-75) - “How to Calculate T_C” (*Migdal, Eliashberg, McMillan, Allen, Dynes*)
- 1964(-76) - “Room Temperature Superconductivity” (*Little, Gutfreund, Ginzburg*)

“Reading & Homework Assignment*”

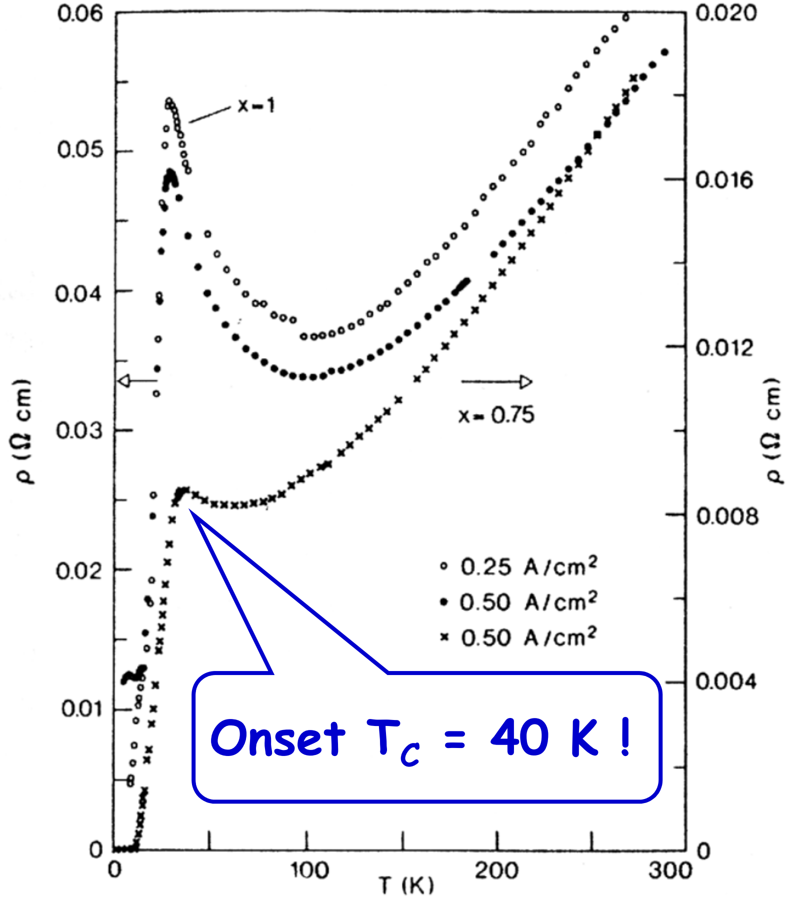
- "Type II Superconductivity: Quest for Understanding," T. G. Berlincourt, IEEE Trans. Mag. MAG-23, 403 (1987).
- "The Critical Current of a Superconductor: An Historical Review," D. Dew-Hughes, Low Temperature Physics 27, 713 (2001).
- “The Discovery of Type II Superconductors (Shubnikov Phase) ," A. G. Shepelev, www.intechopen.com (2010).

* All three can be found at & downloaded from www.w2agz.com/SuperWiki

1986
Another Big Surprise!



Bednorz and Mueller
IBM Zuerich, 1986



Onset T_C = 40 K !

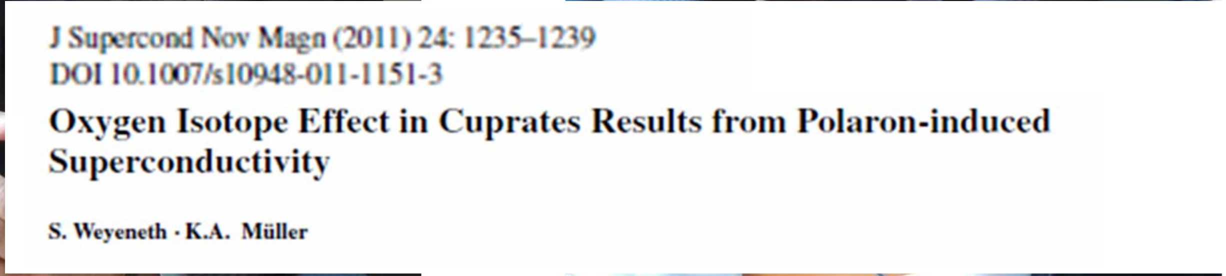
1987

“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



J Supercond Nov Magn (2011) 24: 1235–1239
DOI 10.1007/s10948-011-1151-3

Oxygen Isotope Effect in Cuprates Results from Polaron-induced Superconductivity

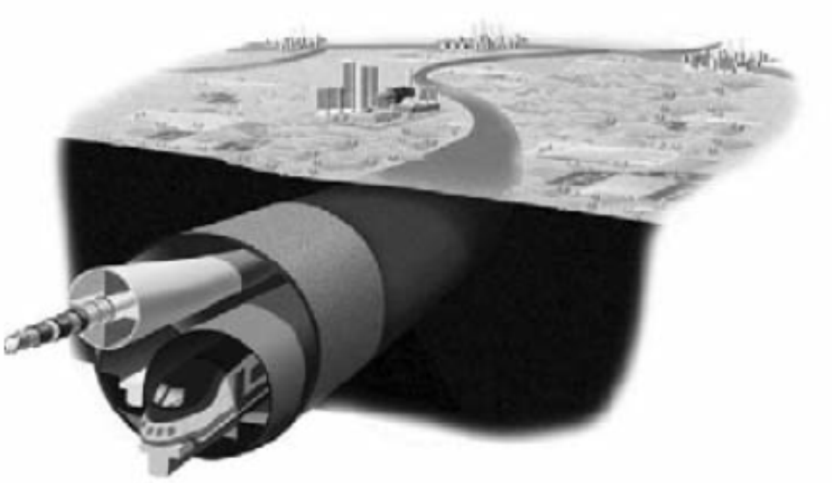
S. Weyeneth · K.A. Müller

Superconductivity: 100 Years and Counting

First in a year-long series of editorial pieces celebrating the history and progress of superconductivity

by Dr. Paul Michael Grant, W2AGZ Technologies, w2agz@w2agz.com, www.w2agz.com

The following invited article is based on a presentation by Dr. Paul Grant at the July 2010 ICEC/ICMC in Wroclaw, Poland. It is the first in a year-long series of articles in which Cold Facts will be celebrating the 100th anniversary of the discovery of superconductivity.



Out into the Cold: Early Experiences with Superconductivity

by Dr. Paul Michael Grant, W2AGZ Technologies, w2agz@w2agz.com, www.w2agz.com

The following article is part of a year-long series celebrating the 100th anniversary of the discovery of superconductivity. Contact CSA if you have ideas for submissions: theresa@cryogenicsociety.org.

One of my earliest memories was watching my parents ice skate on frozen Wappingers Pond where they had taken me swimming for my first time only a few months before. The mid-Hudson Valley was, and still is, notorious for its temperature extremes, the river itself usually completely freezing over between its banks. In mid-winter the outside temperature could approach -50°F (-46°C, 228K). I was reminded of the rigors and discomfort of my boyhood cold climate experiences this past July at ICEC-ICMC held in Wroclaw, Poland, as one of a group of attendees who underwent a "cryotherapy" session at a nearby spa, where "room temperature" was approximately -100°C. Thomas Wolfe was wrong…You can go home again!

Ice was the base cryogenics technology of my childhood years throughout the early 1940s, delivered daily, sawdust covered, in carts drawn by horses due to the wartime rationing of gasoline for automobiles and trucks [1]. Household refrigeration didn't really arrive for working class folks until after WWII. However, while I was in grammar school, although we didn't have formal science classes, we had occasional "science demonstrations," usually conducted by engineers from the nearby IBM plant. I remember two in particular, one on something called "dry ice," really cold to the touch, which just sat there and smoked and didn't melt; the other by a gentleman who brought what looked like a large thermos bottle containing "liquid air" into which was dunked a tomato, which was then withdrawn and struck with a hammer, shattering it as if it were glass. Pretty impressive to a seventh grade male (~1948).

My next encounter with cryogenics didn't occur until I was 18. My high school grades were atrocious, to put it mildly, not good enough to get me into college, and I did not want to go anyway—I wanted a job so I could buy a car. So I did what Wappingers Falls boys usually did: I went to work at IBM, first setting pins in the employee bowling alley and then as a mail boy in the mail room of a new IBM lab in downtown Poughkeepsie. I really wanted to be a bench technician, so between delivery runs I hung out with the engineers. One day one of them called to me, "Hey, kid. Come over here and I'll show you something really cool." (He didn't actually say "cool.") His name was Jim Crowe [2].

Jim splattered some solder on his bench top, scraped it off, cut out a small rectangle with his "dikes," wired it in series with a flashlight battery and a resistor of unknown (to me) size, and also hooked up in parallel with leads to a Hewlett-Packard vacuum tube voltmeter. Next to his bench was a huge stainless steel container which Jim told me held liquid helium, saying it was the coldest substance known to man. He dropped the wired up solder chip through a small opening in the top of the "dewar" and we watched the voltage across it slowly drop…and then suddenly disappear! At the time, I knew enough about electricity and Ohm's Law to complain, "The leads must have come off!" Jim said, "No, that's 'superconductivity'. The resistance of the lead-tin in the solder goes away under liquid helium." I thought to myself, "Yeah, sure!"

That evening I had dinner at home with another IBM engineer, my dad. I told him about my experience, and he replied, "Hmm. I've heard some talk about making a superconducting computer. But I don't know…you would have to fill up a whole building with liquid helium." This was 1953.

That was my first and last experience with superconductivity for some time to come. Shortly after turning 21, IBM decided I was worth educating and sent me (as an employee!) to college and graduate school for nine years, and I wound up with a physics doctorate from Harvard (superconductivity was not taught at Harvard in the early 60s!). IBM assigned me to the San Jose, now Almaden, Research Lab, and in 1972, Rick Greene (now at UMD) and I teamed up to start working on organic metals as possible room temperature superconductors, both of us having become disciples of Bill Little's dream that properly prepared polymeric chains might exhibit really high (> 500K) superconductivity, and in 1975 the group indeed discovered the world's first 300 degree superconductor, the inorganic polymer polysulfur nitride…alas, the units were millikelvin! In 1986, 25 years ago, Bednorz and Mueller taught us we should have been spending our time looking at layered copper oxide perovskites instead.

Paul Grant at 17. This photo shows him about six months before he went to work for IBM.

Nevertheless, I remain an ardent fan of the Little/Ginzburg exciton-mediated BCS-pairing proposal to enable superconductivity well above 300K. In 1998, I wrote a "sci-fi" piece for ***Physics Today*** predicting its fulfillment by 2028 [3]. Maybe then I can finally come in from the cold.

References

1. A fascinating tale of pre-industrial cryogenics technology can be found in Gavin Weightman's book, "The Frozen Water Trade," (ISBN 0-7868-6740-X), the story of two New England brothers who "farmed" almost every northeastern pond and lake each winter to cool the cocktails of Caribbean resorts in the 19th century.

2. Jim Crowe invented one of the very first superconducting memory elements, and arguably the first to employ trapped flux. See J. W. Crowe, "Trapped-Flux Superconducting Memory," IBM Journal, October 1957, p. 295. Jim Crowe became a good friend, mentor and my manager when I returned to work at IBM summers during my college years.

