Superconductivity in Power Applications

The Role of Cryogenics in Transforming the Power Enterprise Worldwide

"A Sober Assessment of Opportunities and Realities"

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W2AGZ Technologies
San Jose, CA USA

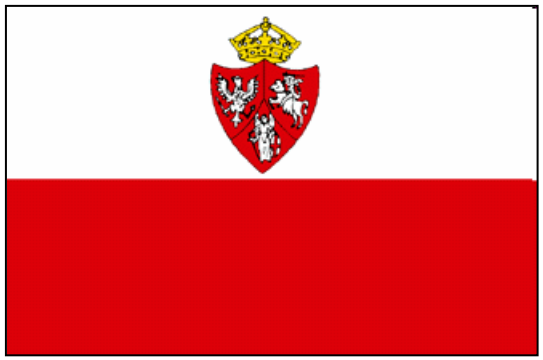
http://www.w2agz.com/BD_WROC10.htm

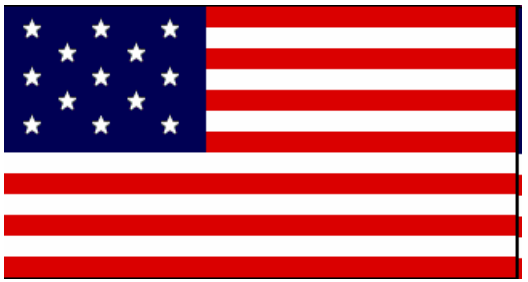
AGING IBM PENSIONER

Acknowledgements

- Financial
  - "IBM Retiree Pension Fund"
- Intellectual
  - Institutions: DOE, EPRI, LANL, ORNL, AMSC, SuperPower, Southwire, Stanford, Wisconsin …
  - Individuals: Bob Hammond, Dave Christen, Vlad Matias, Steve Ashworth, Steve Eckroad, Mac Beasley, Ted Geballe, David Larbalestier, George Crabtree, Yuh Shiohara, Carl Rosner … and many, many more.

The Polish in America





1836

1777

Thaddeus Kosciusko

Casimir Pulaski

The Journey

- History
- Wire
- Applications
- Marketing
- Vision

History

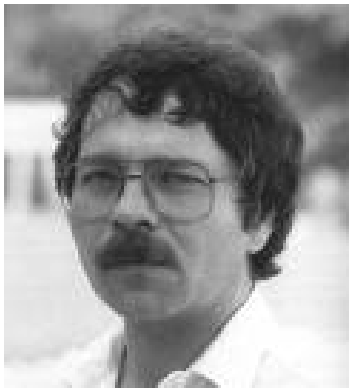
- Discovery
- Theory
- Type II Materials

Discovery

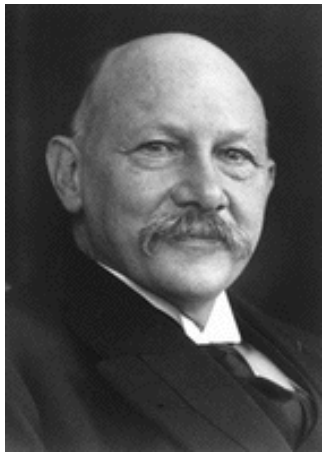
1911 (4.2 K)

Gilles Holst

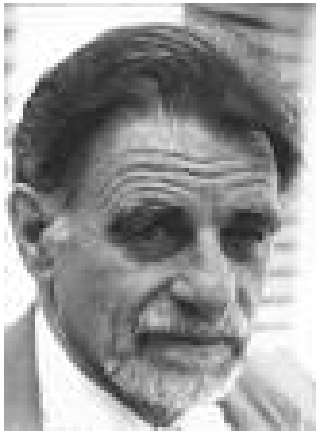
1986 (20-40 K)



Georg Bednorz

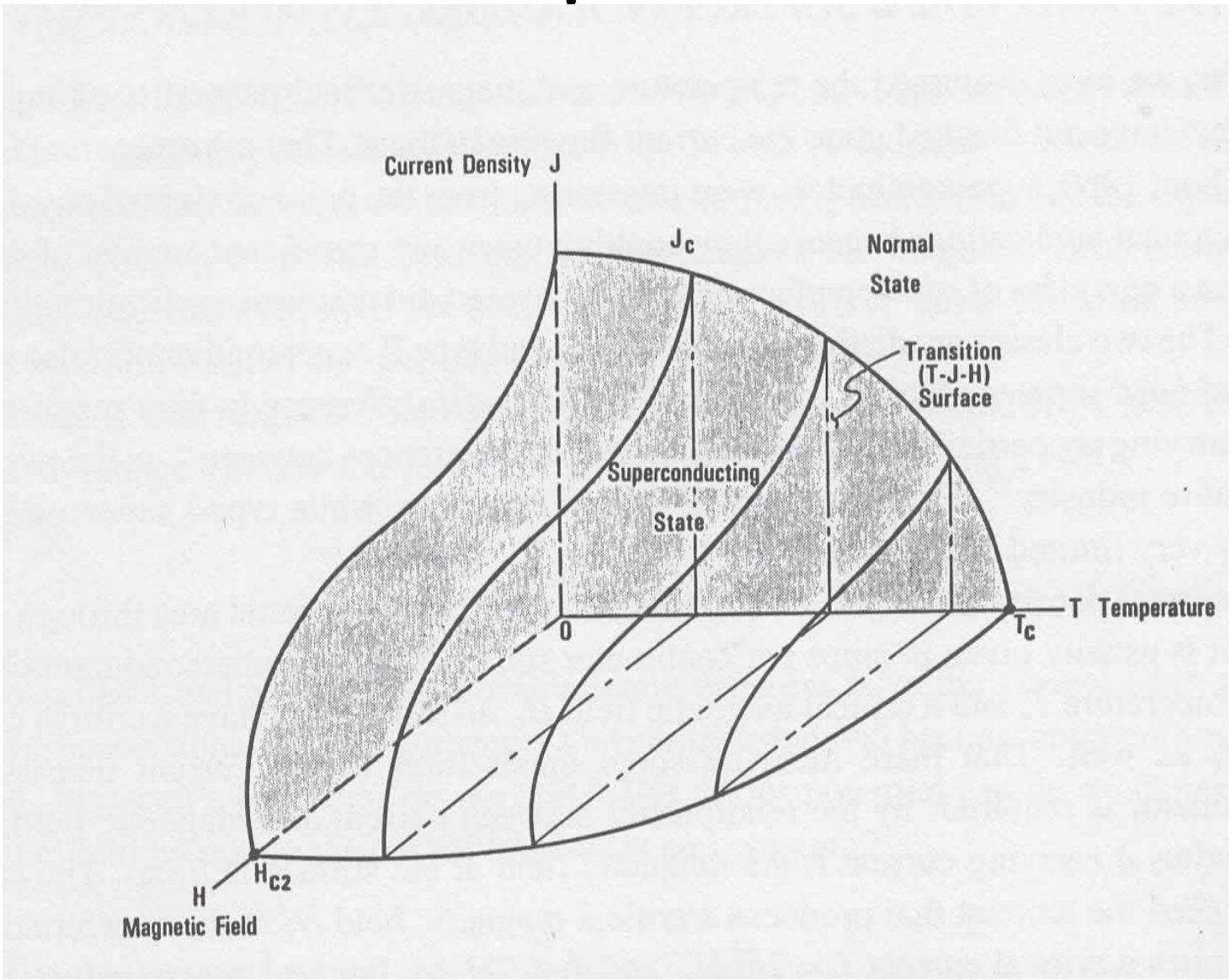


H. Kammerlingh-Onnes

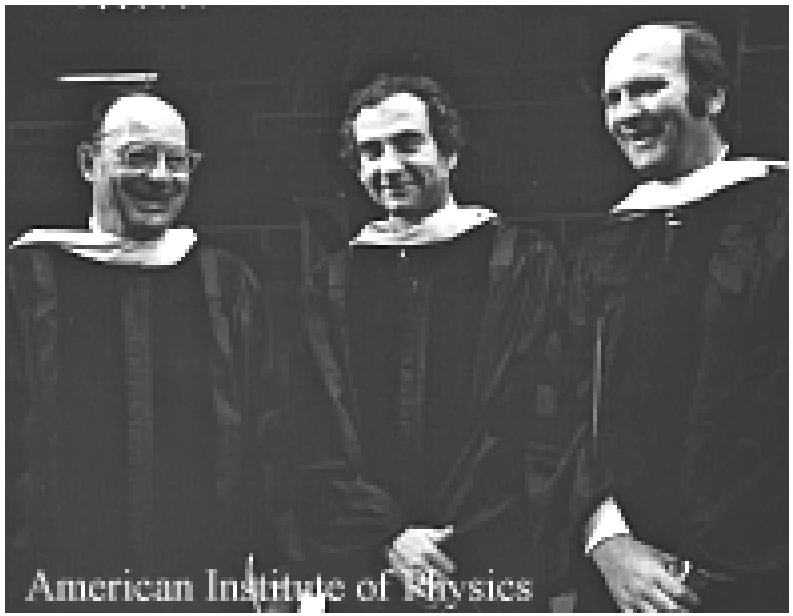


Alex Mueller

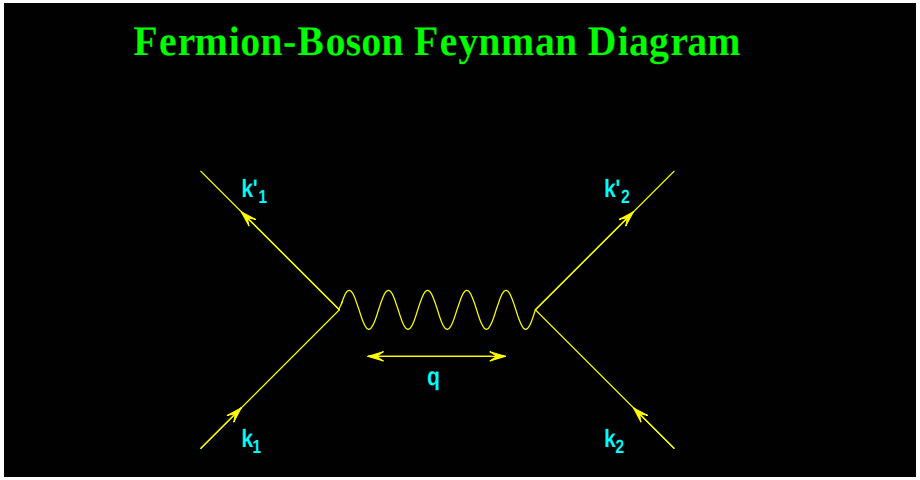
Properties


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

Theory (1956)

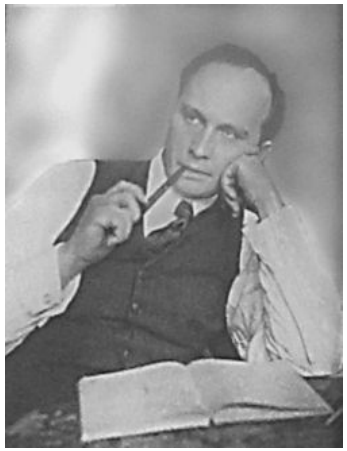


Bardeen-Cooper-Schreiffer (BCS)



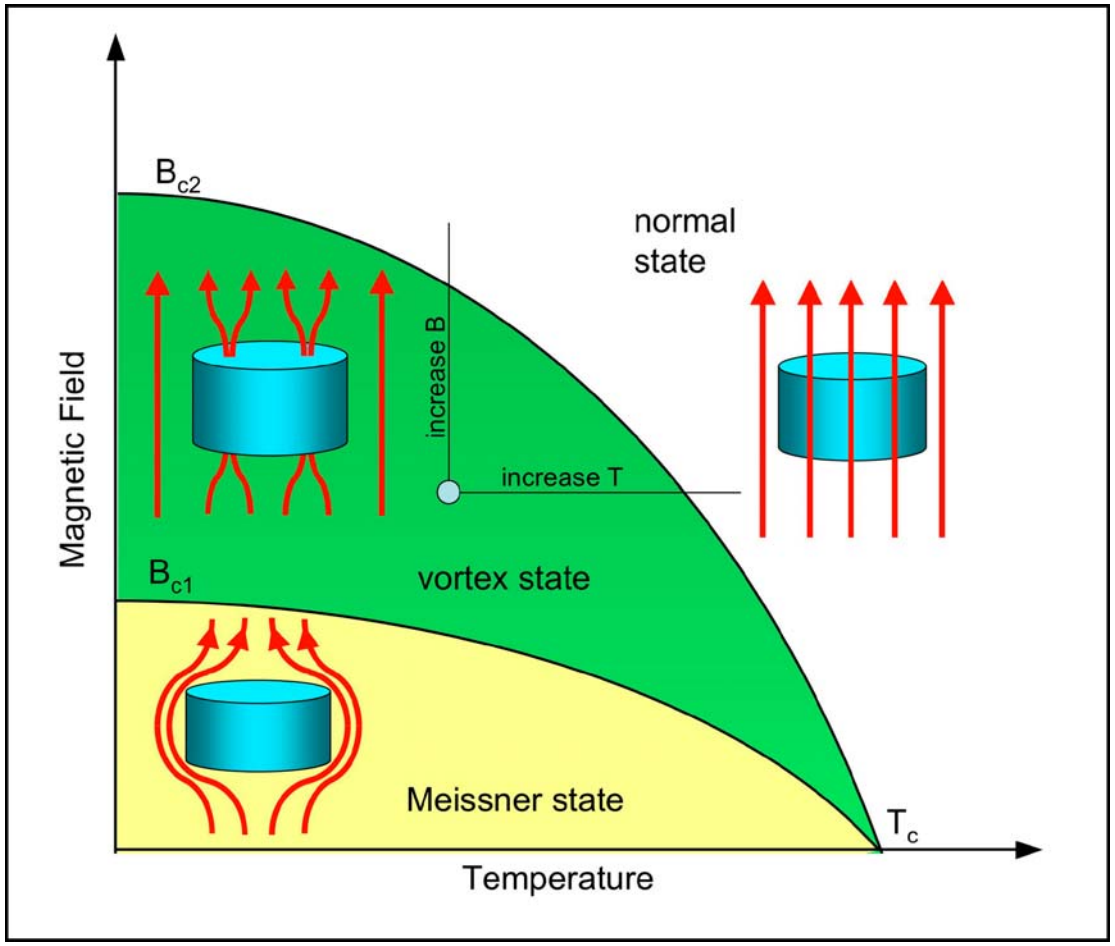
- General Features of All Known Superconductors
  - Second order phase transition yielding energy gap
  - Pairing of two fermions (e.g., electrons) mediated by a boson field (e.g., phonons) into a single quantum state (e.g., q=2e).
  - Devil is in the nature of the pairing mechanism (phonons for LTSC, no agreement wrt HTSC)

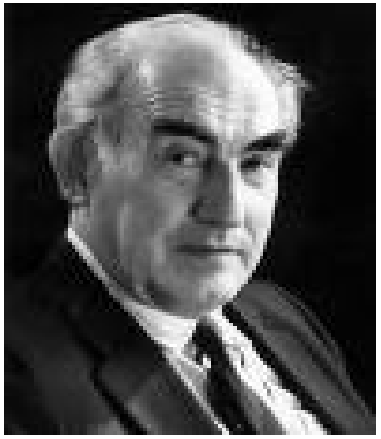
Type II (1930s +)