3. P. M. Grant, "Researchers Find Extraordinarily High Temperature Superconductivity in Bio-Inspired Nanopolymer," Physics Today, May 1998. Nineteen more years to go. http://www.w2agz.com/Publications/Popular%20Science/Bio-Inspired%20Superconductivity,%20Physics%20Today%2051,%2017%20(1998)a.pdf

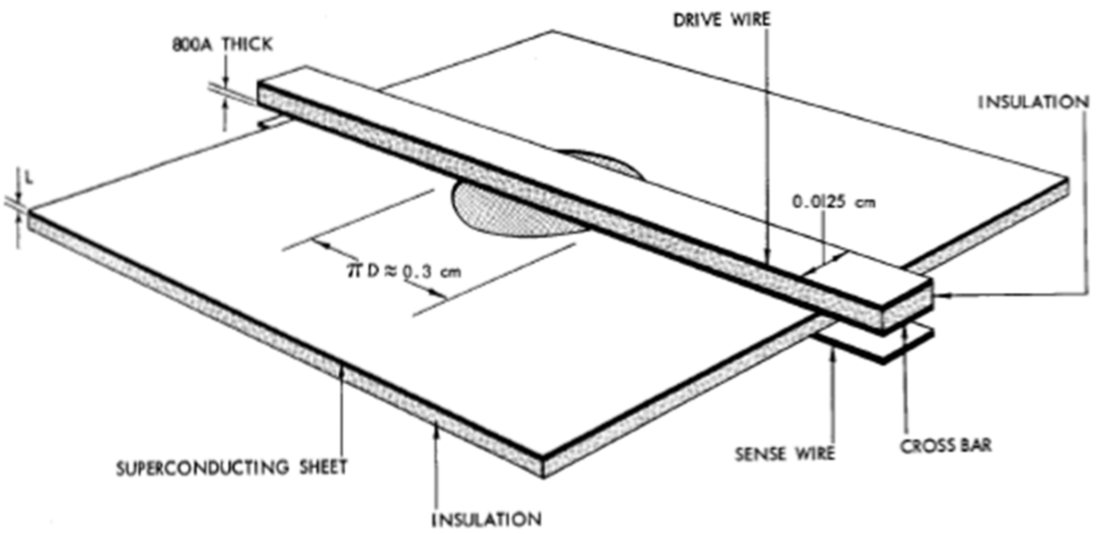
1953

Project Sage – IBM/MIT

J. W. Crowe

Trapped-Flux Superconducting Memory*

Abstract: A memory cell based on trapped flux in superconductors has been built and tested. The cell is constructed entirely by vacuum evaporation of thin films and can be selected by coincident current or by other techniques, with drive-current requirements less than 150 ma. The short transition time of the trapped-flux cell indicates its possible use in high-speed memories. The superconductive film memory does not exhibit the problems of "delta noise" in core memories resulting from the difference in half-select pulse outputs.



Today


physicsworld.com

Superconductivity: Top five applications

Five of the best

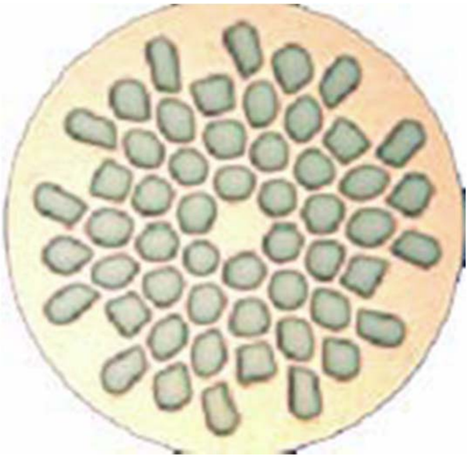
Superconductivity may be a beautiful phenomenon, but materials that can conduct with zero resistance have not quite transformed the world in the way that many might have imagined. Presented here are the top five applications, ranked in terms of their impact on society today

This article lists a top five selected by Paul Michael Grant from W2AGZ Technologies in San Jose, California. Superconducting wires top the list, followed by magnets for medical imaging and for particle colliders in second and third, respectively, with superconducting motors in fourth and a unique dark-matter experiment in fifth.

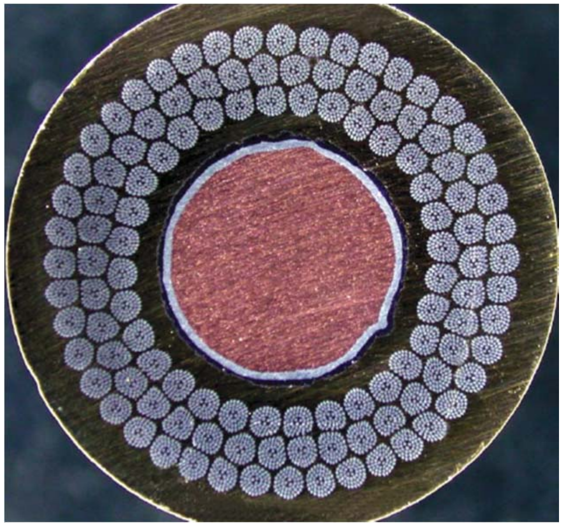
1. Wires & Films
2. Medical Imaging
3. High Energy Physics
4. Rotating Machinery
5. Dark Matter