Lev Shubnikov

Lev Landau





"VL" Ginzburg

Aleksei Abrikosov

GLAG
Ginzburg-Landau-Abrikosov-Gorkov

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

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

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

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

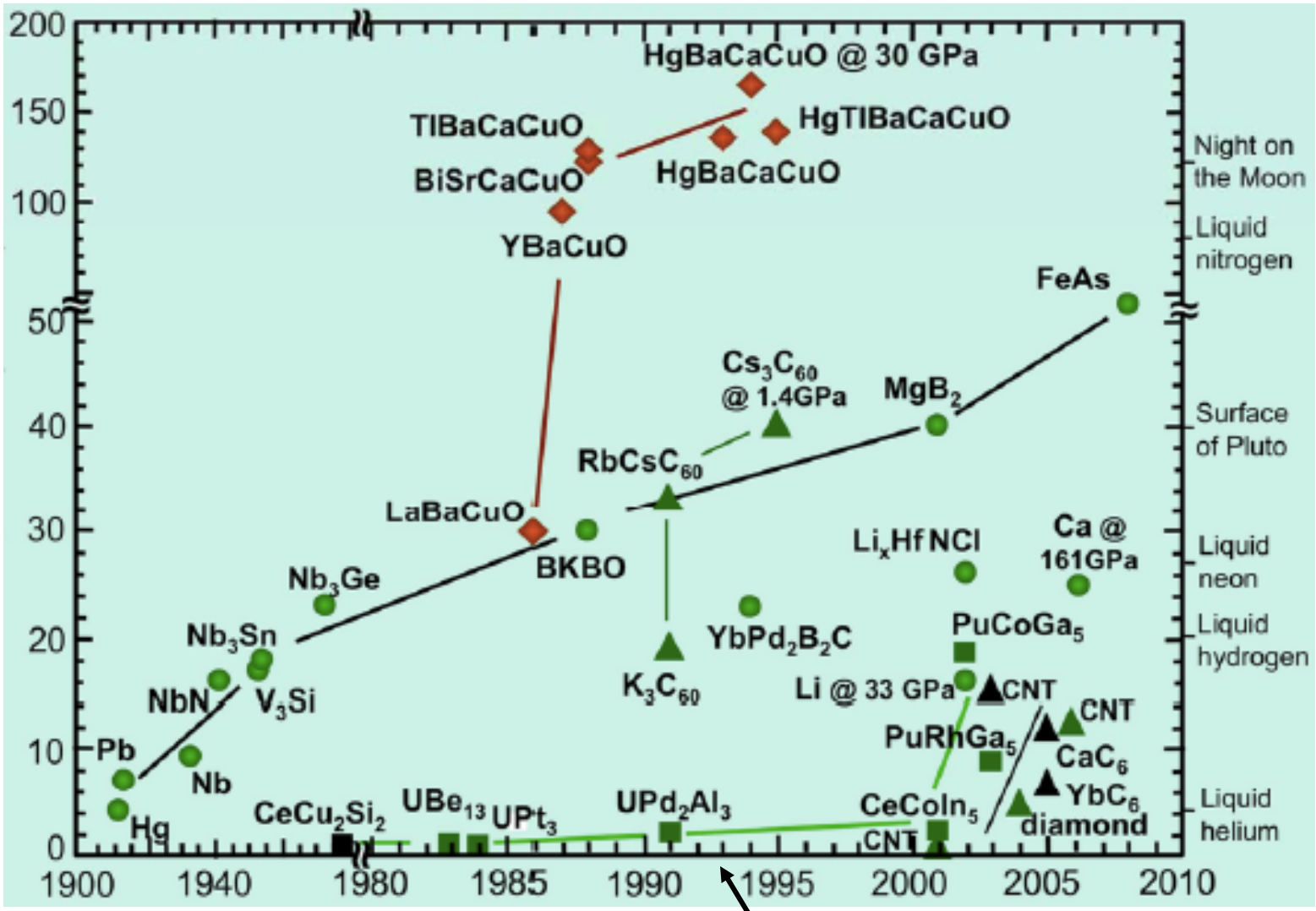
$$A = (\Phi_0 / 2\pi\xi) A$$

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

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

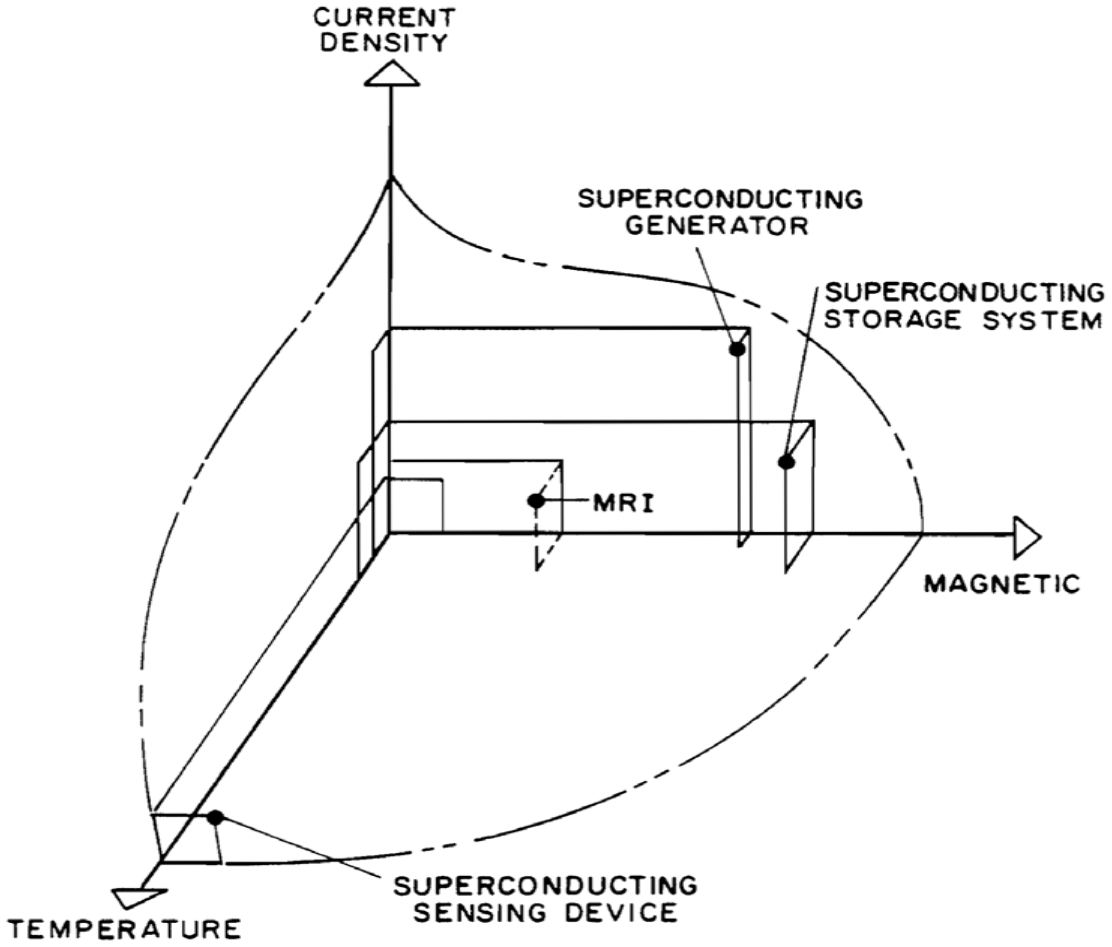
$$\kappa > 1/\sqrt{2} \qquad \text{II}$$

Today



Non-Linear: Hockey Stick !

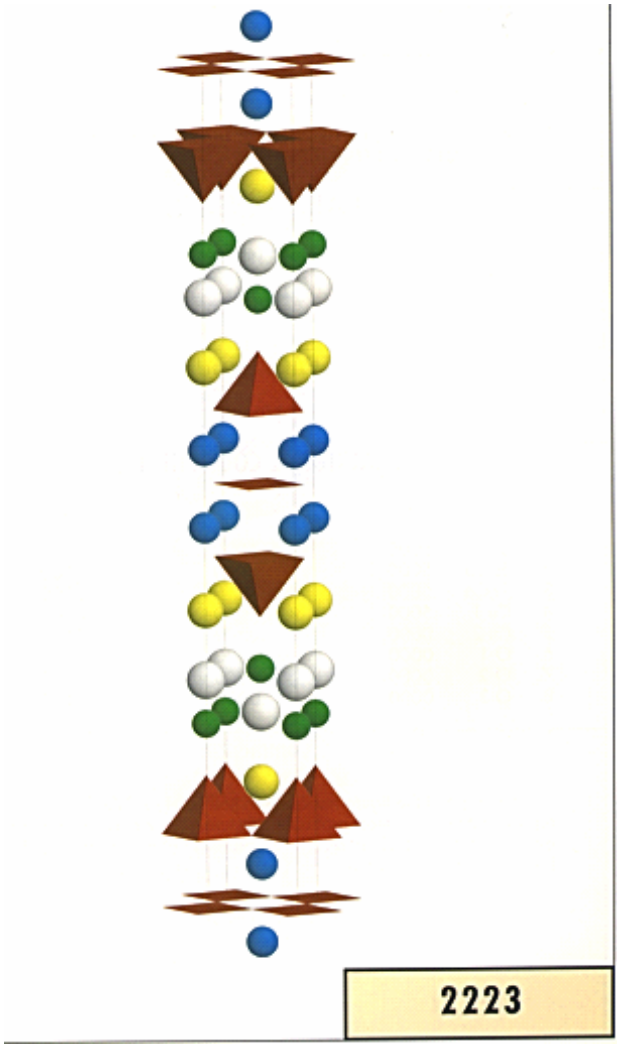
Applications Landscape

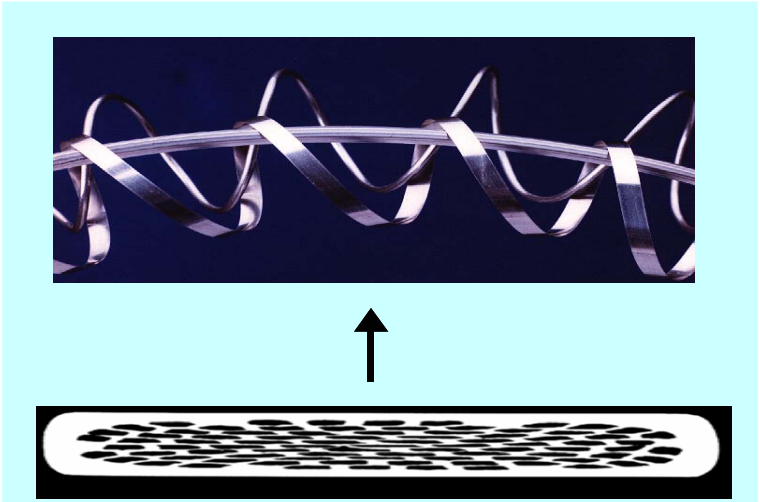


Wire

- Development and Embodiment
- Performance and Specifications

First HTSC "Wire"



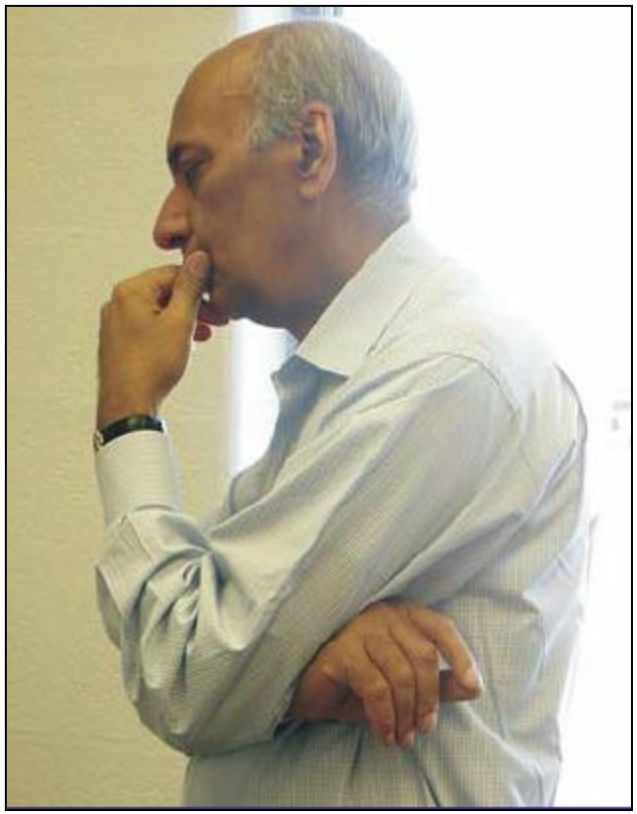


Gen 1

VOLUME 61, NUMBER 2 PHYSICAL REVIEW LETTERS 11 JULY 1988

Orientation Dependence of Grain-Boundary Critical Currents in $YBa_2Cu_3O_{7-\delta}$ Bicrystals

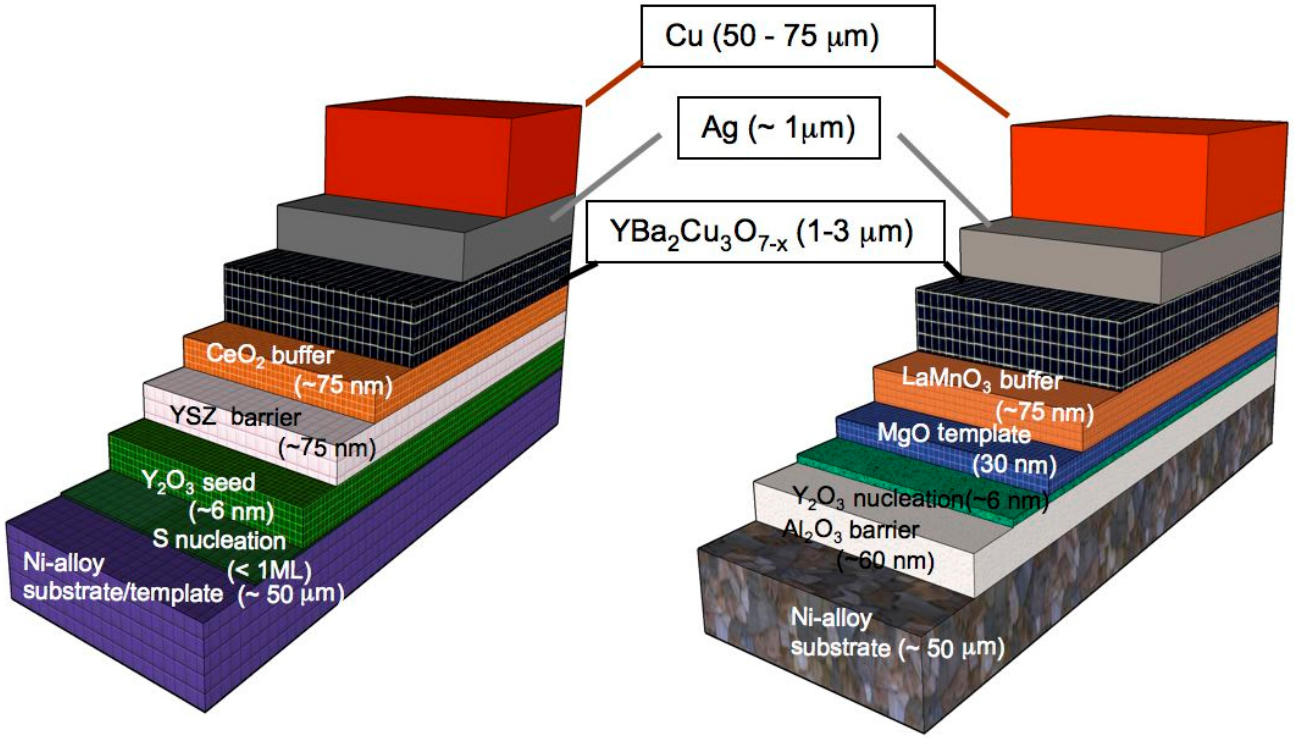
D. Dimos, P. Chaudhari, J. Mannhart, and F. K. LeGoues
Thomas J. Watson Research Center, IBM Research Division,
Yorktown Heights, New York, 10598
(Received 4 May 1988)