1. Wires & Films

LTSC

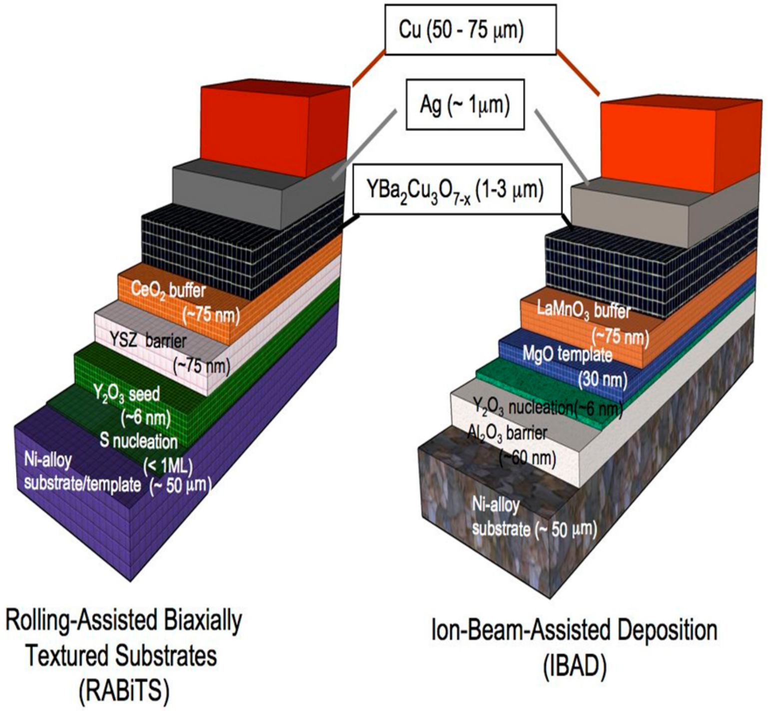


NbTi/Cu
Oxford



Nb_3Sn
Supercon

HTSC



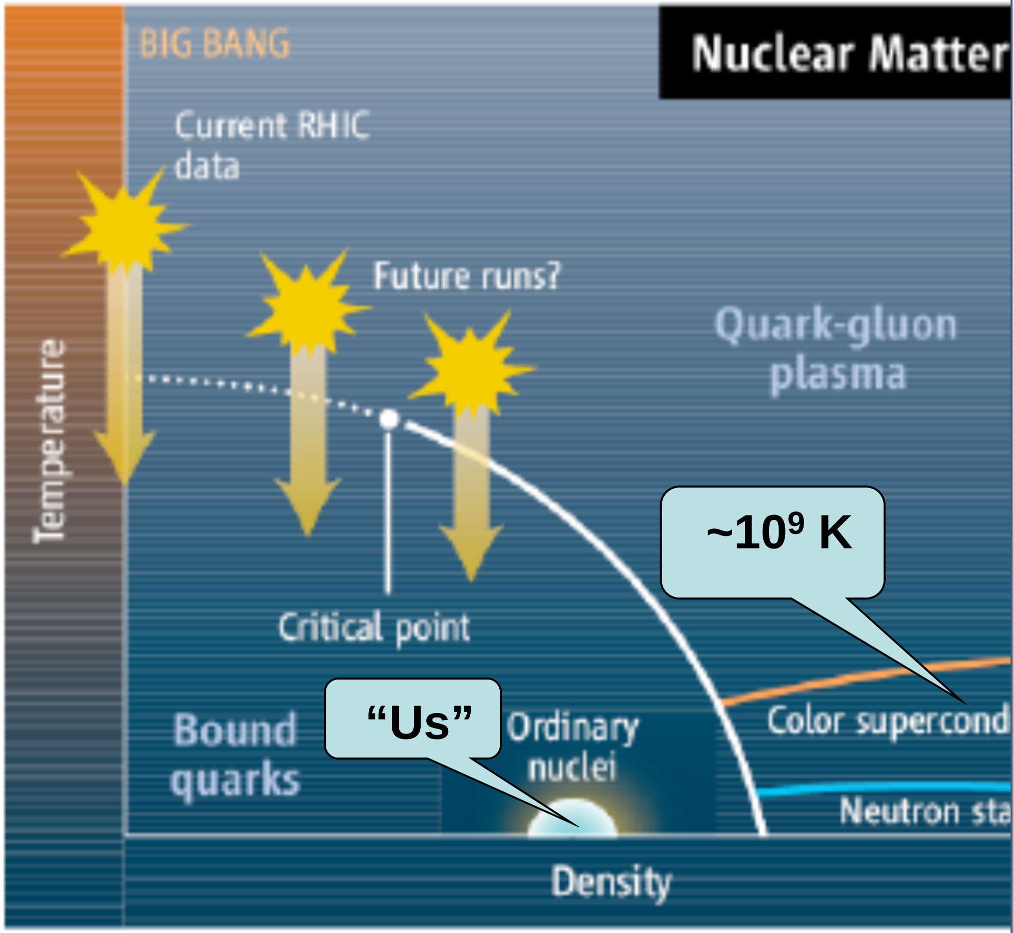
American Superconductor

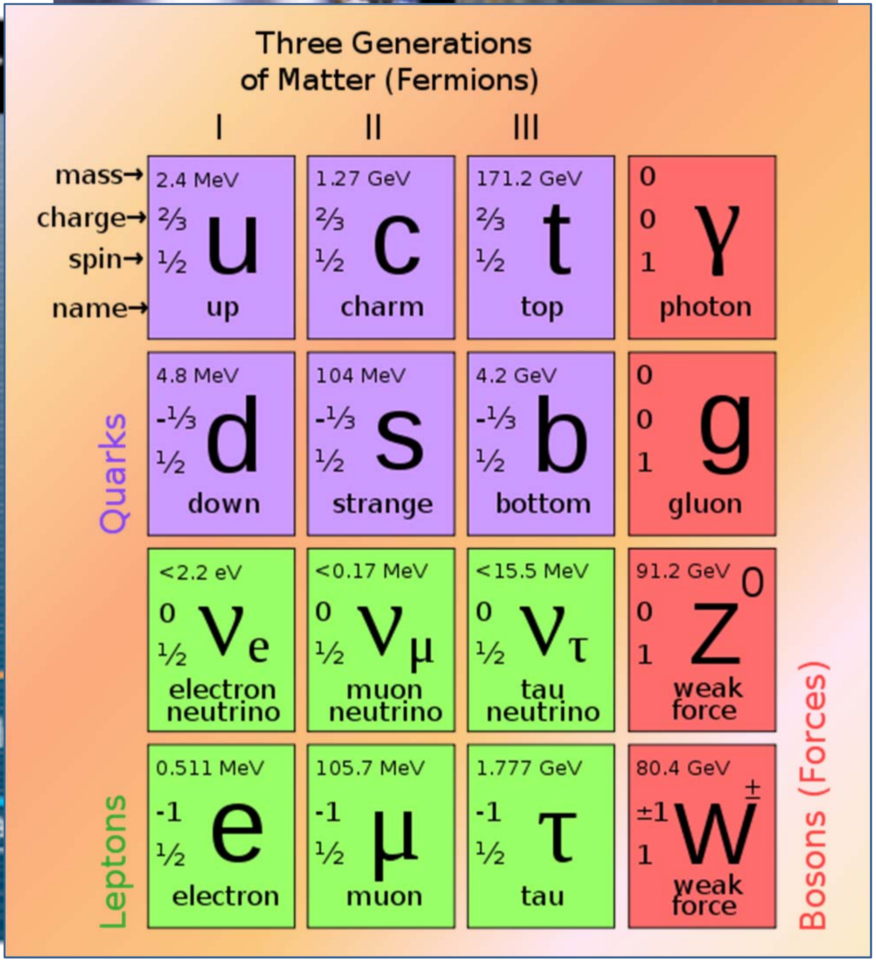
SuperPower

LTSC

2. Medical Imaging

3. High Energy Physics



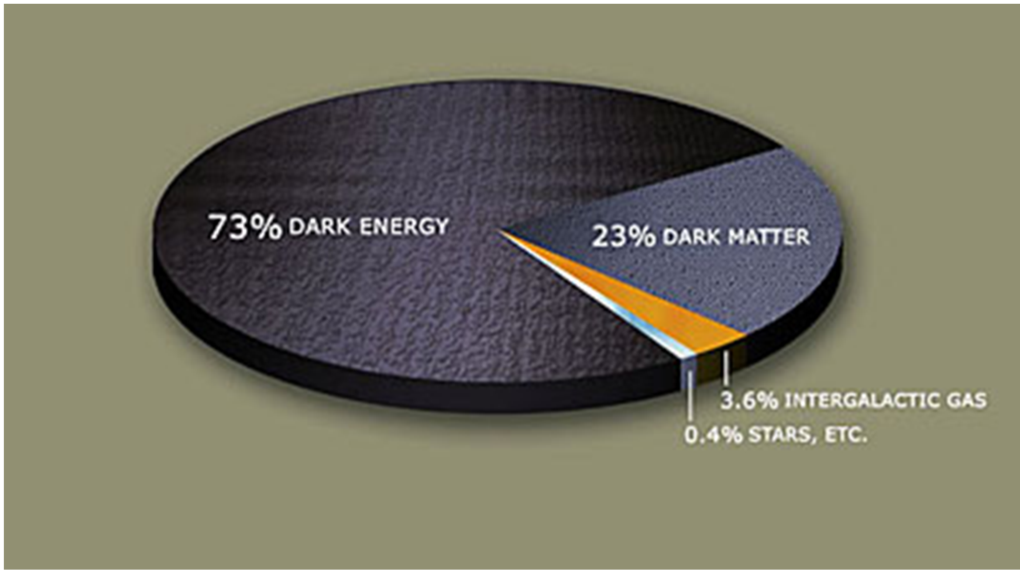


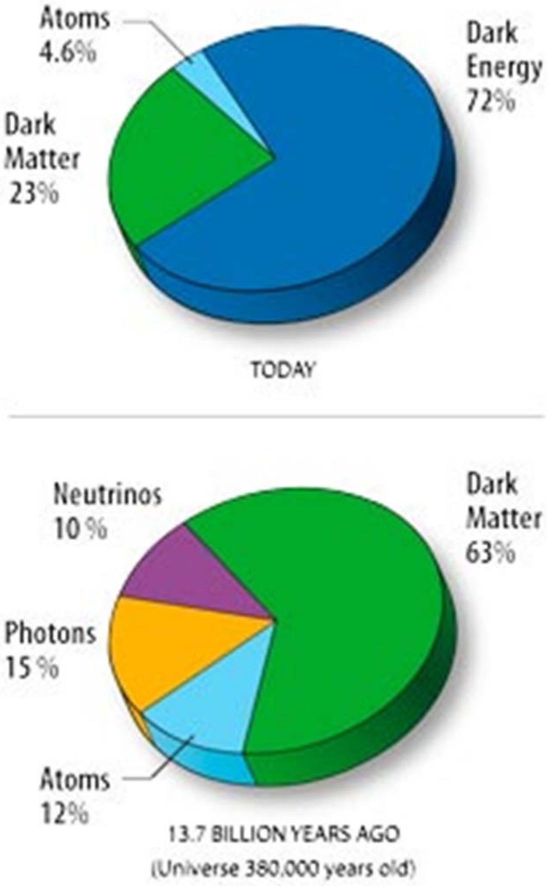
Three Generations of Matter (Fermions)

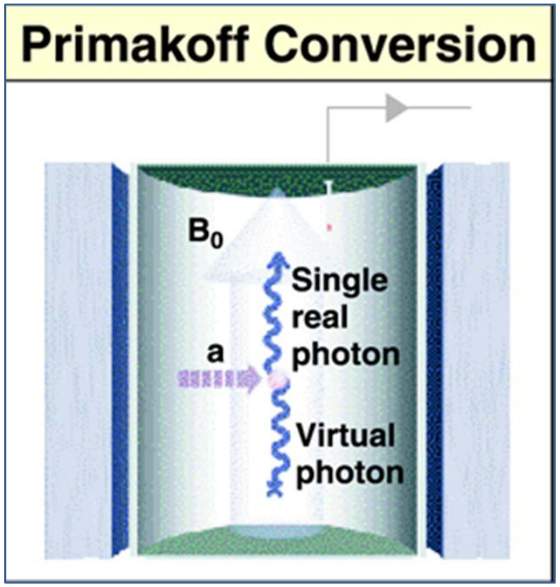
mass→
charge→
spin→
name→

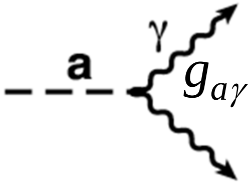
	I	II	III	Bosons (Forces)
Quarks	2.4 MeV ⅔ ½ u up	1.27 GeV ⅔ ½ c charm	171.2 GeV ⅔ ½ t top	0 0 1 γ photon
	4.8 MeV -⅓ ½ d down	104 MeV -⅓ ½ s strange	4.2 GeV -⅓ ½ b bottom	0 0 1 g gluon
Leptons	<2.2 eV 0 ½ ν_e electron neutrino	<0.17 MeV 0 ½ ν_μ muon neutrino	<15.5 MeV 0 ½ ν_τ tau neutrino	91.2 GeV 0 1 Z^0 weak force
	0.511 MeV -1 ½ e electron	105.7 MeV -1 ½ μ muon	1.777 GeV -1 ½ τ tau	80.4 GeV ±1 1 $W^\pm$ weak force

5. Dark Matter









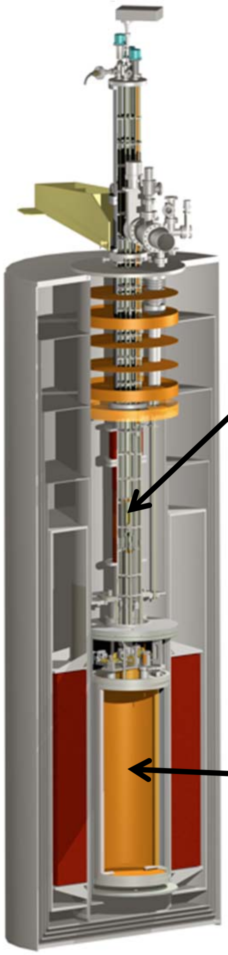
Primakov model predicts axion decay into a (presumably) detectable photon in a sufficiently large magnetic field contained in a superconducting solenoid and resonant cavity

5. Dark Matter, Cont'd (ADMX)

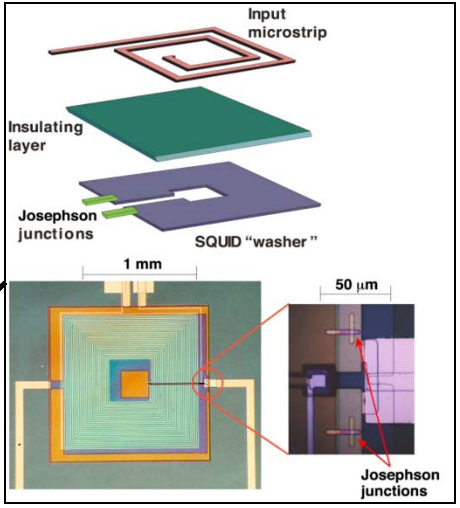
Axion Dark Matter eXperiment

Graphics Stolen from Leslie Rosenberg's U Florida Presentation, January, 2010

ADMX Team
LLNL
MIT
UW
UCB
U Florida
U Chicago
Fermilab



Very Low Noise SQUID



High-Q Cavity

ADMX Phase II SQUID & Dilution Frig Upgrade Status (January 2010)

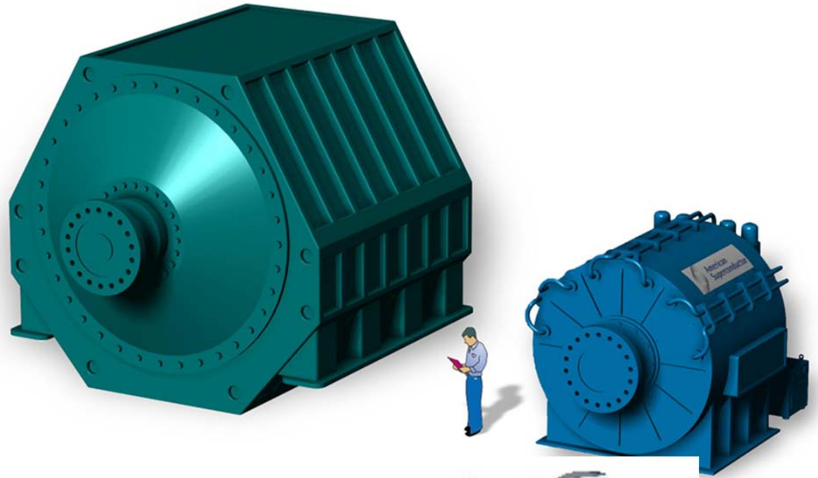
- Three years to construct
- Commissioning in year four (2014?)

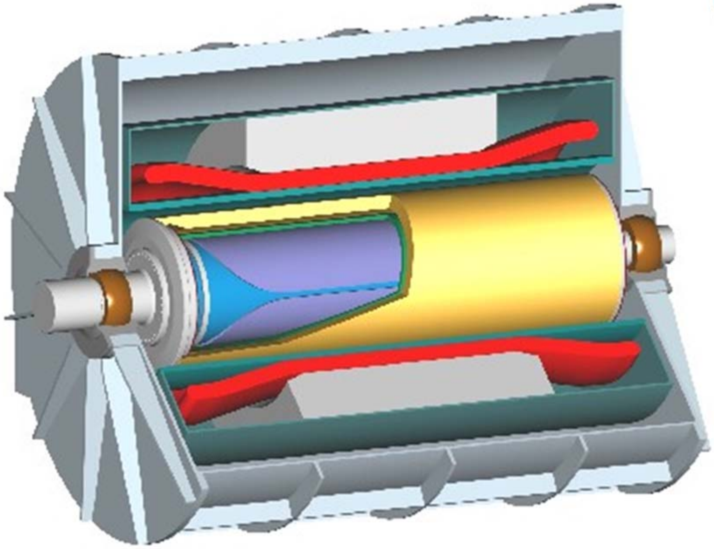
Happy Hunting!

HTSC

4. Rotating Machinery

Courtesy AMSC

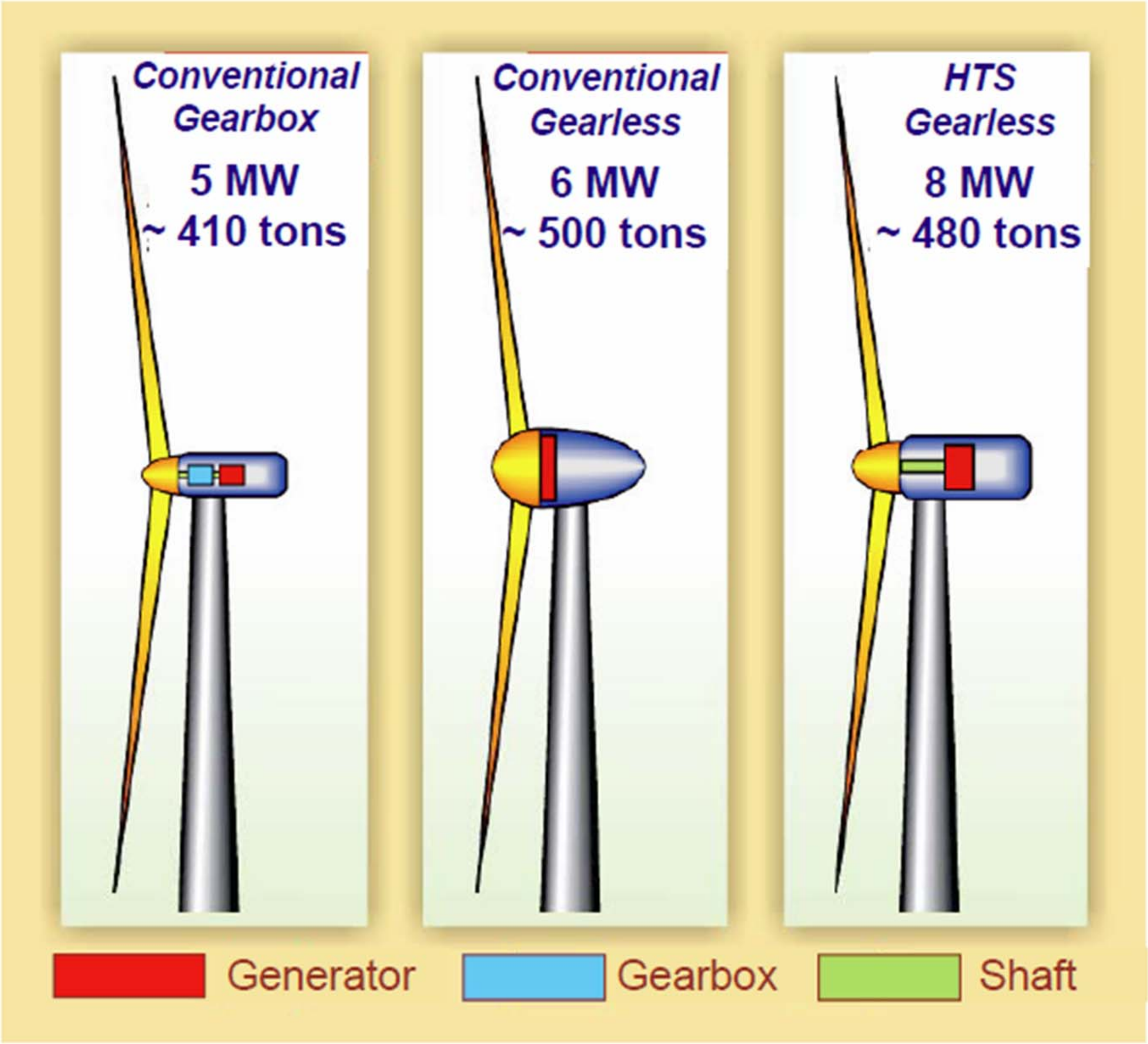




Major Players:

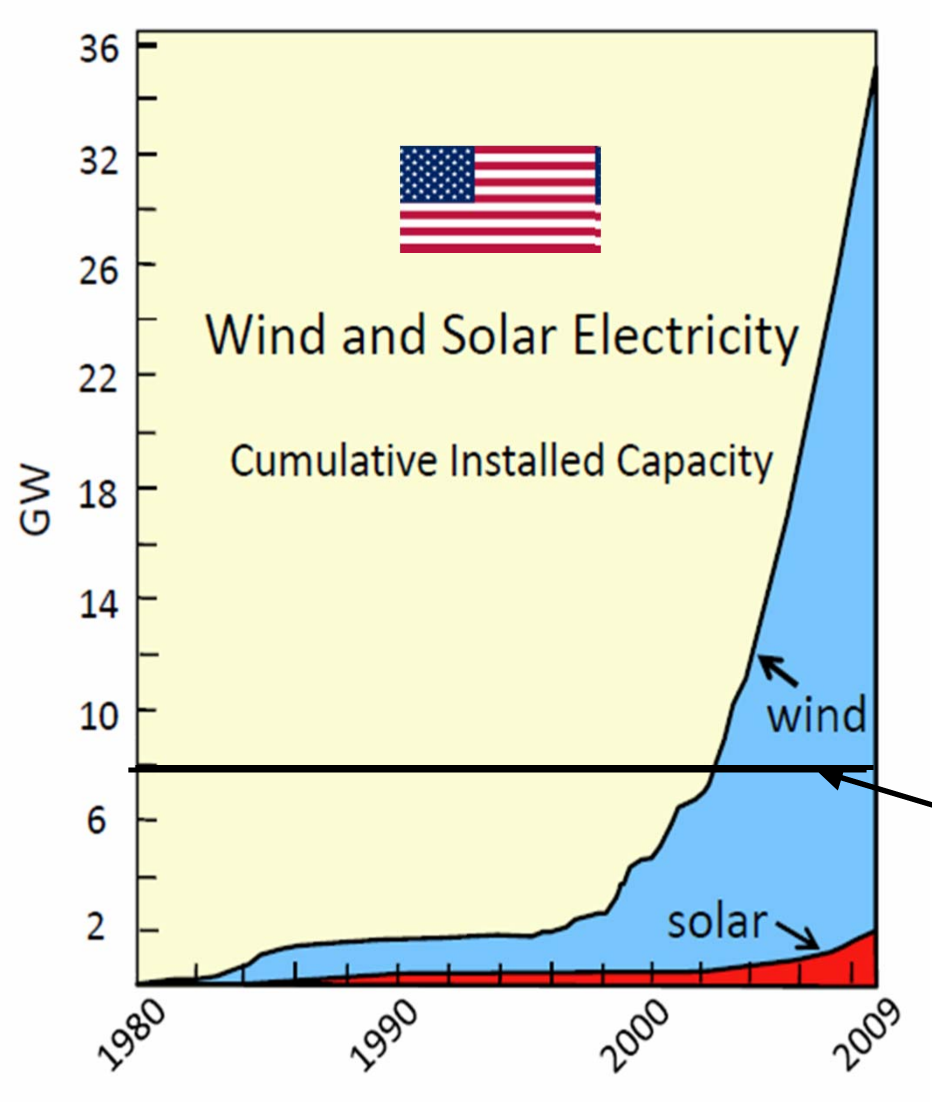
- AMSC
- SEI

Rotating Machinery - Wind Generators



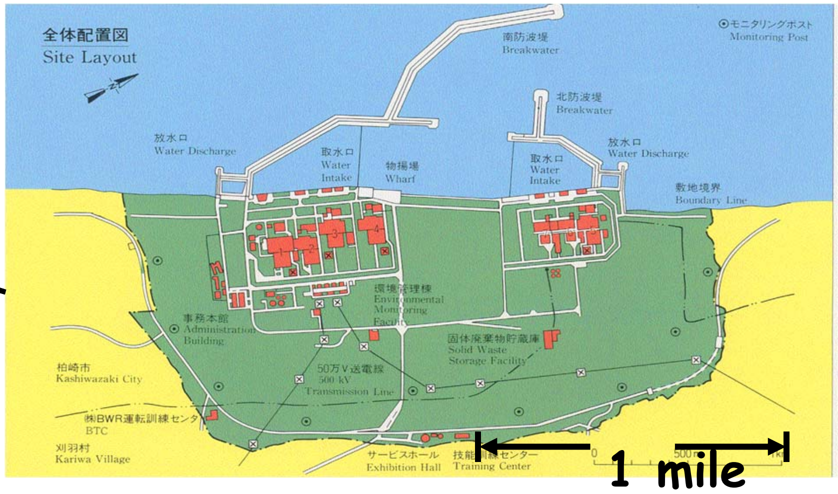
Matthews, Physics Today **62**(4), 25 (April 2009)

Wind Power Factoids



KK Wind Equivalent (8 GW)

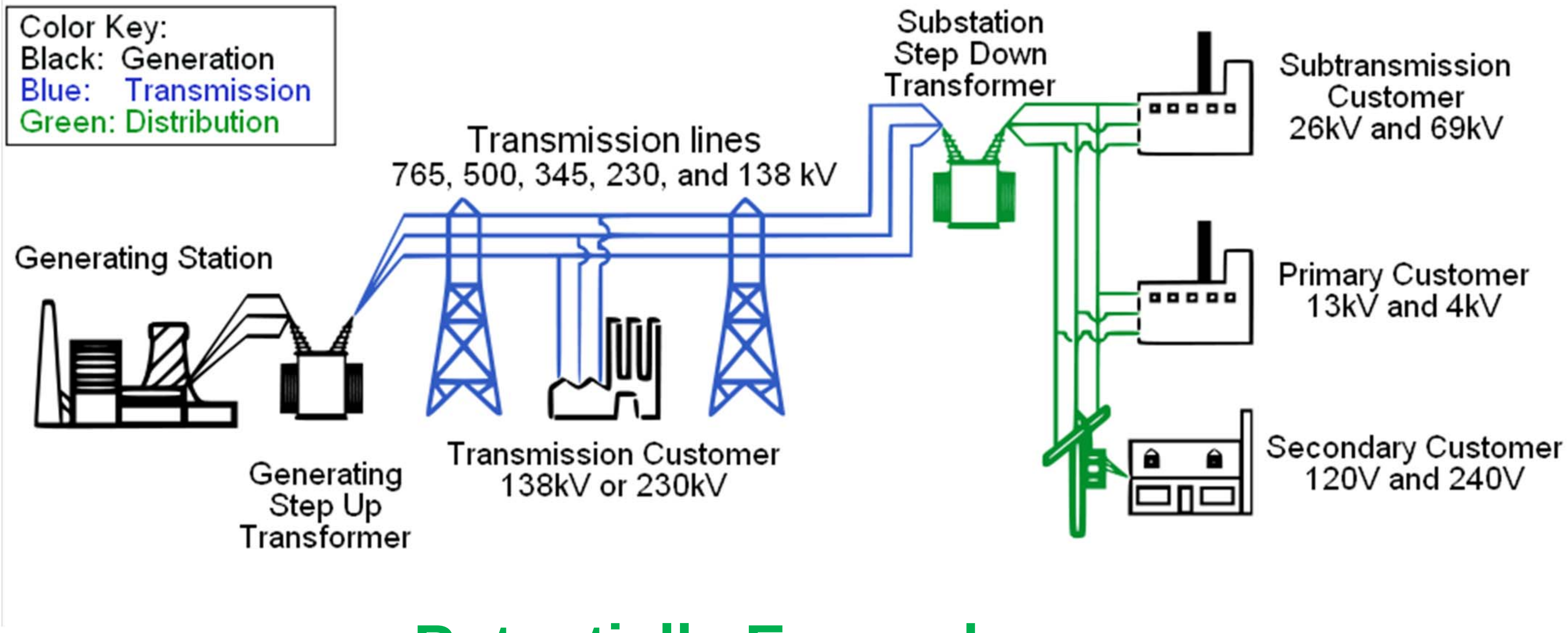
• Power per Tower	8 MW
• Number of Towers	1000
• Inter-tower Distance	1000 ft
• Total Area (miles x miles)	43.5 x 43.5



Kashiwazaki Kariwa: 8 GW !

Diablo Canyon

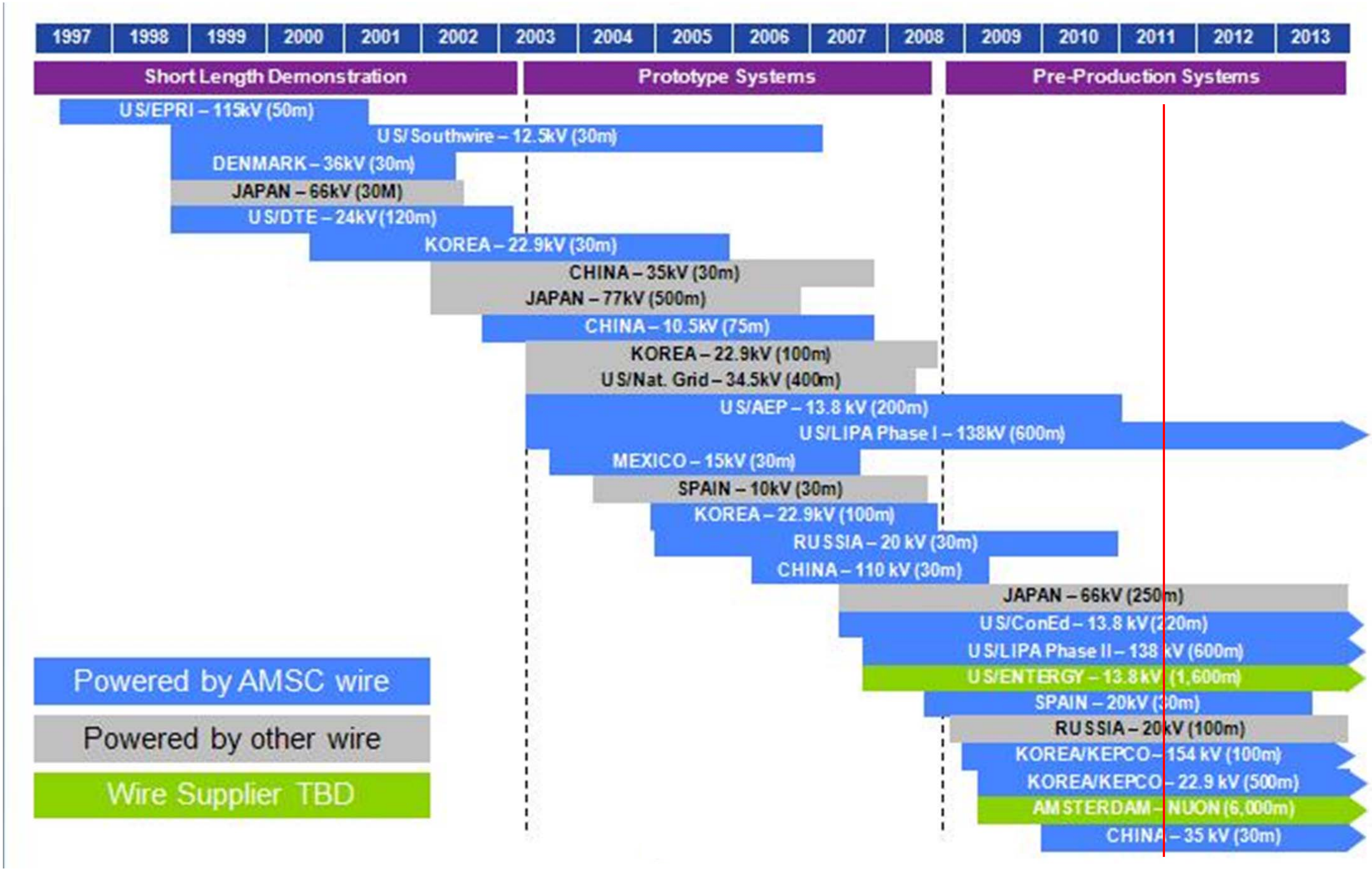
Where Else Can We Apply Superconductivity to Electric Power?



Potentially Everywhere

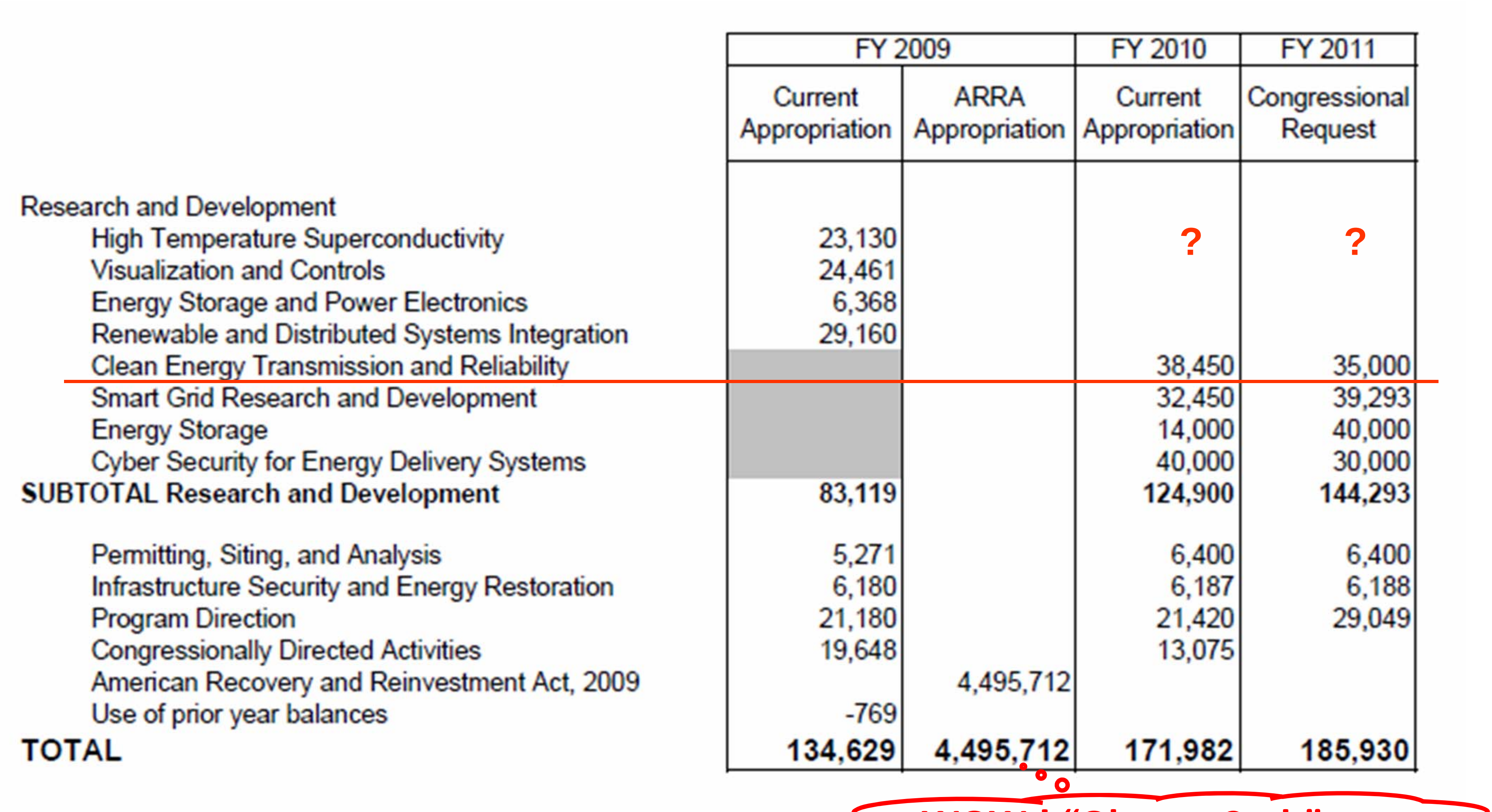
HTSC Cable Projects Worldwide

Past, Present…Future?



US Department of Energy

Budget of the Office of Electricity Delivery and Energy Reliability: FY 2010-11 (10^3 USD)



	FY 2009		FY 2010	FY 2011
	Current Appropriation	ARRA Appropriation	Current Appropriation	Congressional Request
Research and Development				
High Temperature Superconductivity	23,130		?	?
Visualization and Controls	24,461			
Energy Storage and Power Electronics	6,368			
Renewable and Distributed Systems Integration	29,160			
Clean Energy Transmission and Reliability			38,450	35,000
Smart Grid Research and Development			32,450	39,293
Energy Storage			14,000	40,000
Cyber Security for Energy Delivery Systems			40,000	30,000
SUBTOTAL Research and Development	**83,119**		**124,900**	**144,293**
Permitting, Siting, and Analysis	5,271		6,400	6,400
Infrastructure Security and Energy Restoration	6,180		6,187	6,188
Program Direction	21,180		21,420	29,049
Congressionally Directed Activities	19,648		13,075	
American Recovery and Reinvestment Act, 2009		4,495,712		
Use of prior year balances	-769			
TOTAL	**134,629**	**4,495,712**	**171,982**	**185,930**

WOW ! “Obama Cash”

A Modest Proposal

-Upbraiding the Utilities-

- More than a half-century of successful demonstrations/prototyping power applications of superconductivity (1950s - >2000, in Japan and US)…low- and high-Tc…now sitting “on the shelf.”
- Why aren’t they “in the field” today?
- Is their absence due to…
  - Cost?
  - Hassle?
  - or “lack of compelling” need?
  - or “all of the above?”

- US utilities have long claimed to “want”…
  - Efficient long-length cables
  - Oil-free transformers
  - Energy Storage
  - Fast fault current limiters at high voltage (FCLs)
  - Efficient rotating machinery (aka, motors and generators)
- Well, we got ‘em. Utilities claim:
  - They’re too high-cost, because,
    - The wire is too expensive.
    - They have to be kept too cold.
    - Electricity is cheap, and “in field” energy efficiency is not a “compelling” driver
  - Anyway, we can solve our needs by incrementally improving the “old” ways (<u>don’t ever underestimate the ingenuity of a utility engineer to improvise, adopt and adapt</u>)

“Then…a modest proposal…”

- If the “cost” of the wire in any given application were to be “zero,”…
- Would the utilities then “buy them?” And sign a “letter of intent” to purchase “x” number?
  - e.g., Fault Current Limiters, for which US utilities have long claimed a need
- “Zero cost” would be obtained as a Federal or State “tax credit” for the wire cost of the quantity purchased by the utility equipment vendor or the utility itself…
- Well?

Tomorrow

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

R. L. GARWIN AND J. MATISOO

Submitted 24 June 1966

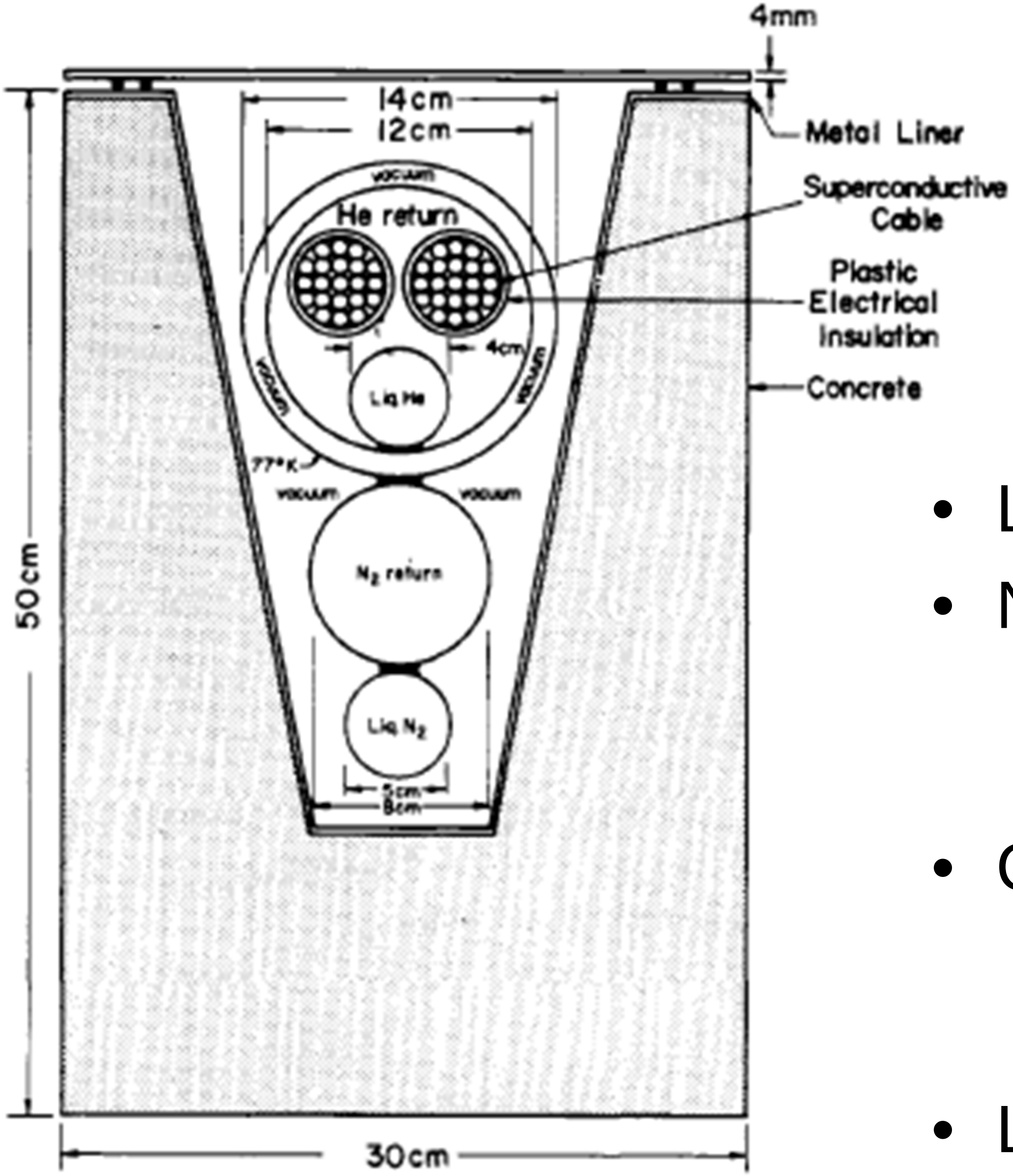
PROCEEDINGS OF THE IEEE, VOL. 55, NO. 4, APRIL 1967

"What's past is prologue" (Bill S.)

Rationale: Huge growth in generation and consumption in the 1950s; cost of transportation of coal; necessity to locate coal and nuke plants far from load centers.

Furthermore, the utilities have recently become aware of the advantages of power pooling. By tying together formerly independent power systems they can save in reserve capacity (particularly if the systems are in different regions of the country), because peak loads, for example, occur at different times of day, or in different seasons. To take advantage of these possible economies, facilities must exist for the transmission of very large blocks of electrical energy over long distances at reasonable cost.