Praveen Chaudhari, 1937 - 2010

Physics Today, p.64, April 2010

Gen II Coated Conductor



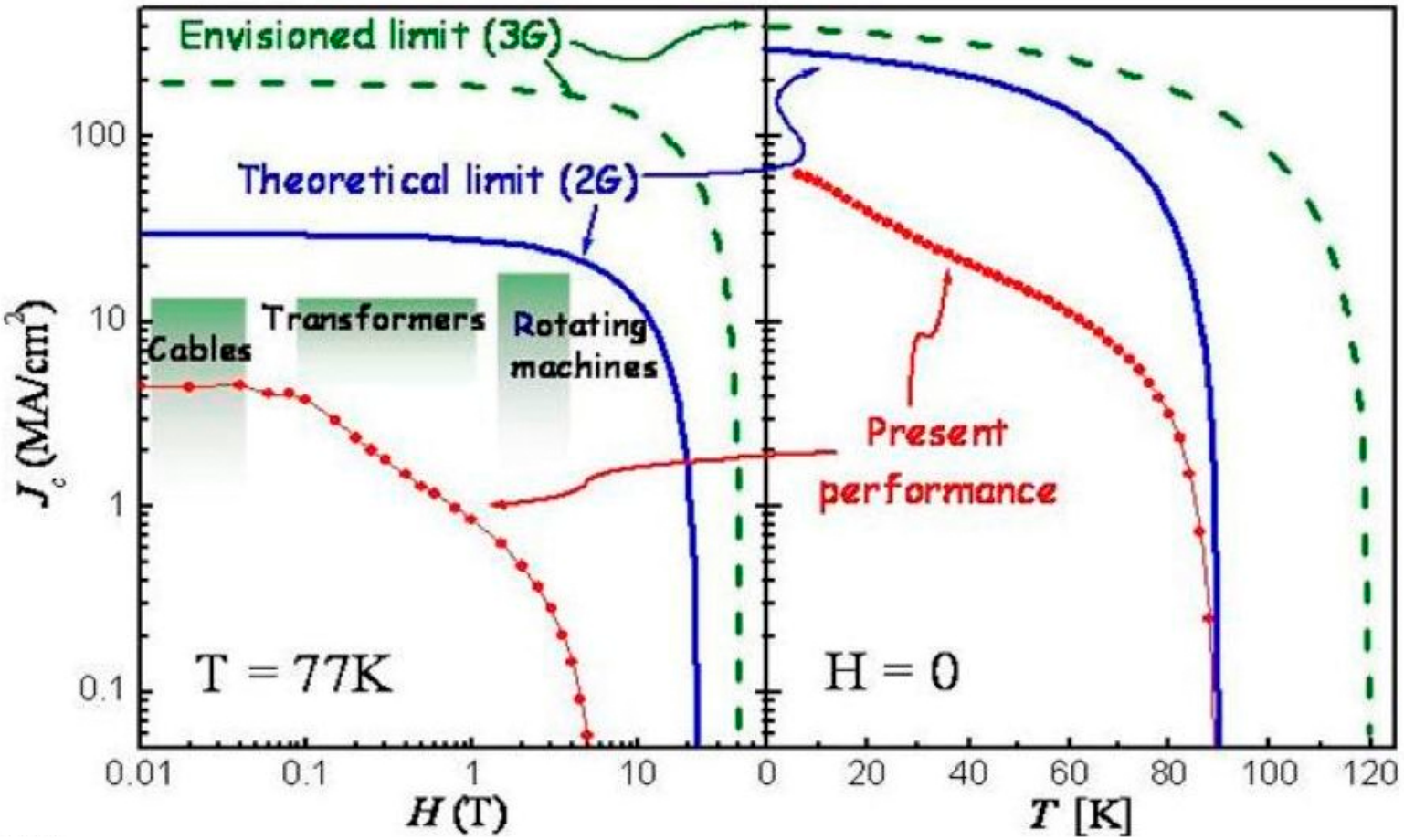
Rolling-Assisted Biaxially Textured Substrates (RABiTS)

Ion-Beam-Assisted Deposition (IBAD)

American Superconductor

SuperPower

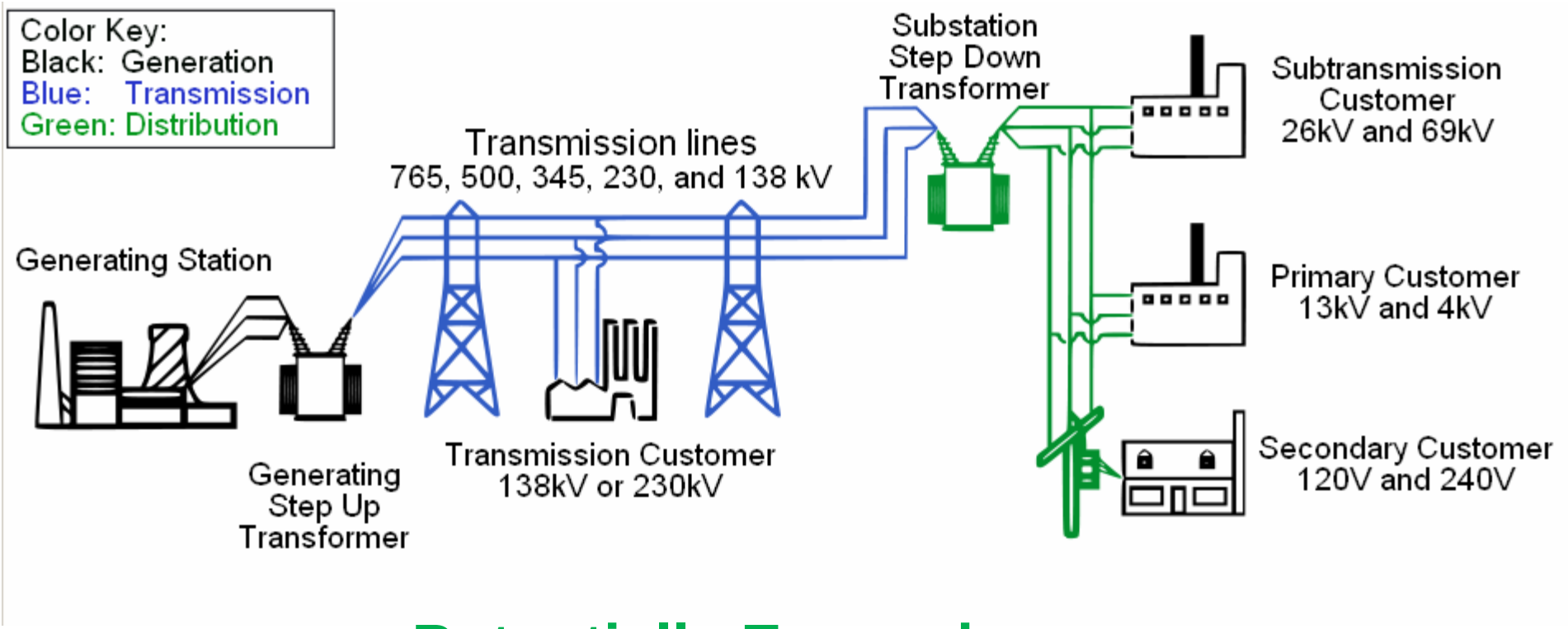
Wire Performance



Applications
- Prototyping & Demonstration -

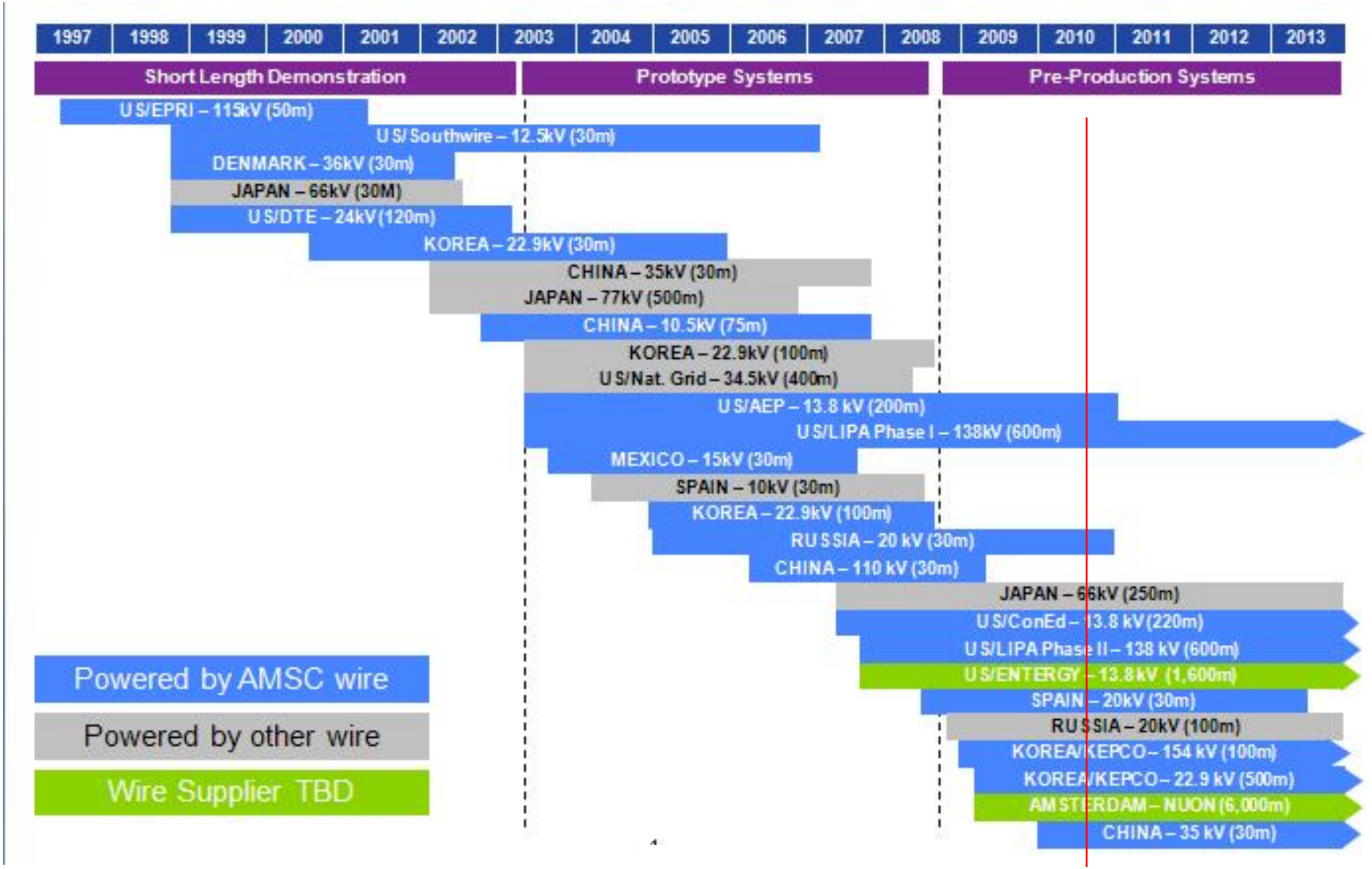
- Cables
- Rotating Machinery
- Passive/Active Devices (SMES, FCL, PQ)
- *What I Won't Talk About !*
  - Big Electromagnets
    - HEP
    - MRI
    - Medical
  - Transportation
  - Military (well…maybe a little!)

Where Can We Apply Superconductivity to Electric Power?



Potentially Everywhere

HTSC Cable Projects Worldwide
Past, Present…Future?

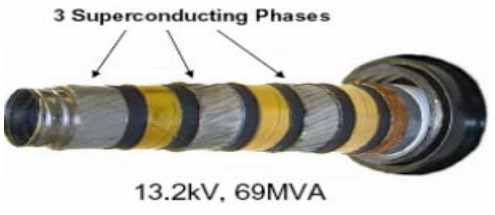


U.S. HTS Cable Installations

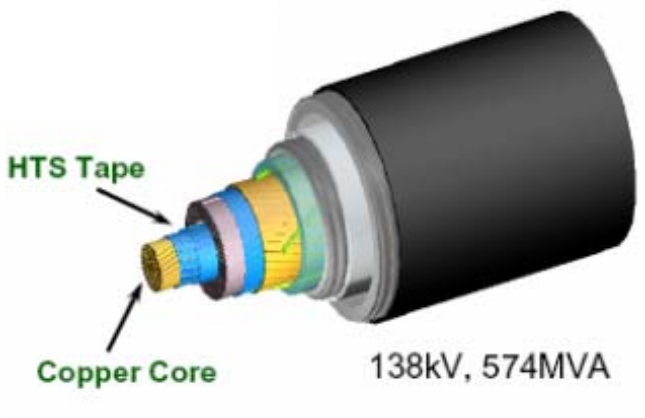
Various ac HTSC Cable Designs

Cable configuration: 3 phases in 1 common cryostat

Sumitomo



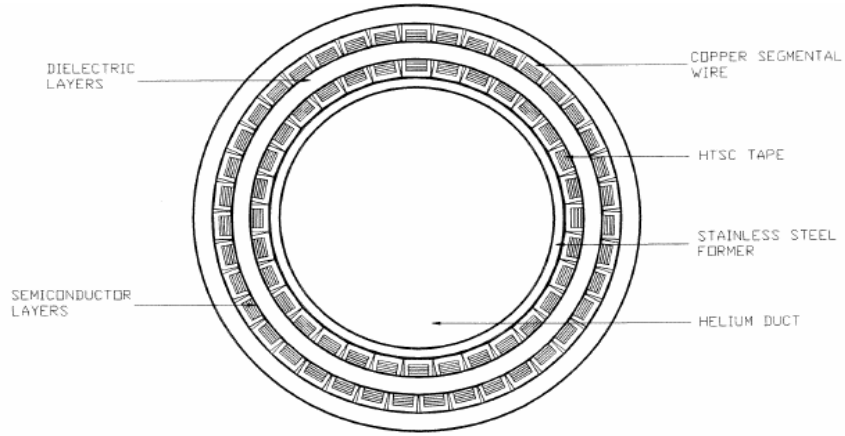
Ultera-ORNL



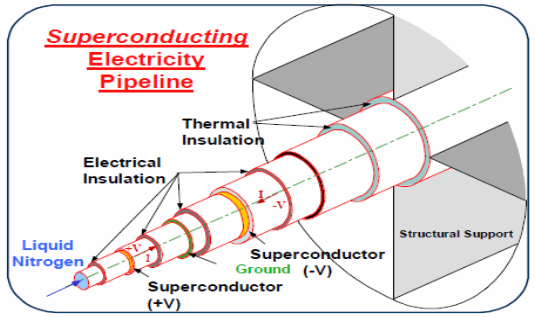
Nexans-AMSC

Pirelli

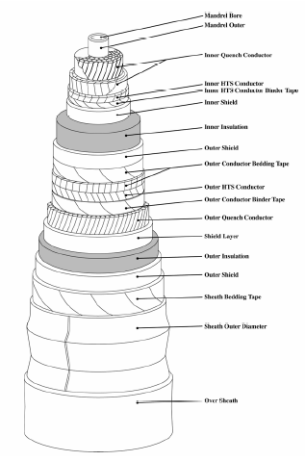
Various dc HTSC Cable Designs

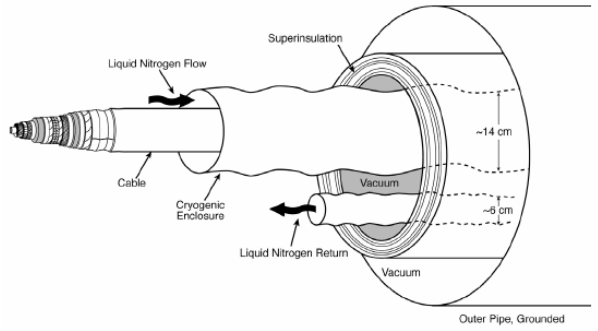


BICC: Beales, et. al, (1995)
40 K, +/- 20 kV, 10 kA, 400 MW



EPRI: Schoenung, Hassenzahl, Grant (1997)
+/- 50 kV, 50 kA, 5 GW



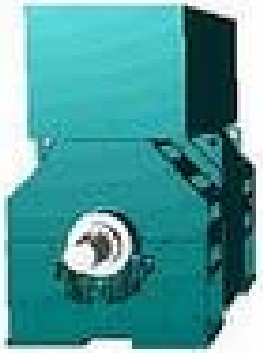


EPRI: Hassenzahl, Gregory, Eckroad, Nilsson, Daneshpooy, Grant (2009)
+/- 50 kV, 100 kA, 10 GW