Specs



- LHe cooled
- Nb_3Sn (T_C = 18 K)
  - J_C = 200 kA/cm^2
  - H* = 10 T
- Capacity = 100 GW
  - +/- 100 kV dc
  - 500 kA
- Length = 1000 km

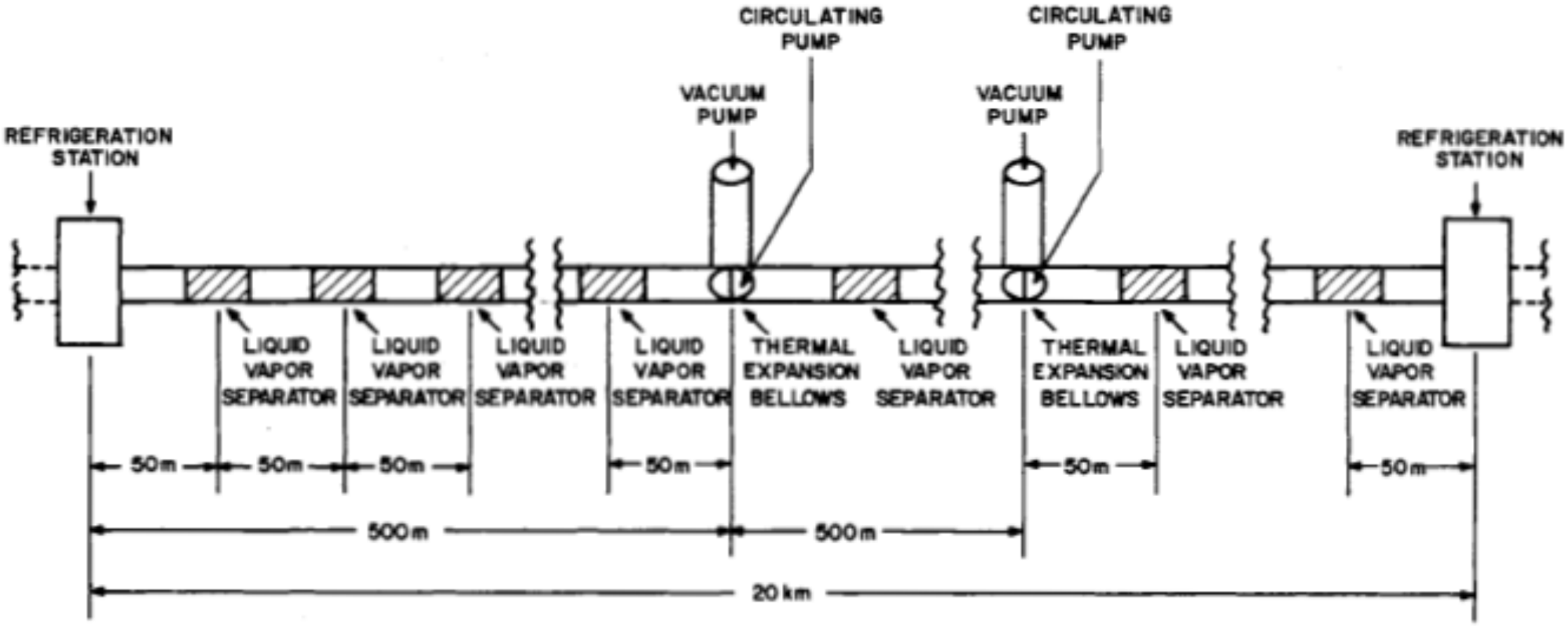
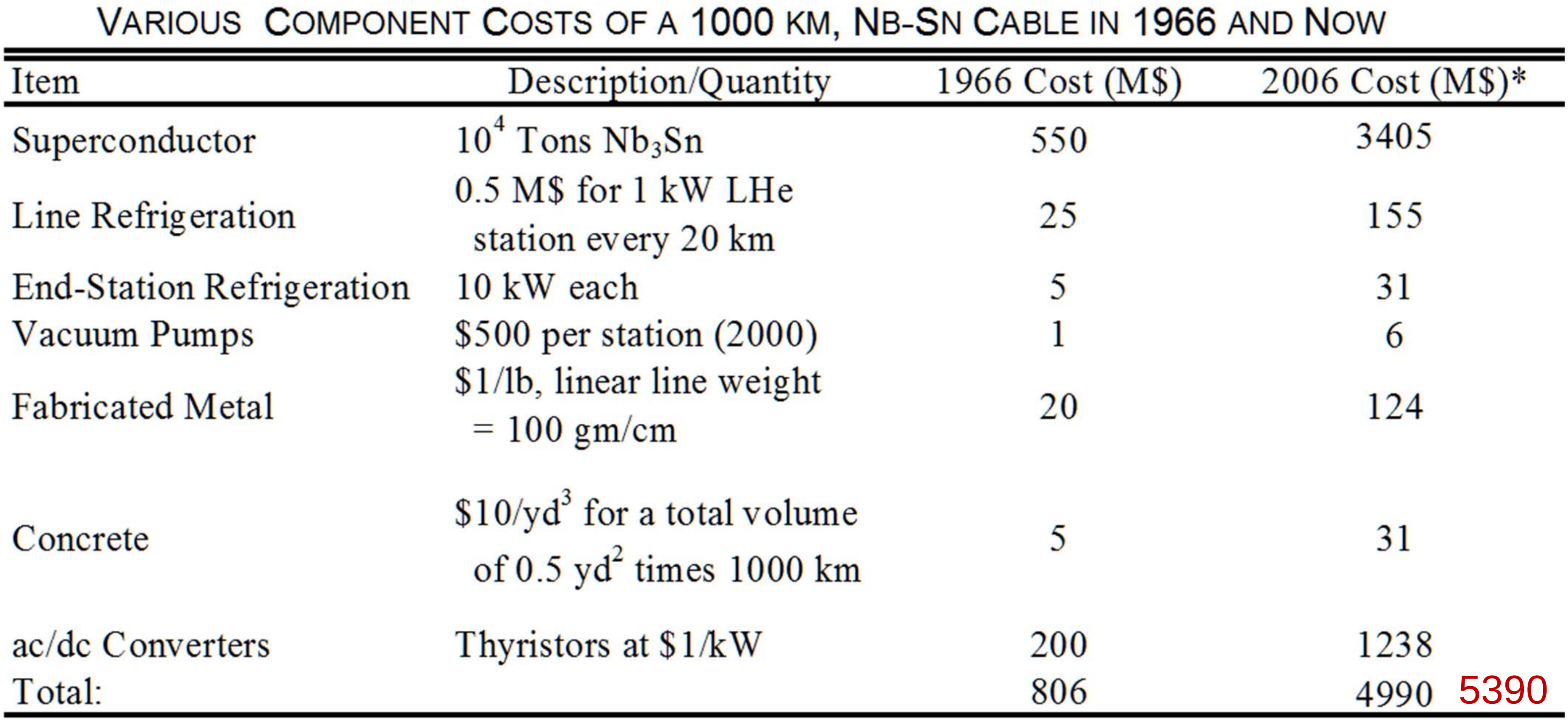


Fig. 2. A 20-km module of the 1000-km, 100-GW line.

• Refrigeration Spacing	20 km
• G-L Separator Distance	50 m
• Booster Pump Intervals	500 m
• Vacuum Pump Spacing	500 m

G-M Engineering Economy
- Yesterday & Today -



VARIOUS COMPONENT COSTS OF A 1000 KM, NB-SN CABLE IN 1966 AND NOW

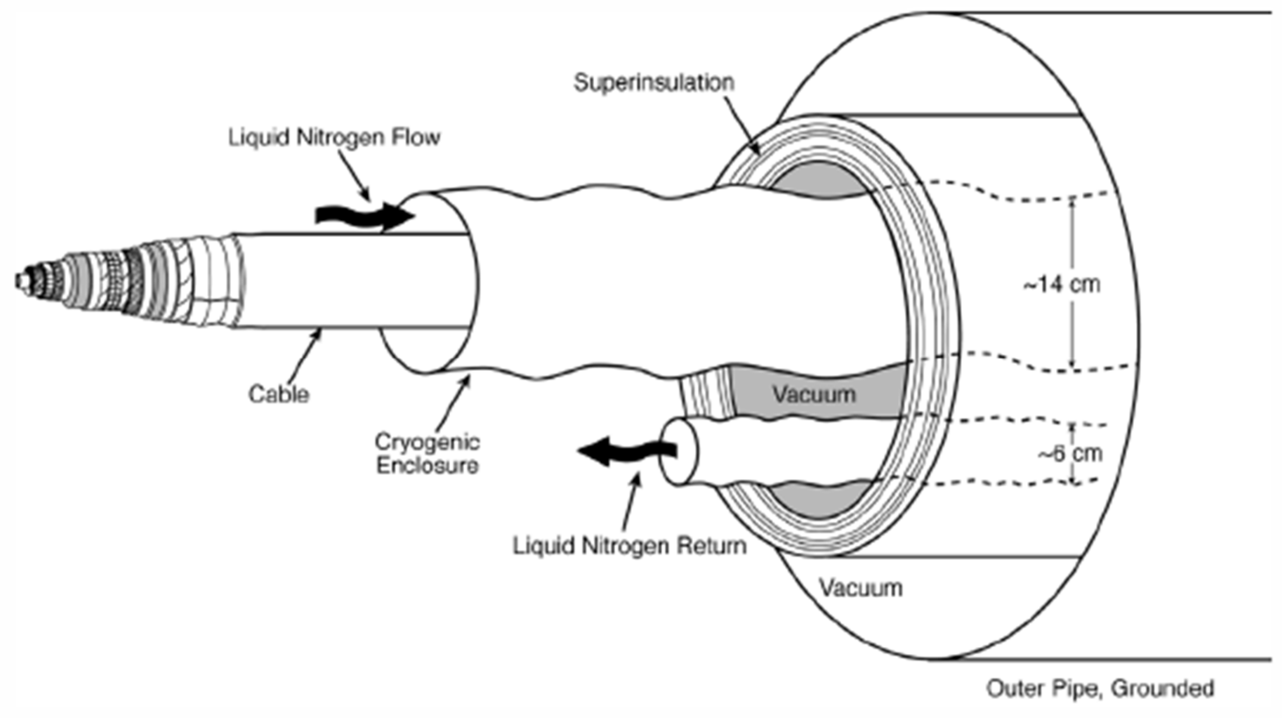
Item	Description/Quantity	1966 Cost (M$)	2006 Cost (M$)*
Superconductor	10^4 Tons Nb_3Sn	550	3405
Line Refrigeration	0.5 M$ for 1 kW LHe station every 20 km	25	155
End-Station Refrigeration	10 kW each	5	31
Vacuum Pumps	$500 per station (2000)	1	6
Fabricated Metal	$1/lb, linear line weight = 100 gm/cm	20	124
Concrete	$10/yd^3 for a total volume of 0.5 yd^2 times 1000 km	5	31
ac/dc Converters	Thyristors at $1/kW	200	1238
Total:		806	4990 5390

*2006 costs relative to 1966 are estimated from the Bureau of Labor Statistics table of annual Consumer Price Indices that can be found at ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt. The 2006/1966 ratio used above is 6.19. The YE2010 costs would be about **8%** higher that YE2006.

A Superconducting dc Cable

EPRI Report 1020458 (2009)