Example:
Long Island Power Authority

Superconducting Motors

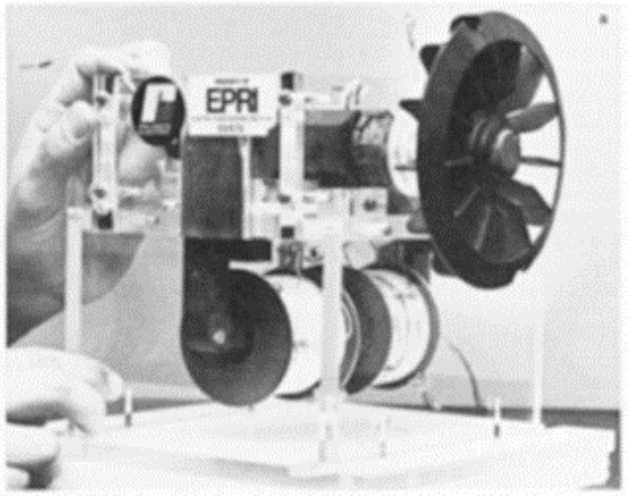
HTS Motor



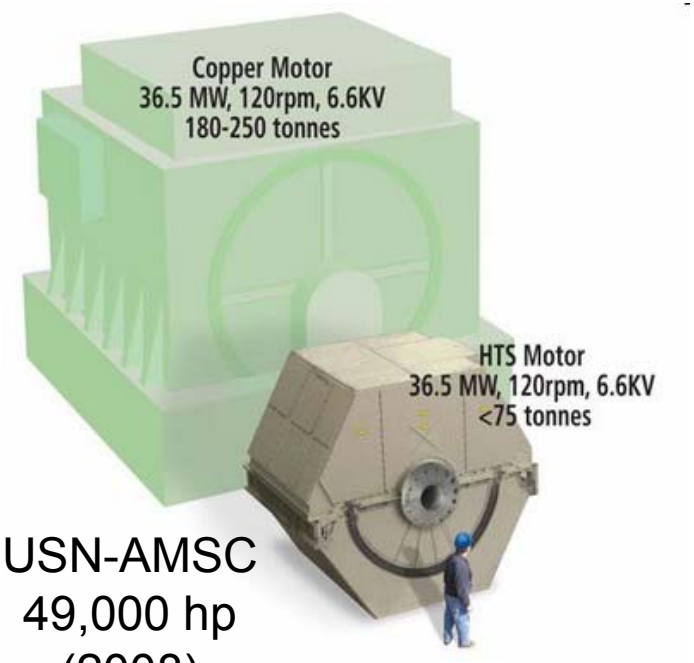
- Efficiency = 98.6%
  - 43% of the loss in the conventional motor
- Smaller volume
  - 47% of the volume of the conventional motor

High Efficiency Conventional

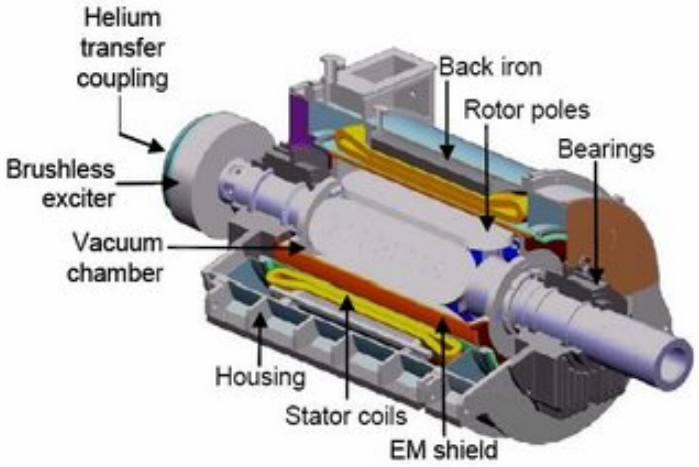
- Efficiency = 96.8%
  - 230% of the loss in the HTS motor
  - Annual energy costs to operate may be **$50,000 more** than HTS motor.
- Larger volume



EPRI 1 hp (1988)



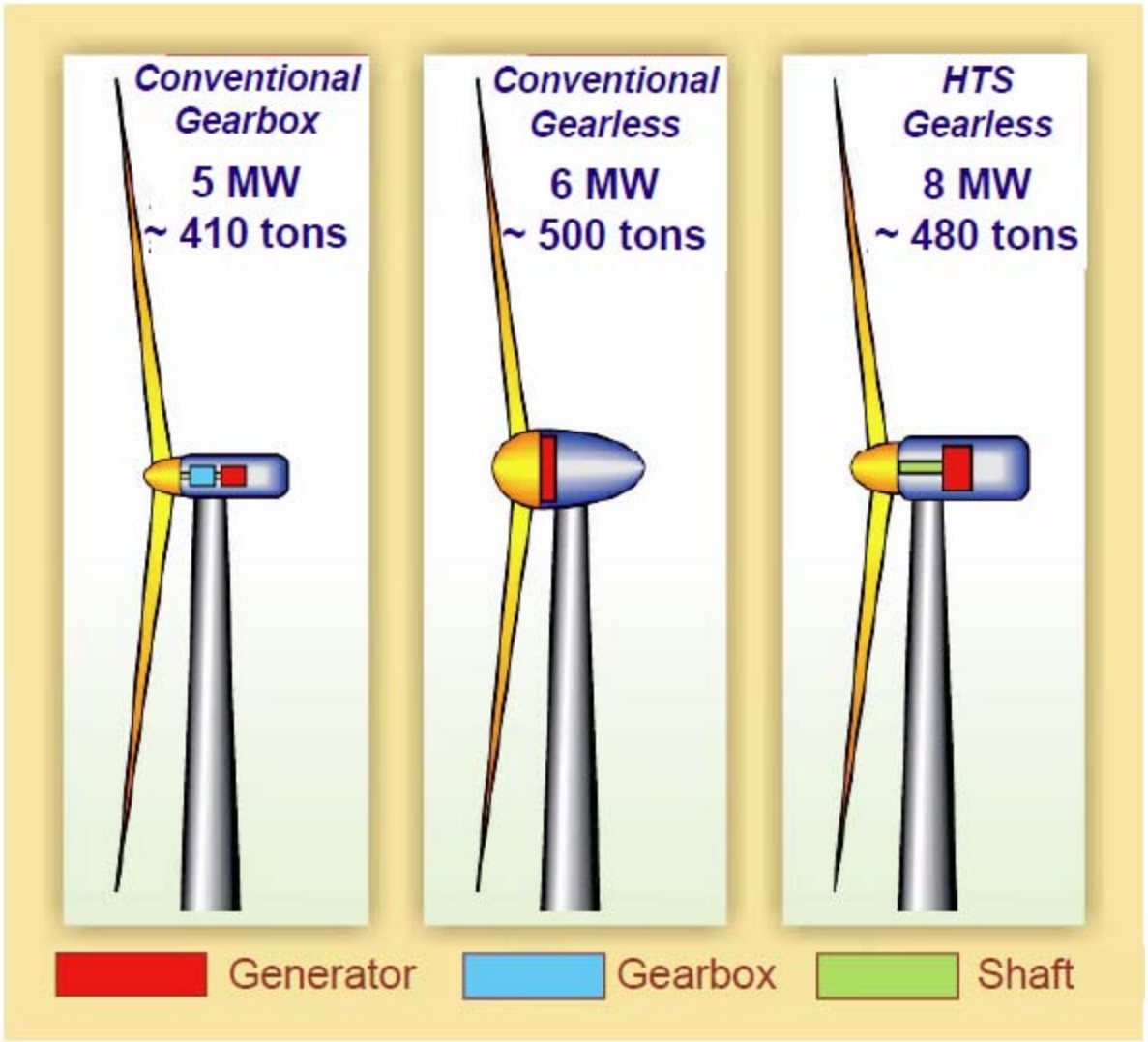
USN-AMSC
49,000 hp
(2008)



AMSC 7000 hp
(2003)

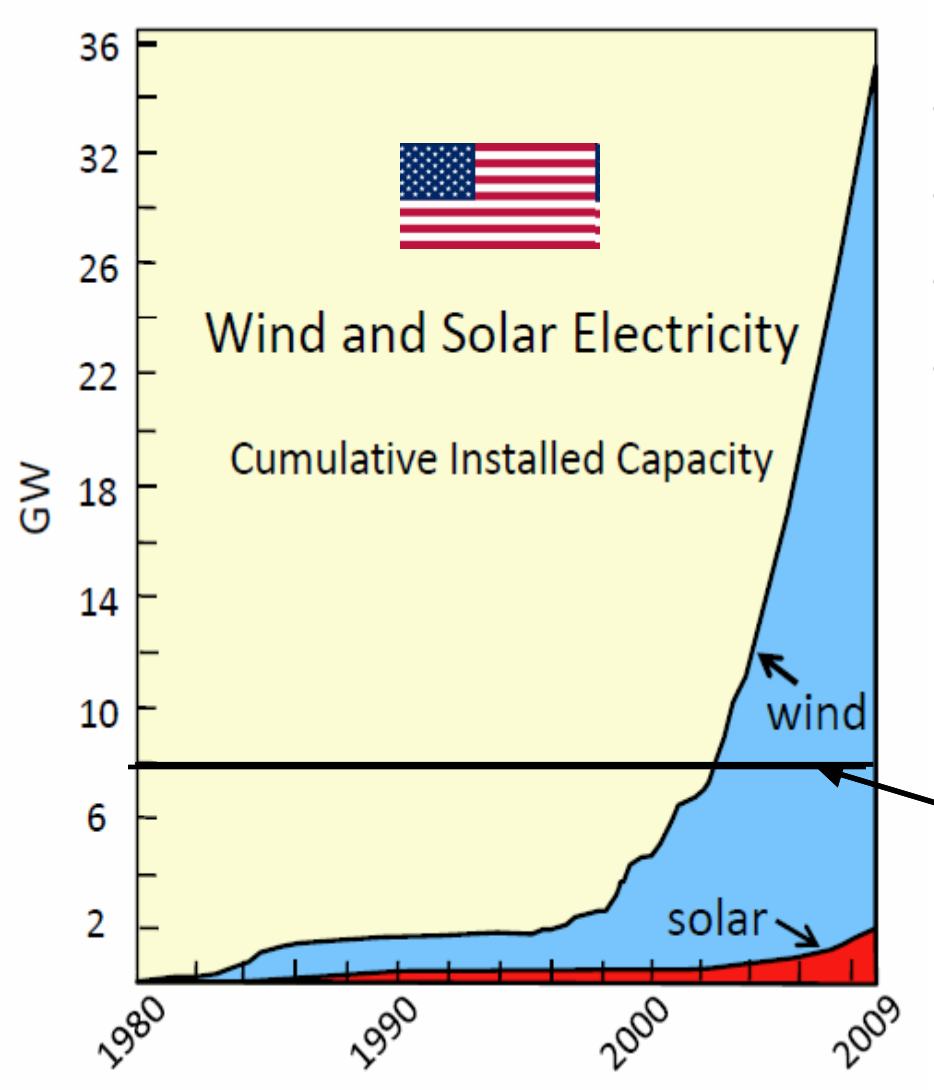
Sumitomo 70-460 hp
(2009)

Rotating Machinery - Wind Generators



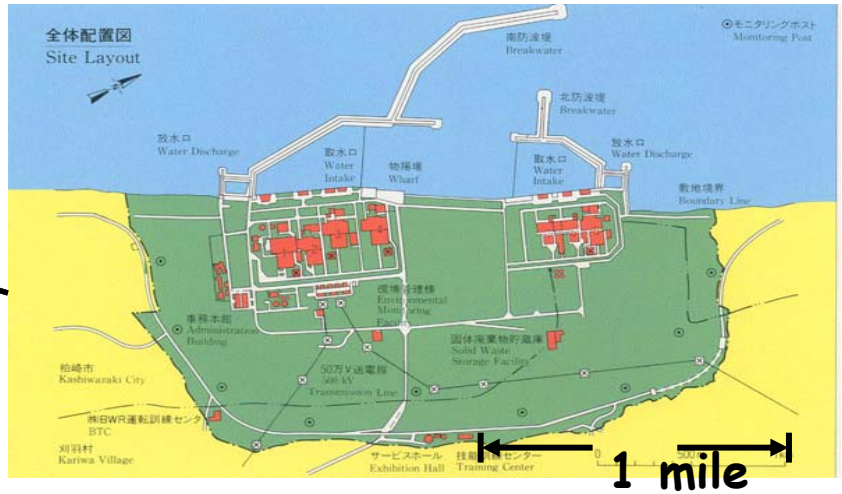
Matthews, Physics Today **62**(4), 25 (April 2009)