Hassenzahl, Gregory, Eckroad, Nilsson, Daneshpooy, Grant



<u>Monopole Specs</u>

100-kV, 100-kA, 10-GW
66 K < T< 69 K

A Canadian’s View of the World

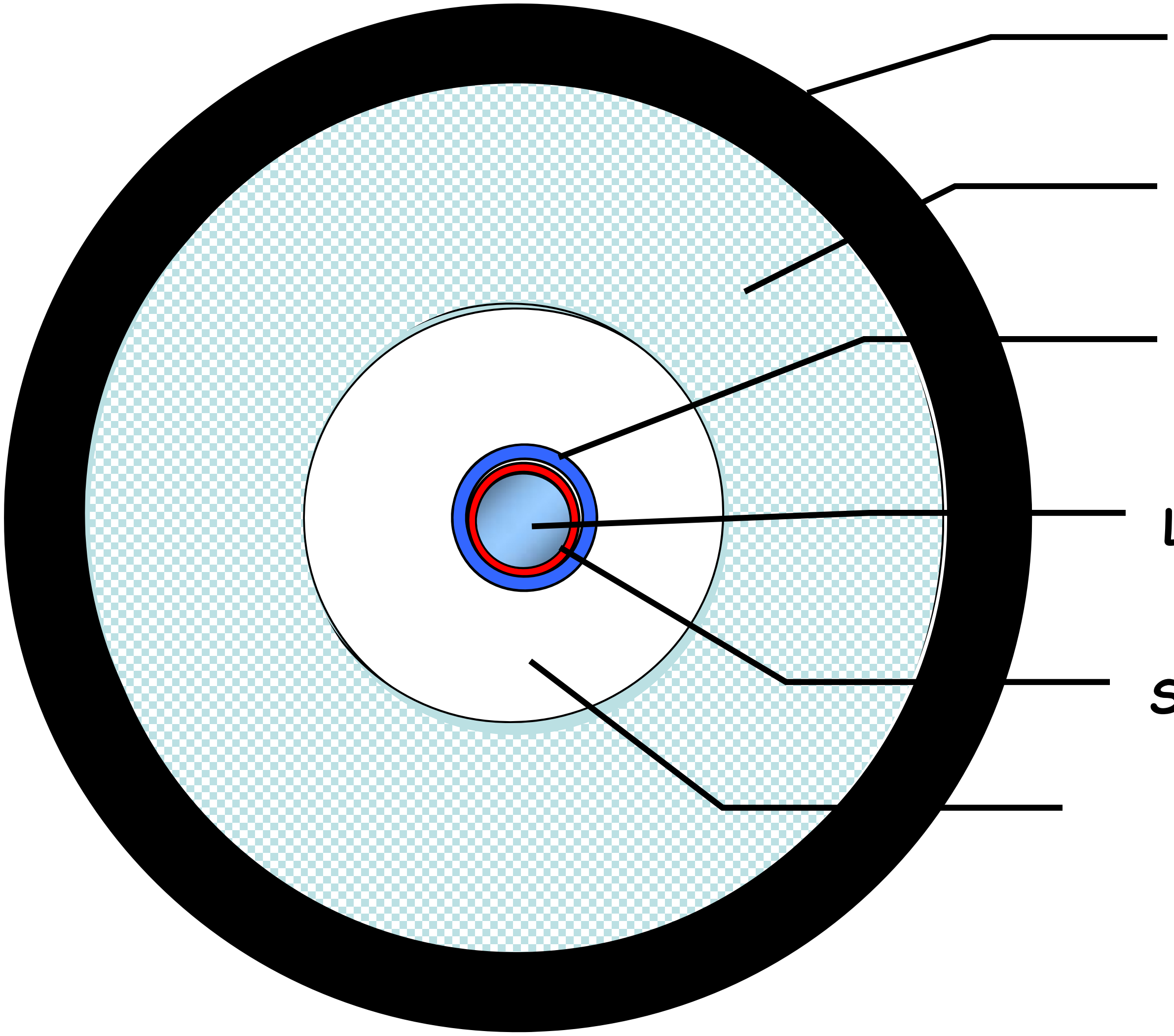
The Mackenzie Valley Pipeline

http://www.mackenziegasproject.com

1220 km
18 GW-thermal
2006 - 2010

Design for eventual conversion to high pressure cold or liquid H_2

LNG SuperCable



Electrical Insulation

"Super-Insulation"

Thermal Barrier to LNG

Liquid Nitrogen @ 77 K

Superconductor

LNG @ 105 K
1 atm (14.7 psia)

Wellhead LNG + Electricity

MVP Scenario

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)

SuperCable Parameters for LNG Transport

CH_4 Mass Flow (12 GW (HHV))	230 kg/s @ 5.3 m/s
LNG Density (100 K)	440 kg/m^3
LNG Volume Flow	0.53 m^3/s @ 5.3 m/s
Effective Pipe Cross-section	0.1 m^2
Effective Pipe Diameter	0.35 m (14 in)

It’s 2030

- *The Gas runs out!*
- We have built the LNG SuperCable years before
- Put HTCGR Nukes on the now empty gas fields to make hydrogen and electricity (some of the electricity infrastructure, e.g., I/C stations, already in place)
- Enable the pre-engineered hydrogen capabilities of the LNG SuperCable to now transport protons and electrons.

Transporting Tens of Gigawatts to the Green Market

12 – 13 May 2011
Institute for Advanced Sustainability Studies
Potsdam, Germany

An American Paradox!

The international Brainstorming Workshop on the future of long-distance high-power electric transmission (Superconducting DC lines) was held on May 12th-13th 2011 in Potsdam. Renewable energy sources, such as solar, wind, geothermal and tidal power, are increasingly becoming more widely available in many parts of the world.

As renewable energy sources will be located where suitable conditions (solar radiation, wind) are available, the generated energy will have to be transported over long distances, up to several thousands of kilometres.

Powering Europe with Sahara Solar

NEW DEAL

EURO-MAGHREB

Tewfik HASNI

APEQUE' S President and Energy' s Consultant

Postdam 12 may 2011

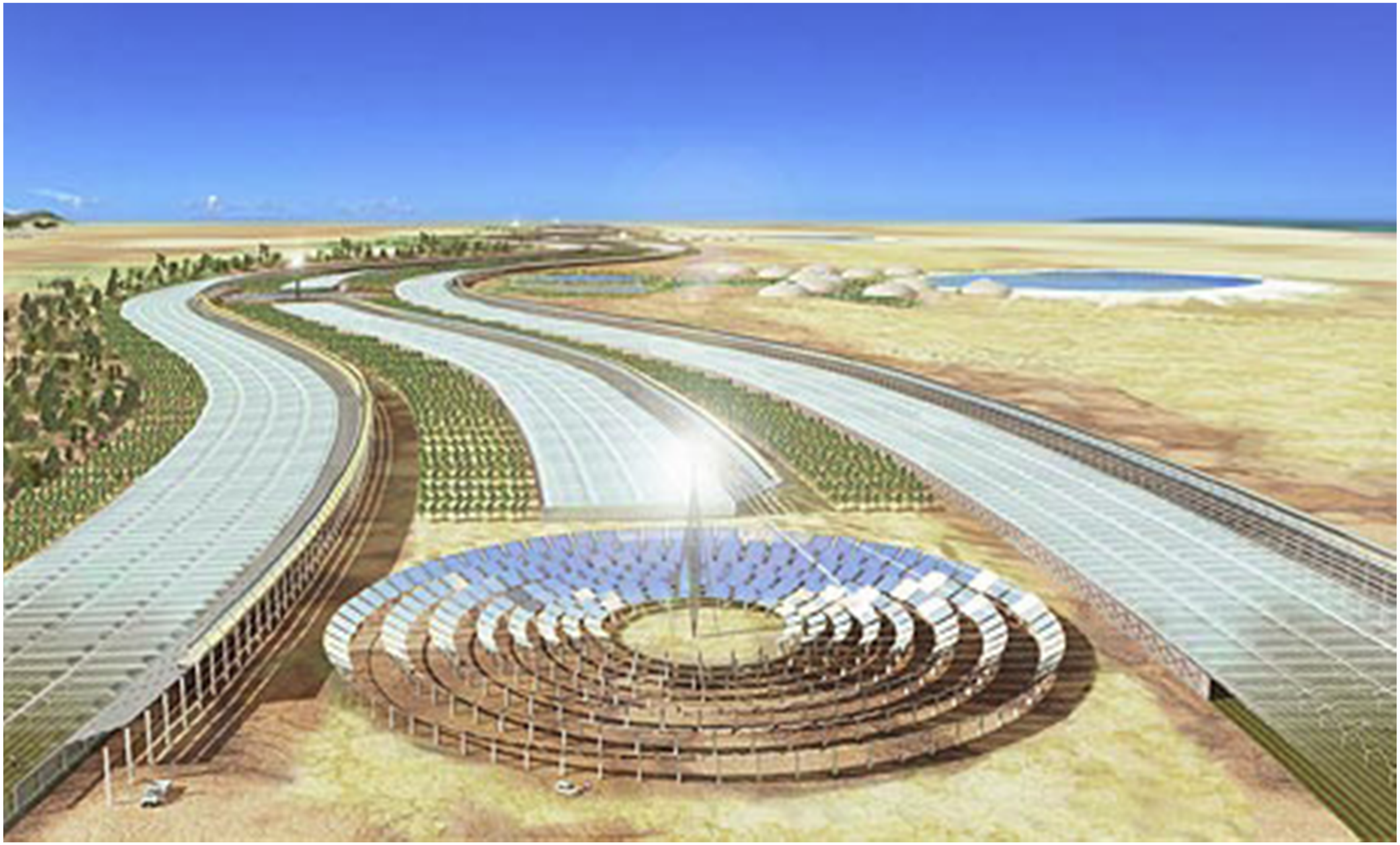
LES TENDANCES ENERGETIQUES

- Le modèle énergétique de l' UE

	2009	2029
-Coal	7,7%	14 %
-Oil	32,2%	10%
-Gas	28,6%	25%
-Nuclear	12,4%	13%
-Hydro	2%	2%
-Biomass	11,5%	11,5%
-Renewables	5,6%	10%+15% import

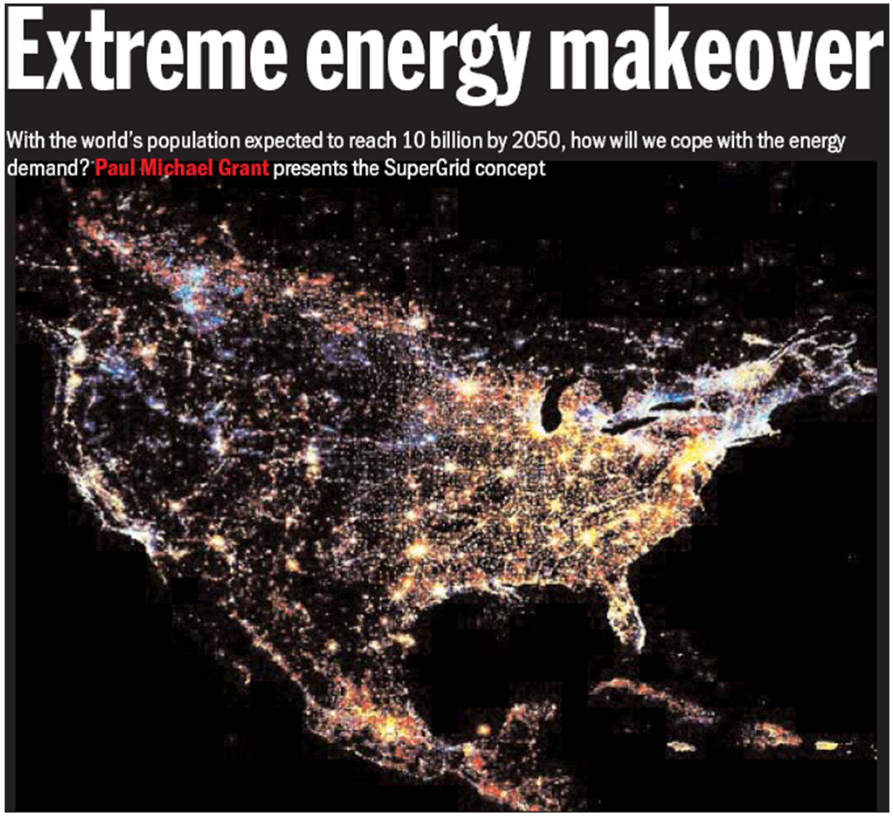
Go Where the Sun Shines

Solar – PV & Thermal



Superconducting SolarPipe

Physics World, October 2009



Extreme energy makeover

With the world's population expected to reach 10 billion by 2050, how will we cope with the energy demand? **Paul Michael Grant** presents the SuperGrid concept

From The Times

October 3, 2009

Science: Stand by for the Supergrid

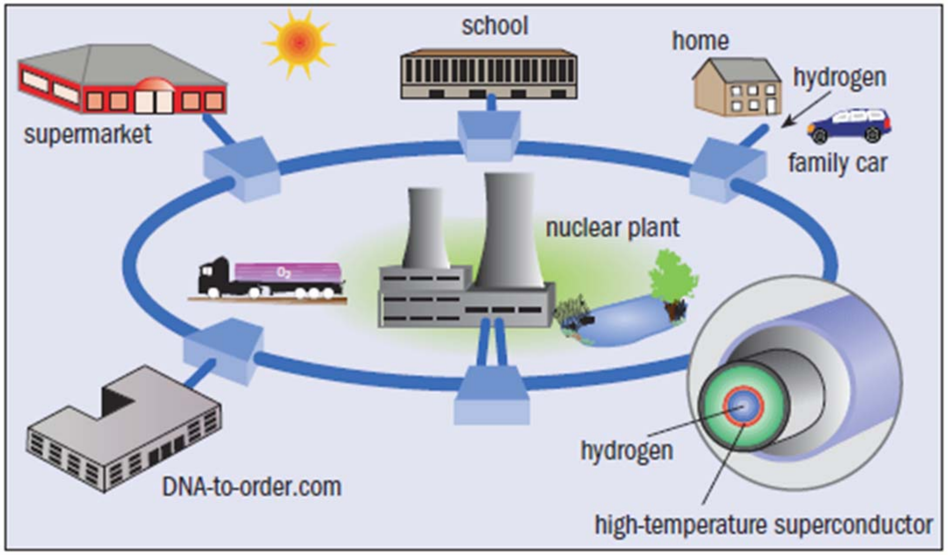
Why the world needs an 'extreme energy makeover'