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

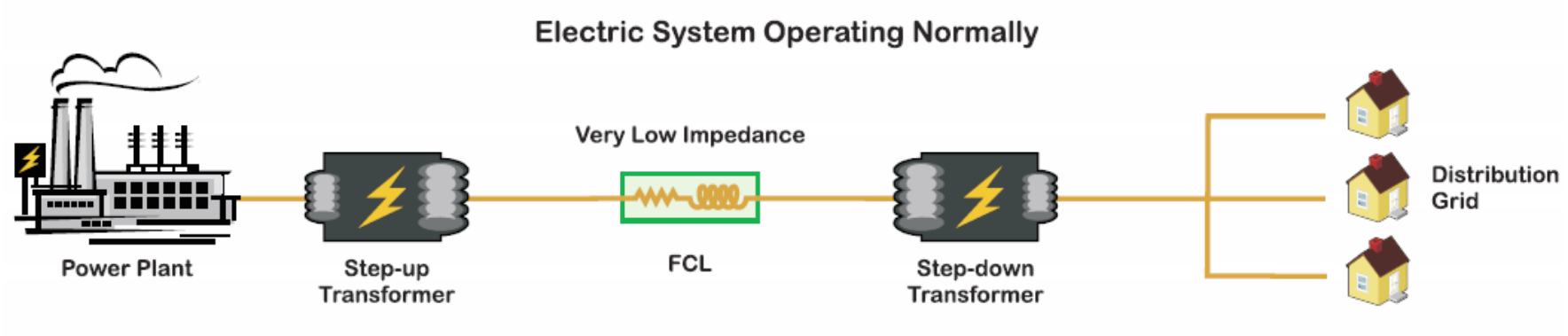
Power Conditioning

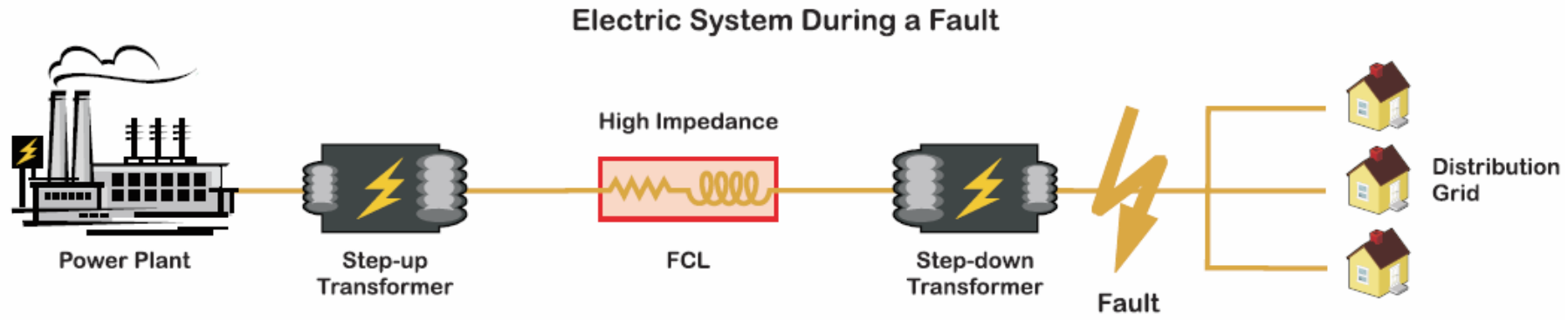
Bruker 2 MJ SMES

AMSC D-Var

- "Orthogonal" to SMES…stores reactive power in an ordinary coil
- Great for intermittent generation…like wind

Fault Current Limiters 101

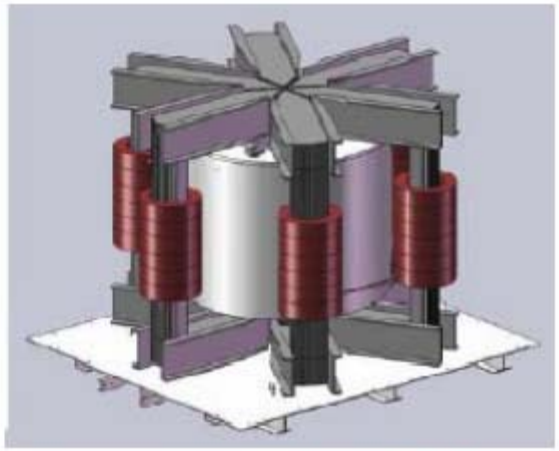




Stand-alone fault current limiters – Saturable iron core

- DC superconducting coil used to saturate iron core
  - Operation between 30 K to 50 K
  - Not in the ac circuit itself although exposed to ac field
- Initial 15 kV, 1200 A 3-Φ system inserted in Southern California Edison grid
  - Designed for 23 kA_{rms} fault limited by 20%
  - System operation over past year used to gain system experience
- Final 138 kV, 1300 A 3-Φ system design to be inserted in the AEP's Tidd substation

ZENERGY POWER



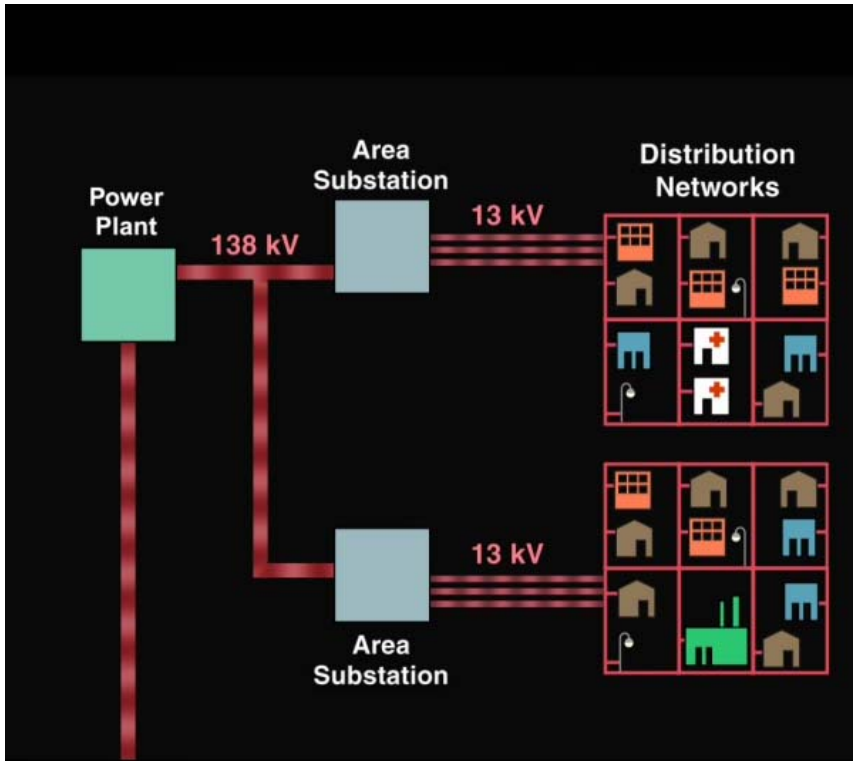
Schematic of 3-Φ FCL unit

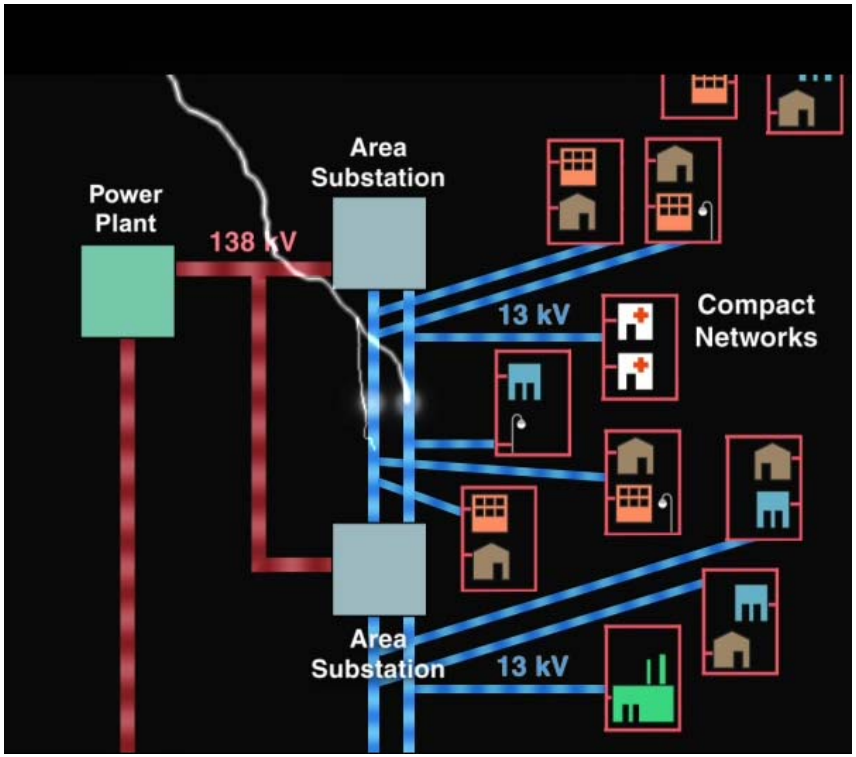
Actual installed device in Southern California Edison grid

Nom. 2G tape length requirements 10 to 100 km

Project Hydra
DHS, NYC, ConEd, AMSC

Concept: Combine High Capacity HTSC Cables With FCL Functionality





US Department of Energy

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

DOE Conclusion: HTSC Power Technology is now "on the shelf" and ready to deploy !

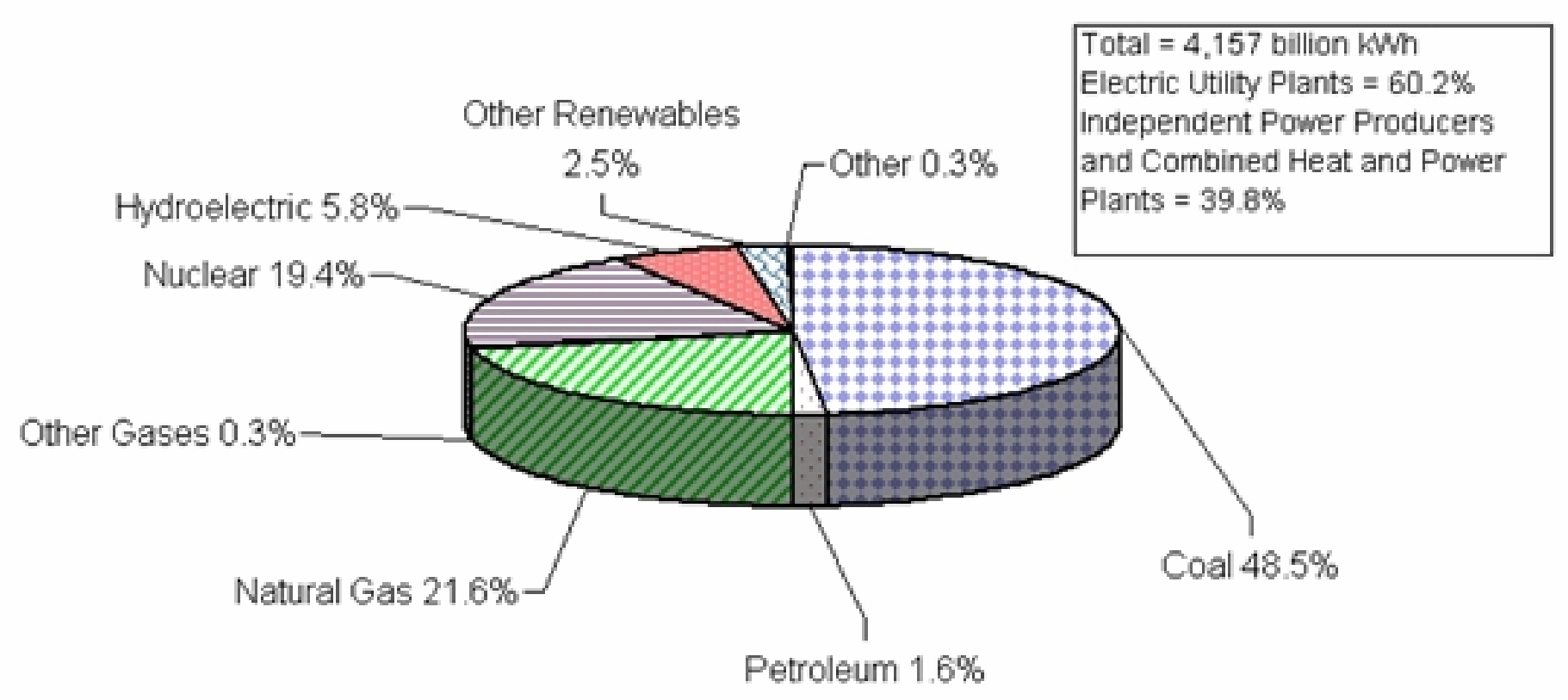
	FY 2009		FY 2010	FY 2011
	Current Appropriation	ARRA Appropriation	Current Appropriation	Congressional Request
Research and Development				
High Temperature Superconductivity	23,130		?	?
Visualization and Controls	24,461			
Energy Storage and Power Electronics	6,368			
Renewable and Distributed Systems 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"

Marketing

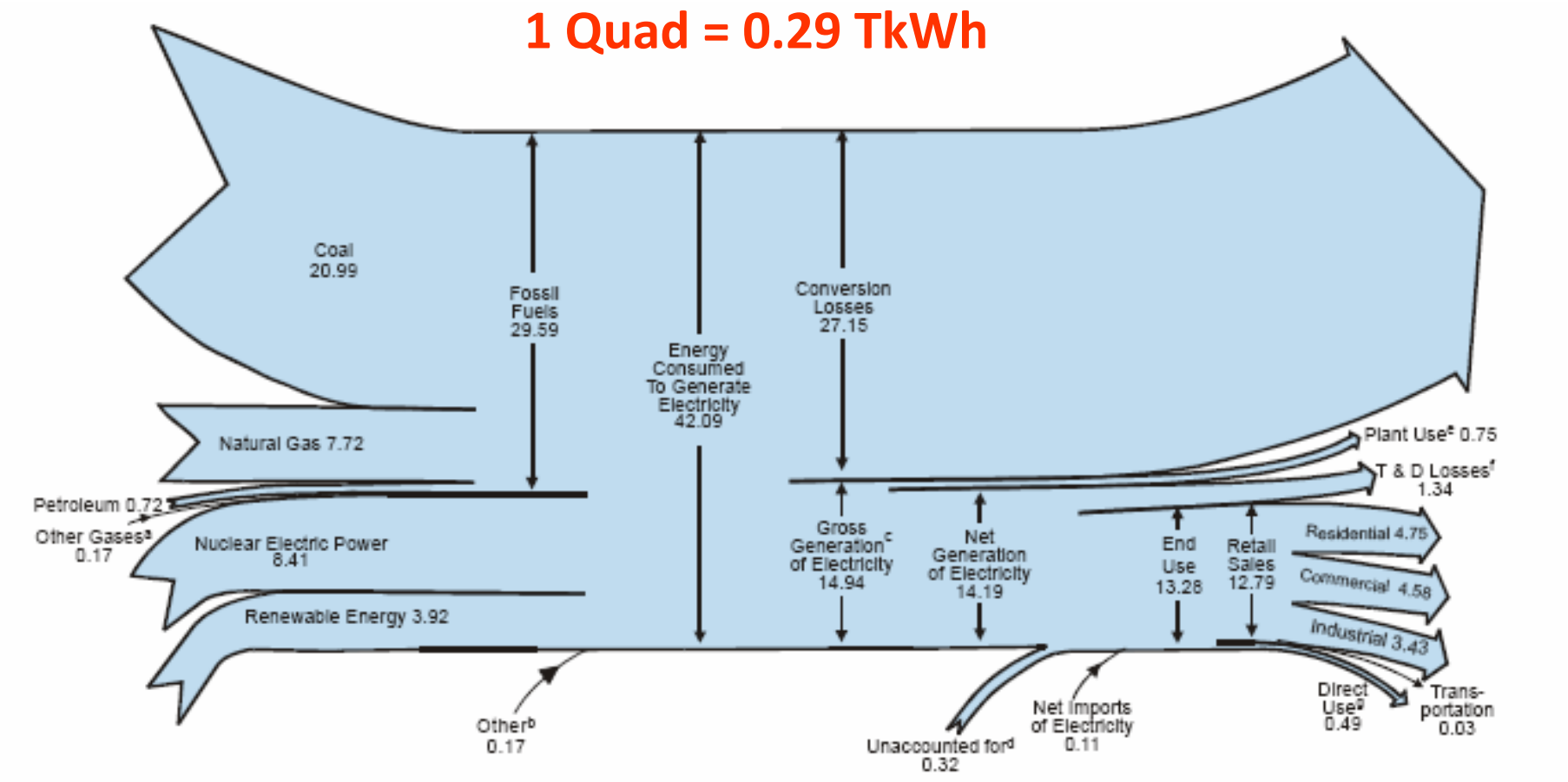
- Insertion and Deployment
- Compelling Needs?
- Killer Apps?

US Electricity Generation Sources



US Electricity Flow - 2007

1 Quad = 0.29 TkWh

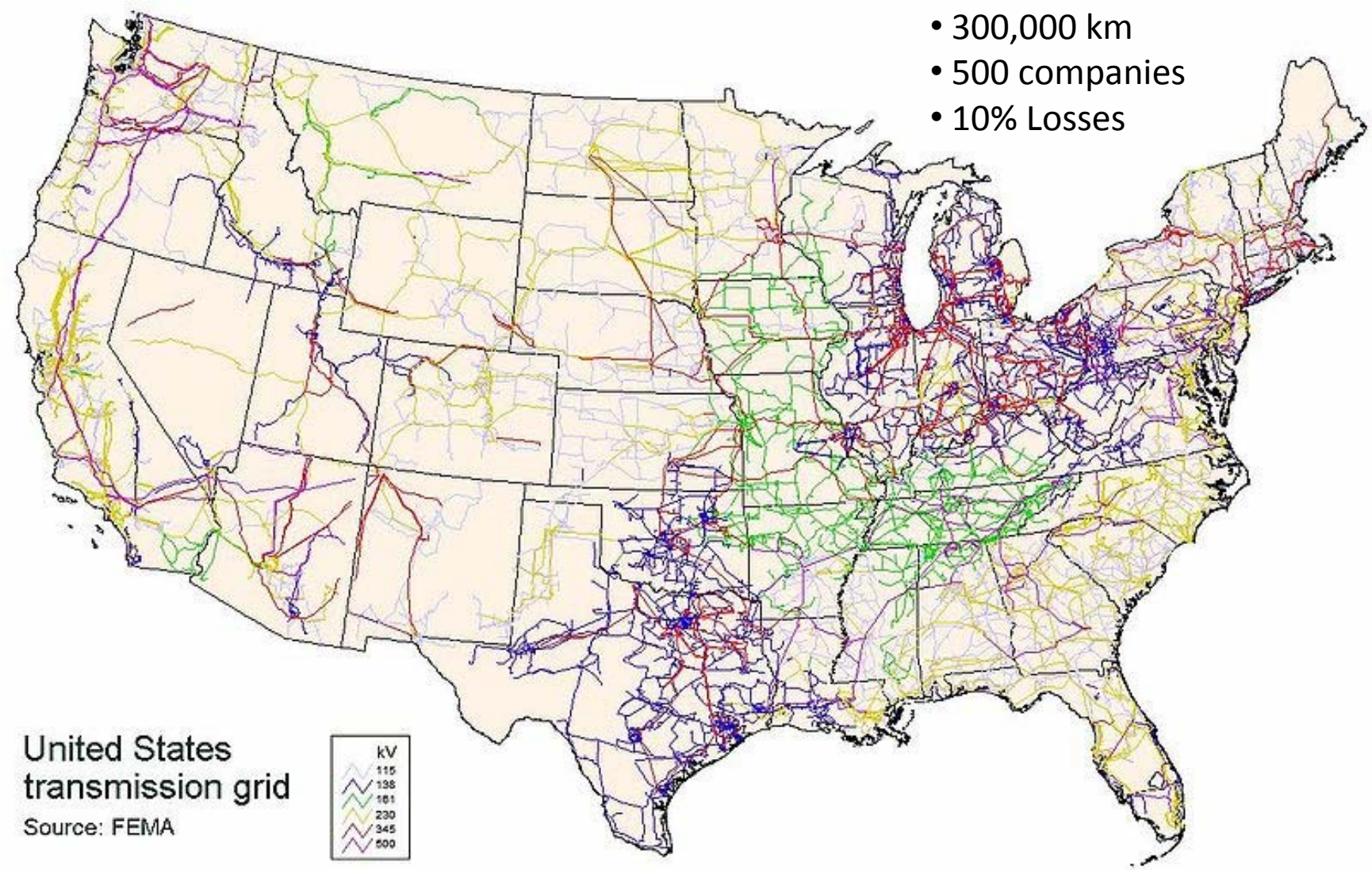


US Generation Capacity = 1.1 TW

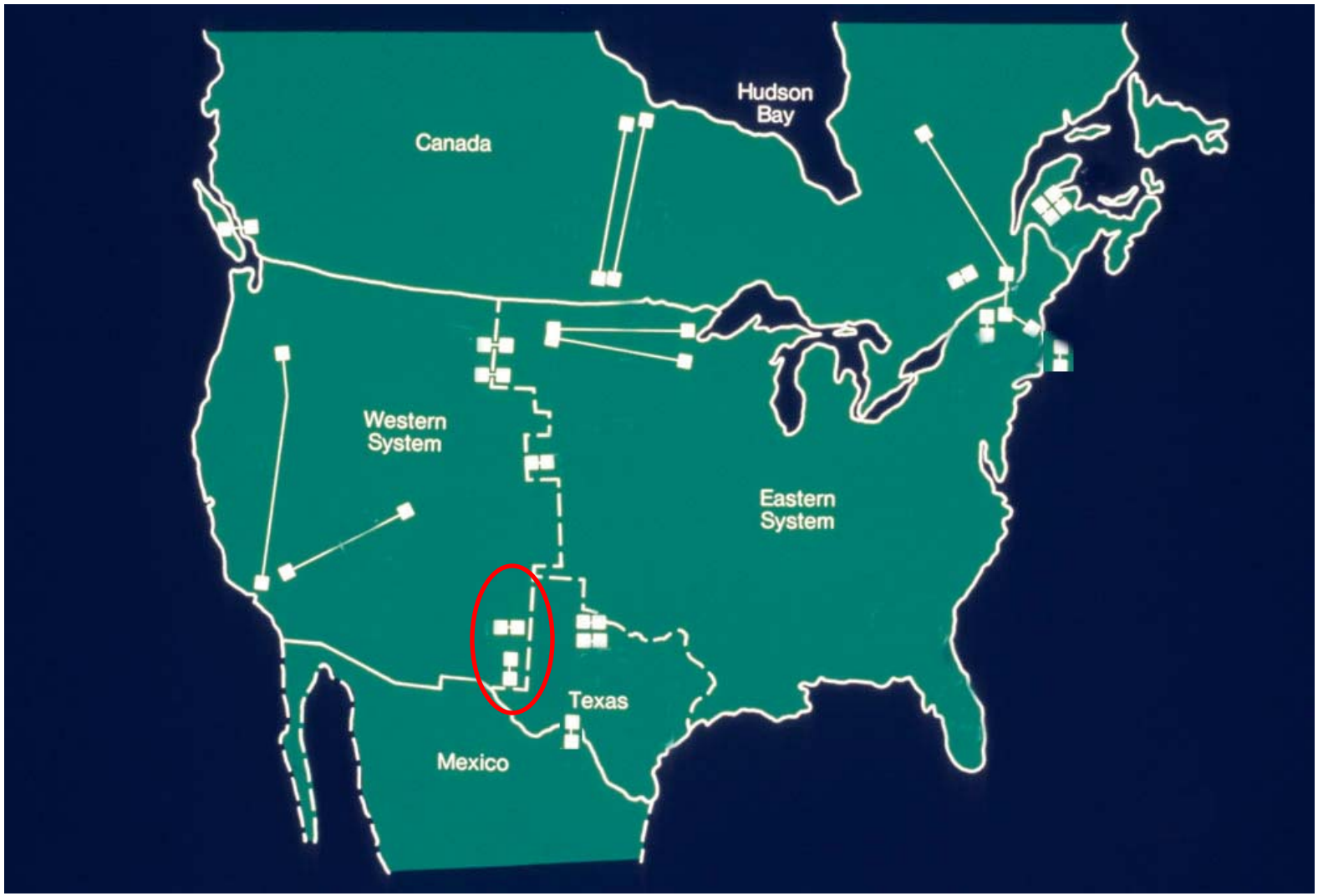
Gross Generation = 4.33 GkWh

(T&D Losses)/(End Use) = 10%

The US Transmission Grid(s)



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"

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 8/14/03
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

As Night Falls…

The Party Begins…

…and Continues…

It Gets Better…

and Better…

The Morning After

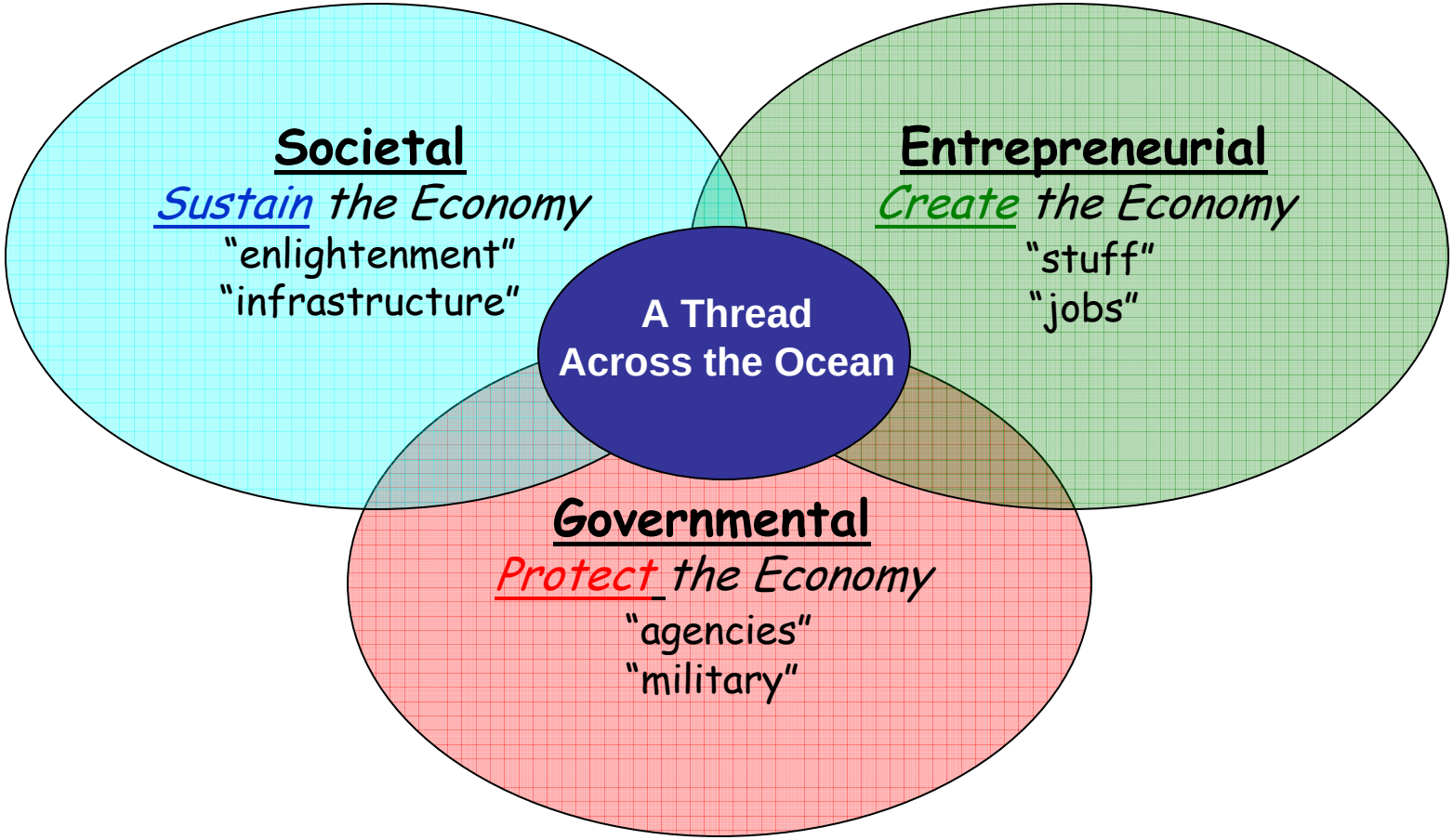
Viva New York!

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

P. M. Grant, DOE Presentation, 2004

The Economic Troika That Drives and Exploits Technology Innovation



"A Thread Across the Ocean"