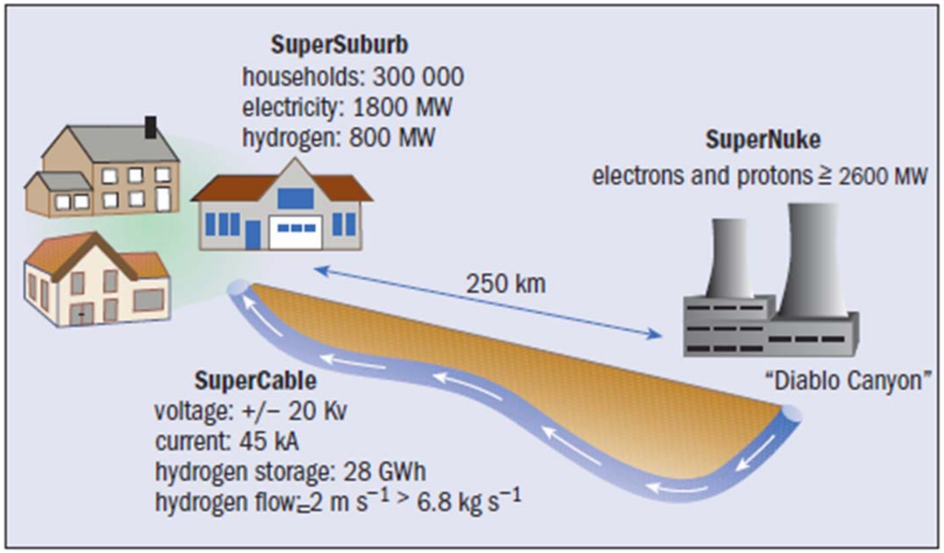
Anjana Ahuja

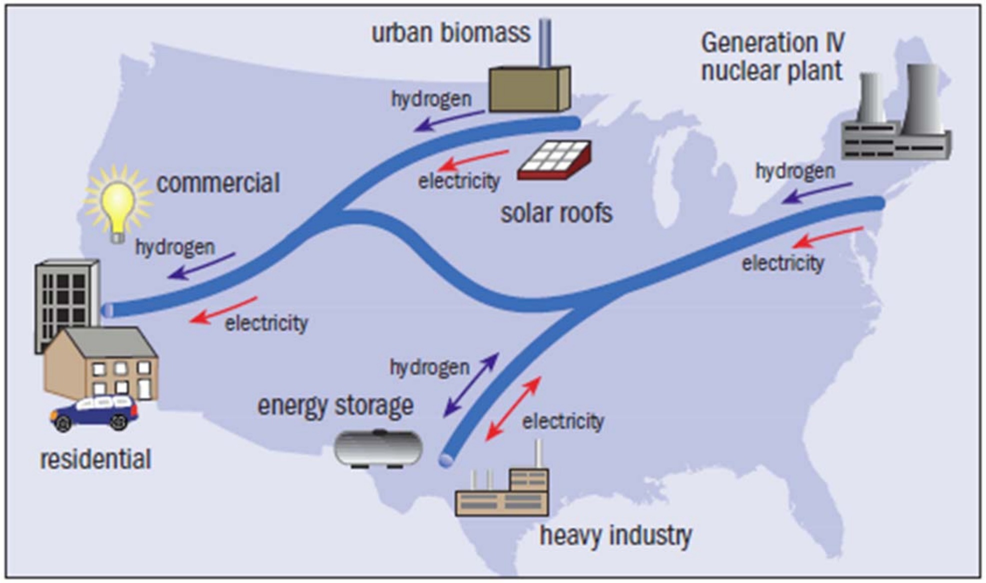
…a future editor of Nature…?

SuperCities - SuperSuburbs – SuperGrids

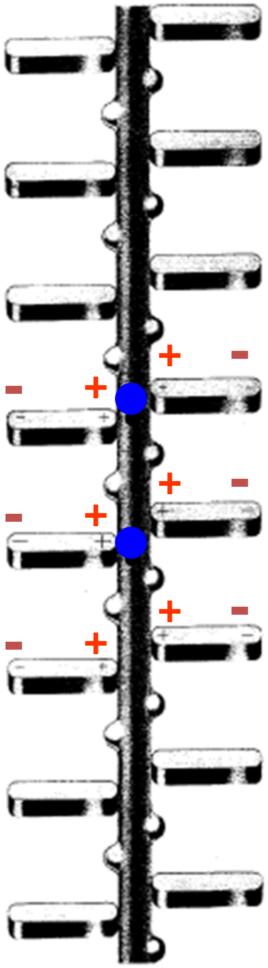
Grant, Overbye, Starr, SciAm 295, 76 (2006)

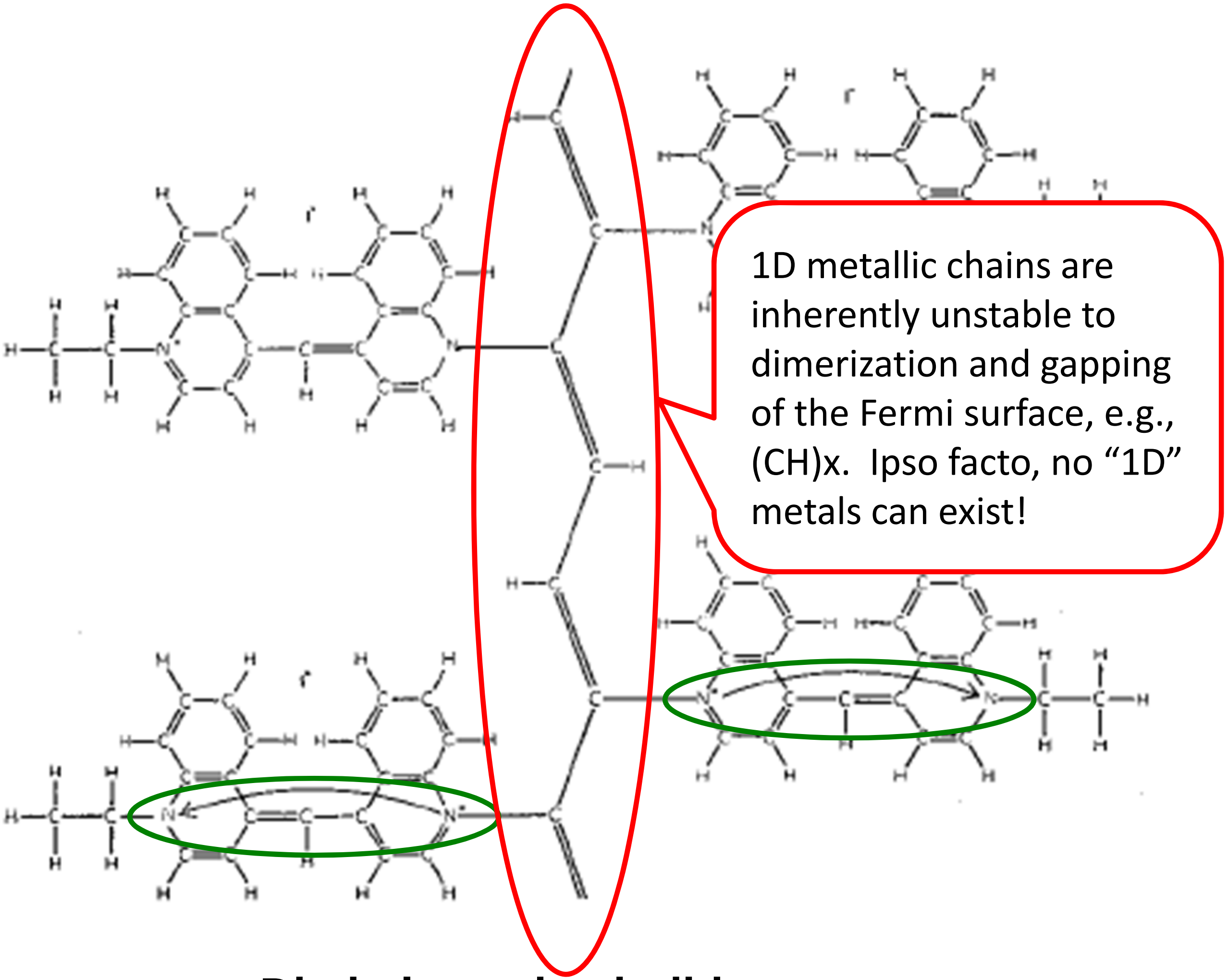






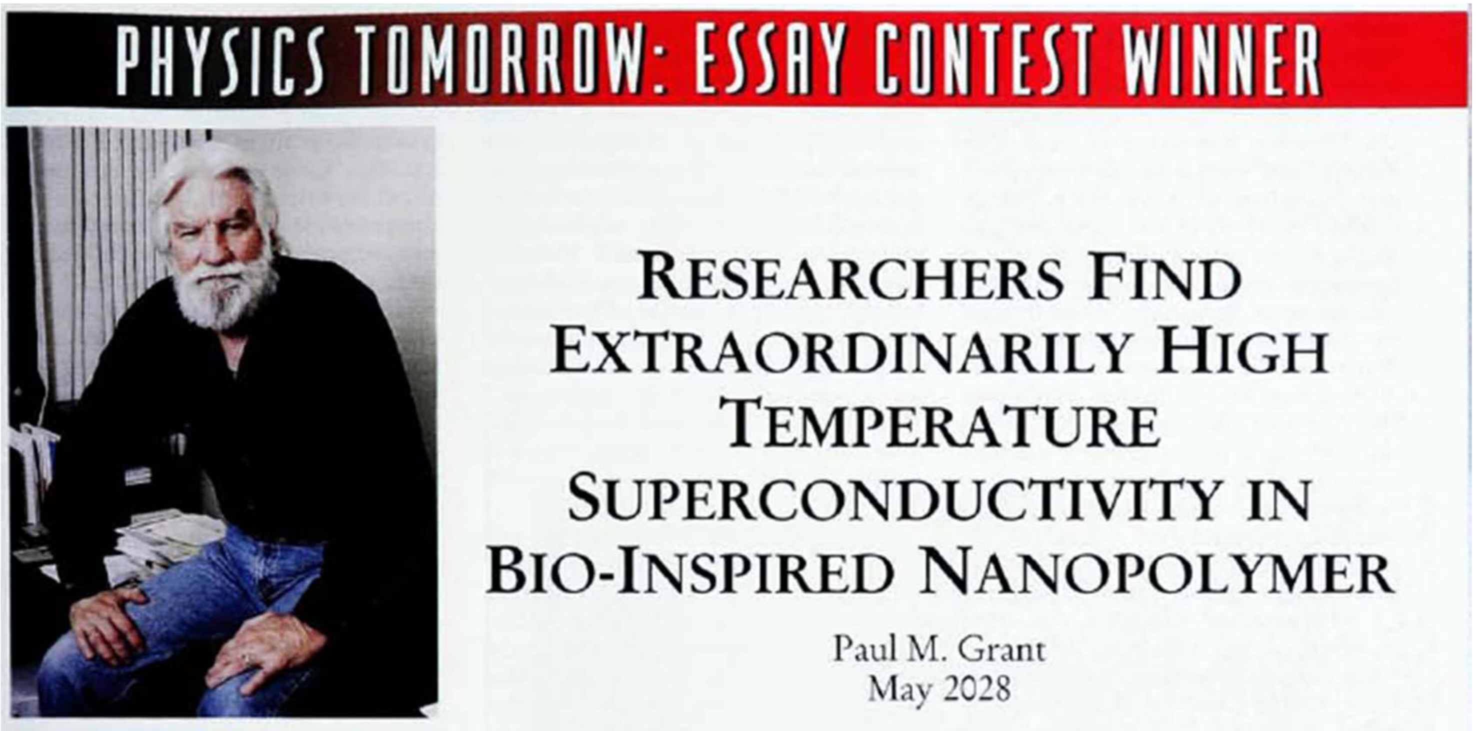
Room Temperature Superconductor
Little, Ginzburg, 1963




1D metallic chains are inherently unstable to dimerization and gapping of the Fermi surface, e.g., (CH)x. Ipso facto, no “1D” metals can exist!

Diethyl-cyanine iodide

Does the DA VINCI CODE Hold the Key to Room Temperature Superconductivity?



PHYSICS TOMORROW: ESSAY CONTEST WINNER

RESEARCHERS FIND EXTRAORDINARILY HIGH TEMPERATURE SUPERCONDUCTIVITY IN BIO-INSPIRED NANOPOLYMER

Paul M. Grant
May 2028

50th Anniversary of Physics Today, May 1998

“You can’t always get what you want…”

“…you get what you need!”