Cyrus Field
American Capitalist

Isambard Kingdom Brunel
English Engineer

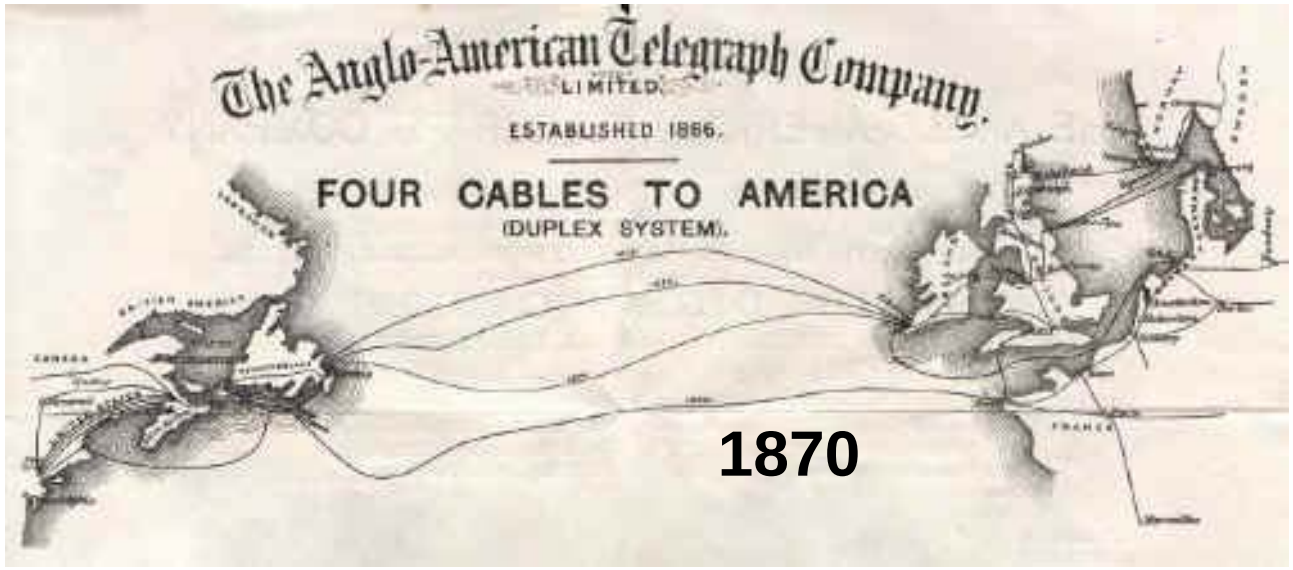
William Thomson
Irish Physicist

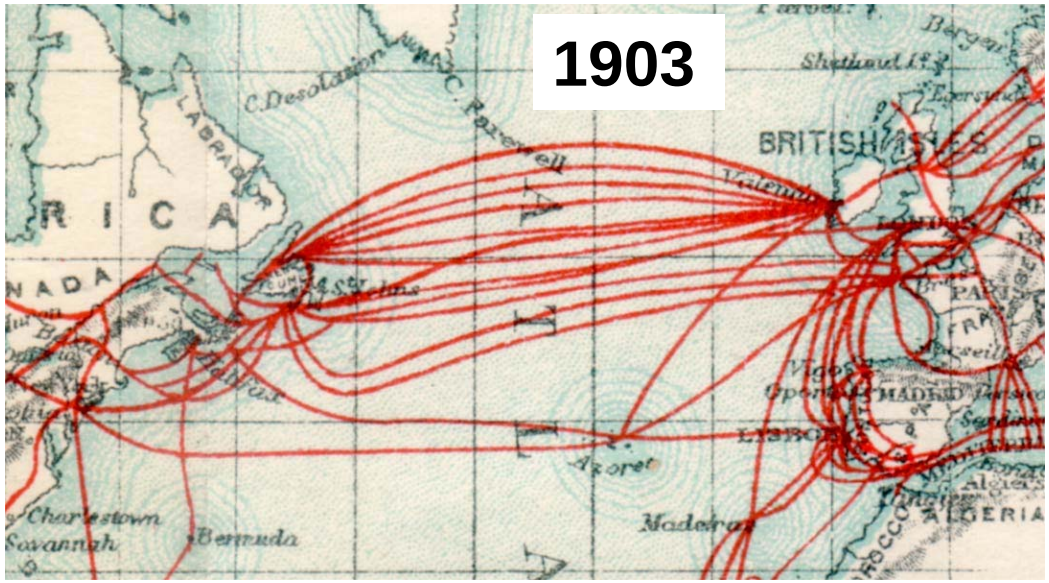
John Steele Gordon

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





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

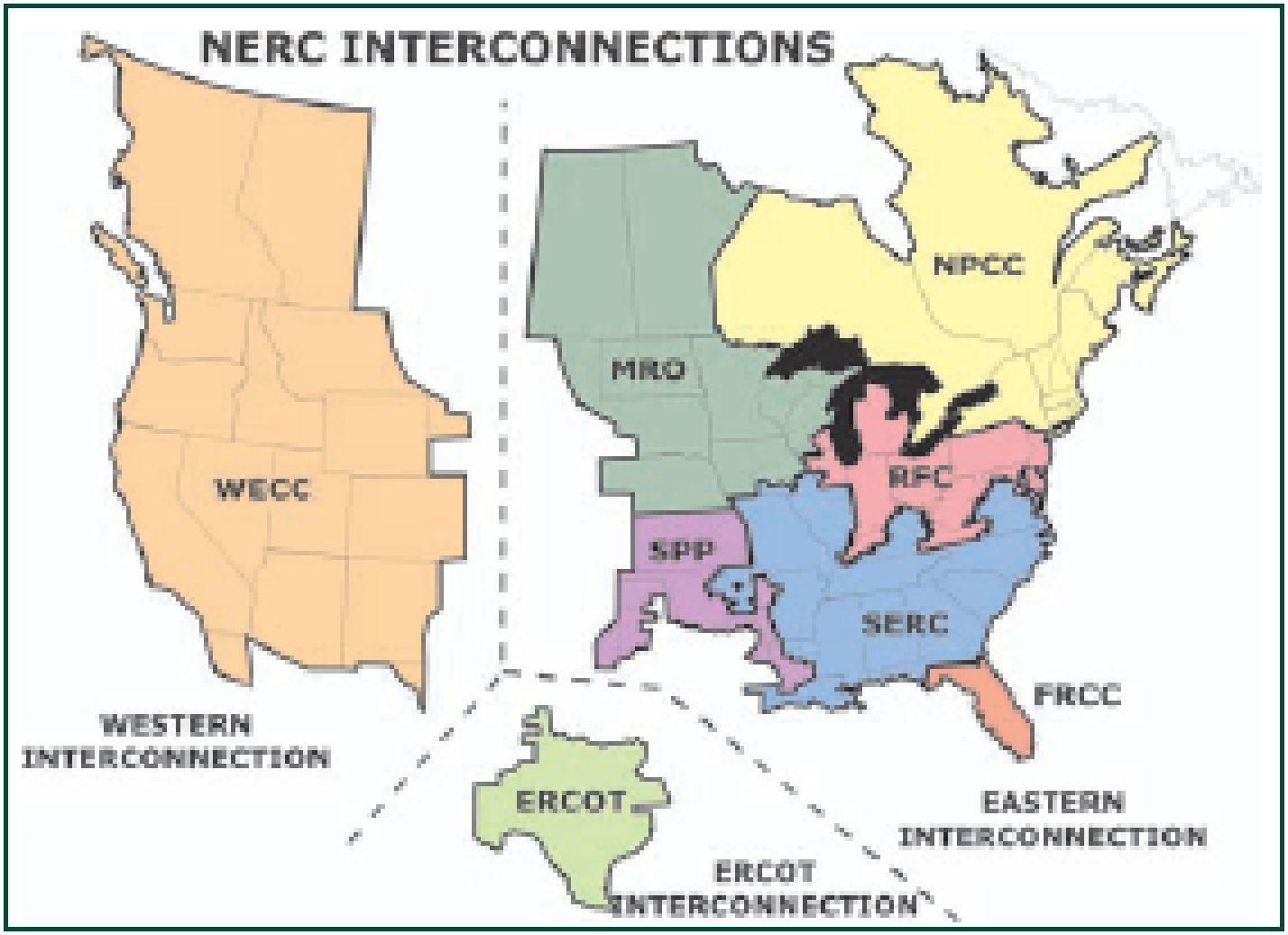
A Canadian's View of the World

The Mackenzie Valley Pipeline

http://www.mackenziegasproject.com

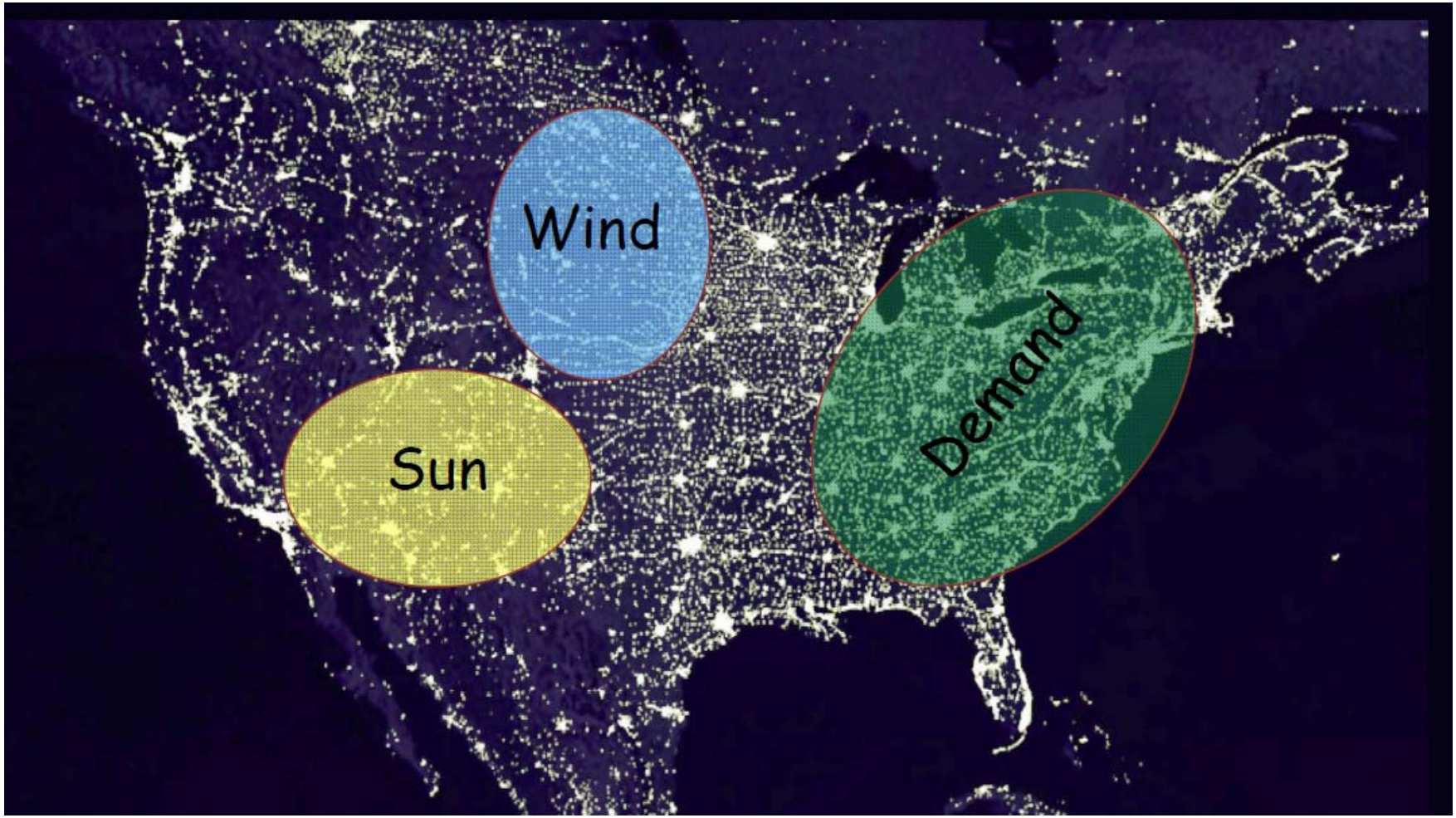
1220 km
18 GW-thermal
2006 - 2010

NERC Interconnects



Source: DOE 2006 National Electric Transmission Study

The "Green" Energy Economy

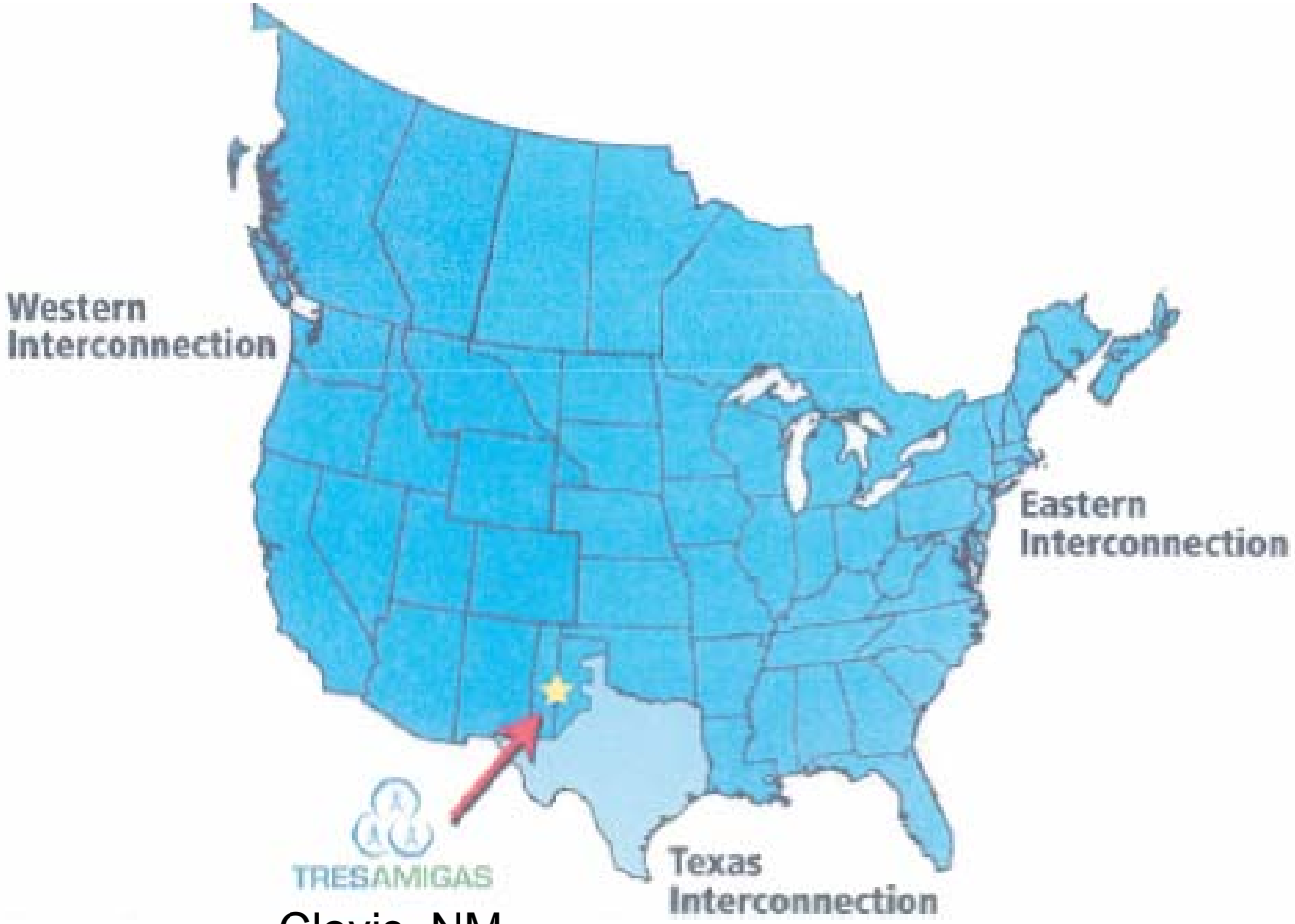


THE TRES AMIGAS PROJECT

October 2009

- Tres Amigas Super Station (TASS) will be the first system to unite the three U.S. power grids
- Able to carry gigawatts of renewable power from region to region
- Centrally located in Clovis, New Mexico
- Will utilize the latest advances in energy technologies, including superconductor power cables, voltage source converters and large-scale energy storage systems
- Will form the nation's first renewable energy market hub

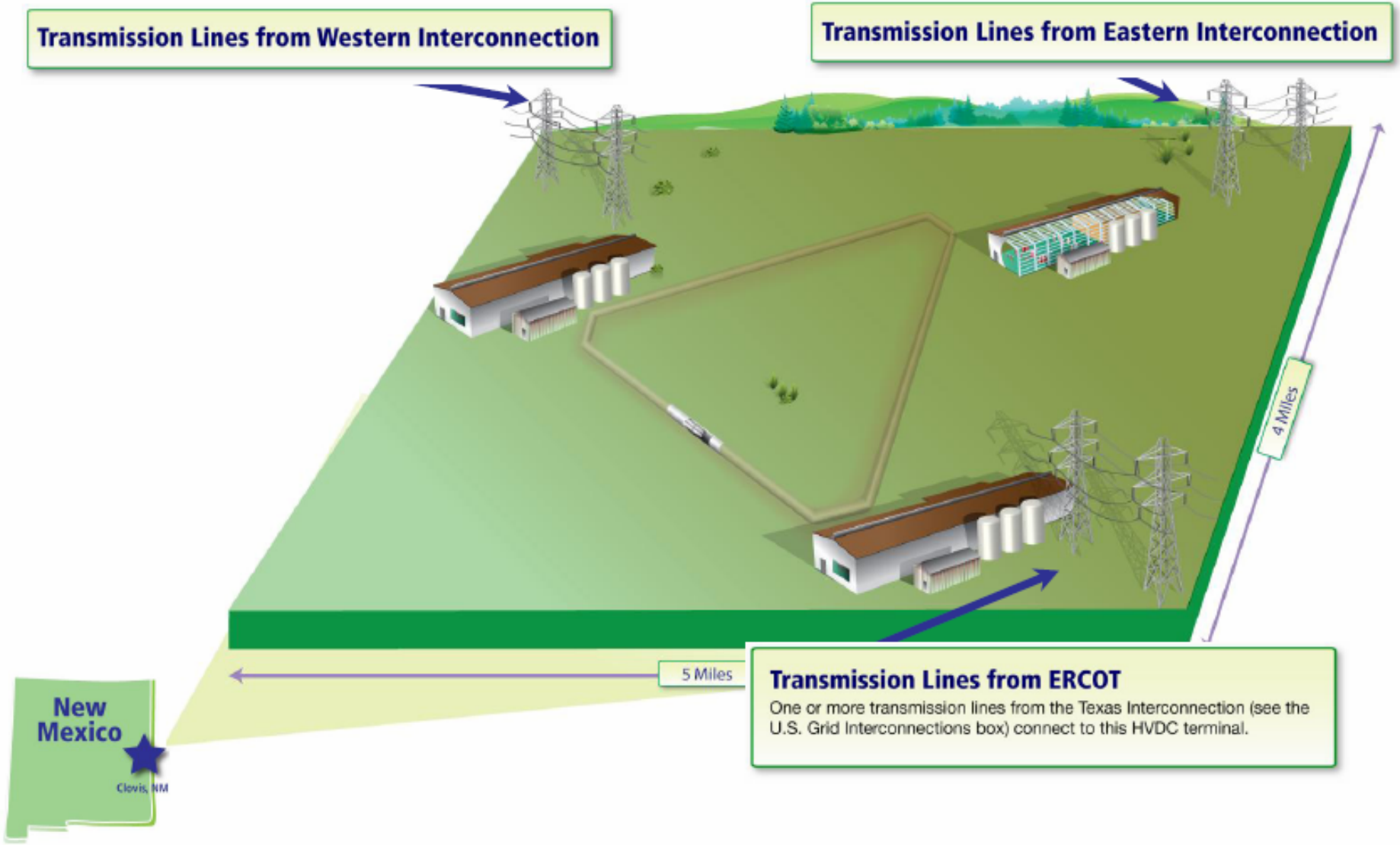
"Three Girl Friends"



Clovis, NM

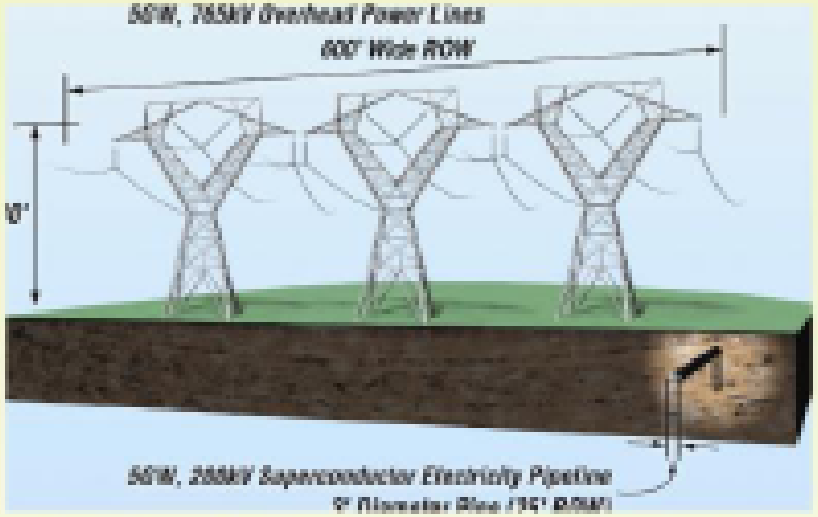
The Tres Amigas SuperStation

TRESAMIGAS LLC



DC Superconductor Ring

Key to the Tres Amigas SuperStation is an underground pipeline of direct current (DC) superconductor cables less than three feet in diameter capable of carrying more than 5,000,000,000 watts (5 giga-watts) of electricity with no electrical losses; enough electricity to power 2.5 million homes. Superconductor cables:



Enhance efficiency: When the station is running at full power, the superconductor pipeline can save as much as 60,000,000 kW-Hrs of energy annually compared with conventional transmission technology. That's equivalent to the electricity usage of 30,000 homes and a 40,000 ton reduction in CO_2 emissions.

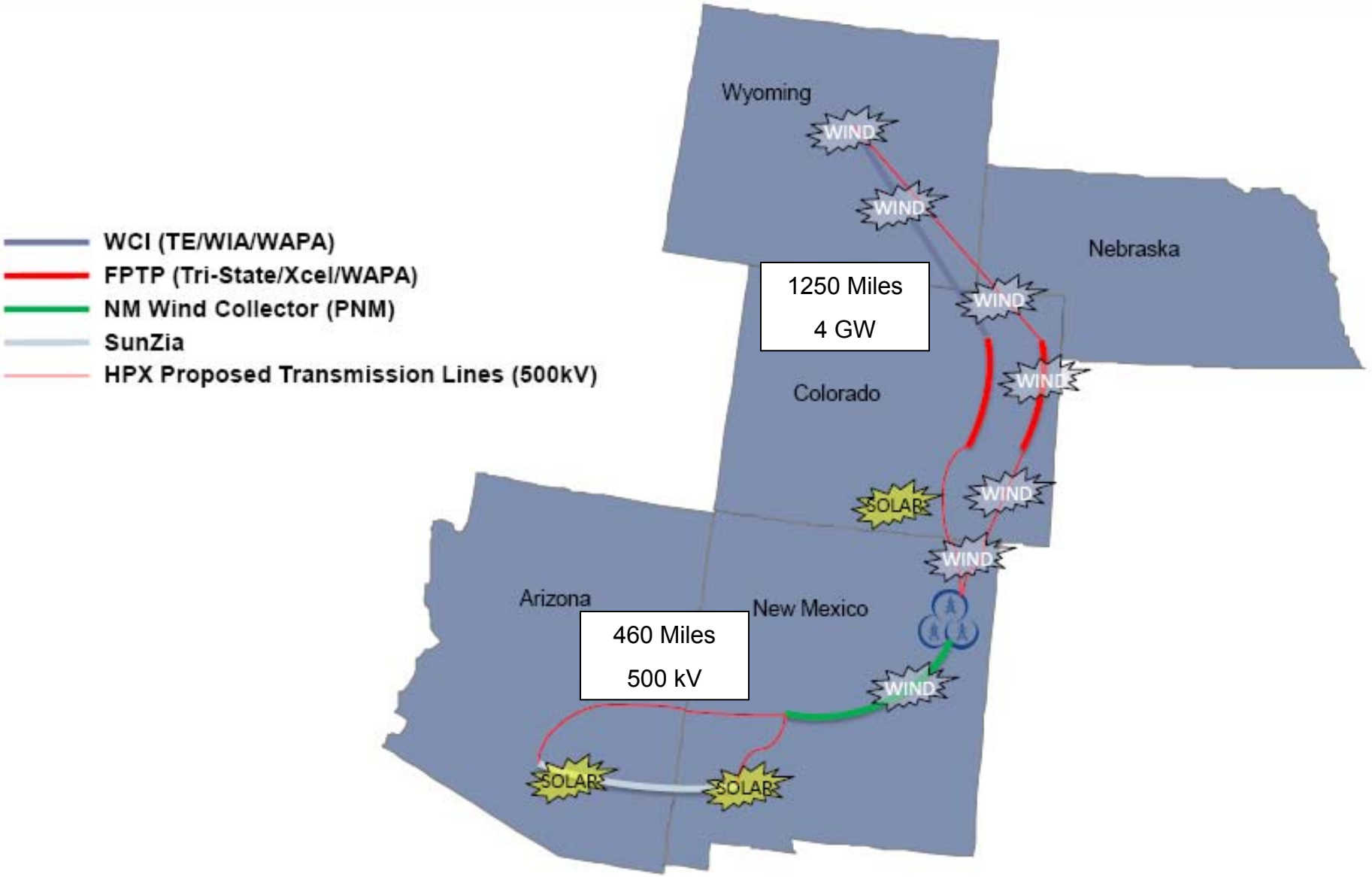
1.2%

Are out of sight: A single, underground superconductor pipeline can carry as much power as three, 765kV AC overhead transmission lines (see figure).

Increase power security: Unlike overhead lines, underground cables are virtually immune to weather-related outages, the most common cause of power disruptions. Similarly, underground placement makes them less subject to vandalism and other forms of willful attack.

Potential Beneficiaries in WECC

TRESAMIGAS



(Pending FERC Ruling on ERCOT)

- The Texas grid (ERCOT) is not connected to the rest of the US (dc interties are not considered "real" connections by lawyers)
- Therefore, under the US Constitution's interstate commerce clause, Texan electricity lies outside federal control (FERC)!
- But, FERC approval is necessary for Tres Amigas to operate and may thus insist Texas is "now connected" and under regulation by Washington.
- However, it is certain ERCOT will consequently refuse to join Tres Amigas thus dealing a severe blow to its probable commercial success.

What the @#$% does any of this have to do with Superconductivity?

“Superconduct-ress”

Mr. Electric Utility Good Ol' Boy

Miss Same Old Technology

Together Forever?

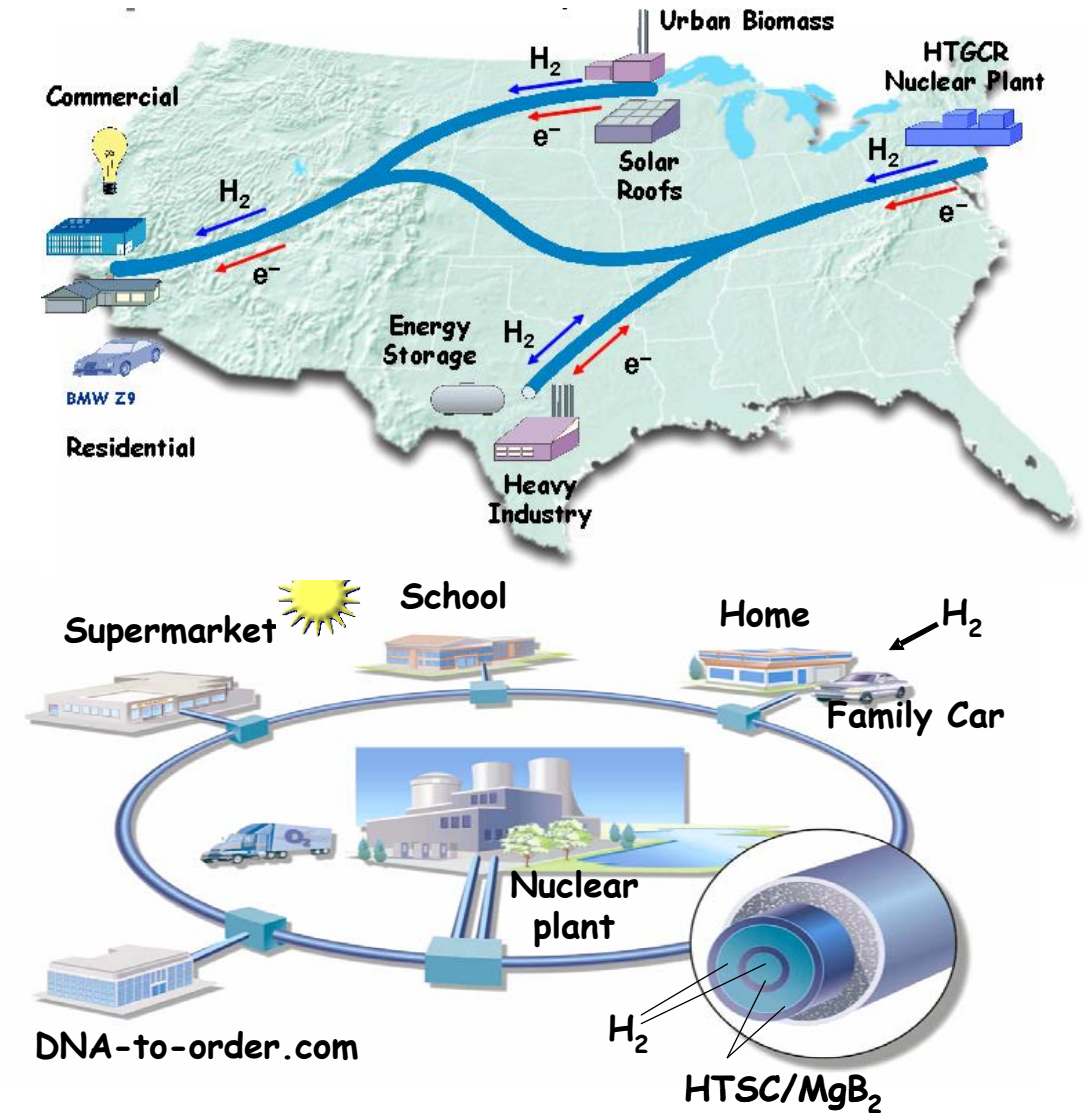
“Al Gore” – He’s Available !

Vision

"Where there is no vision, the people perish…Proverbs"

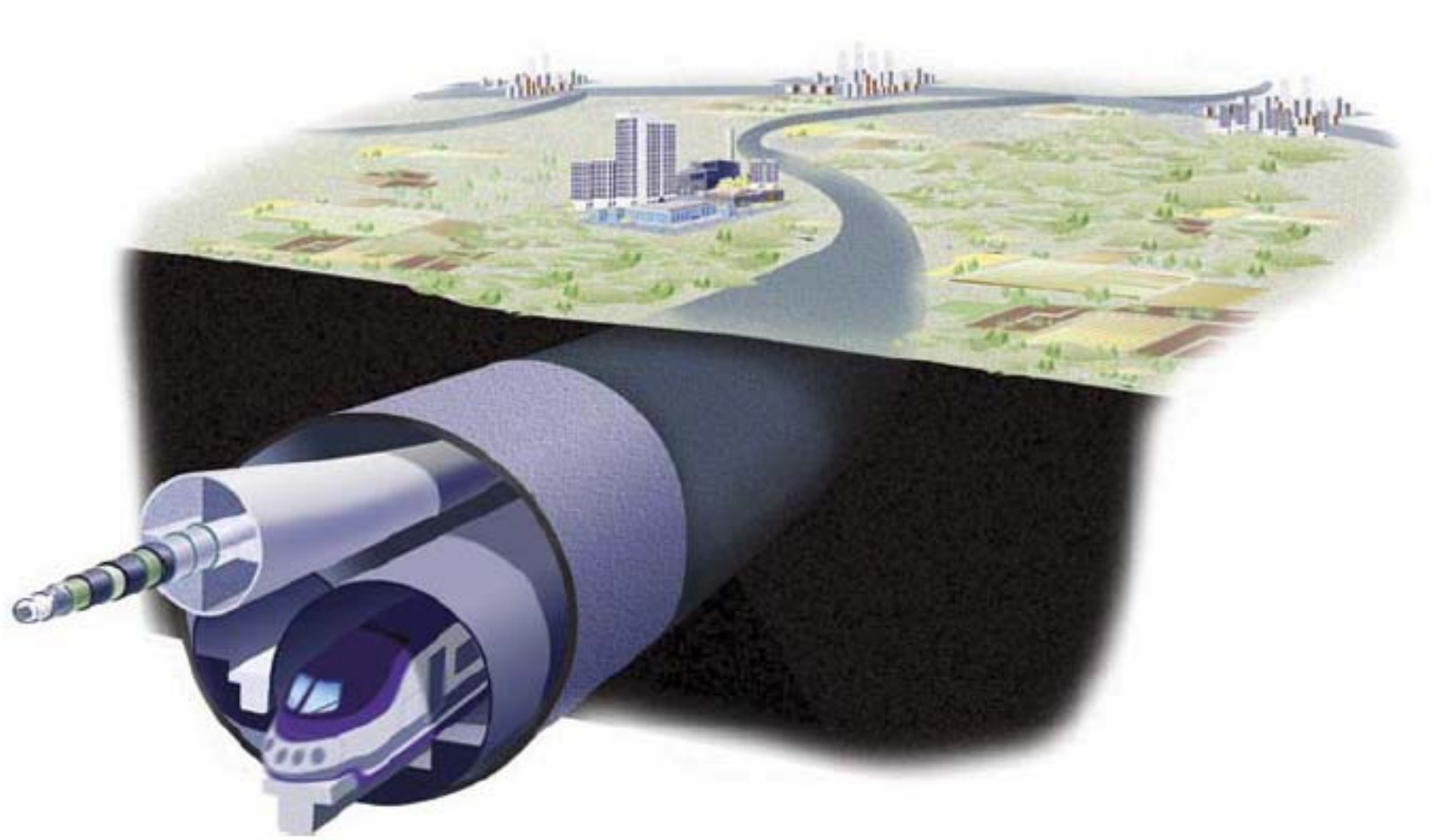
Extreme Energy Makeover

SuperCities & SuperGrids



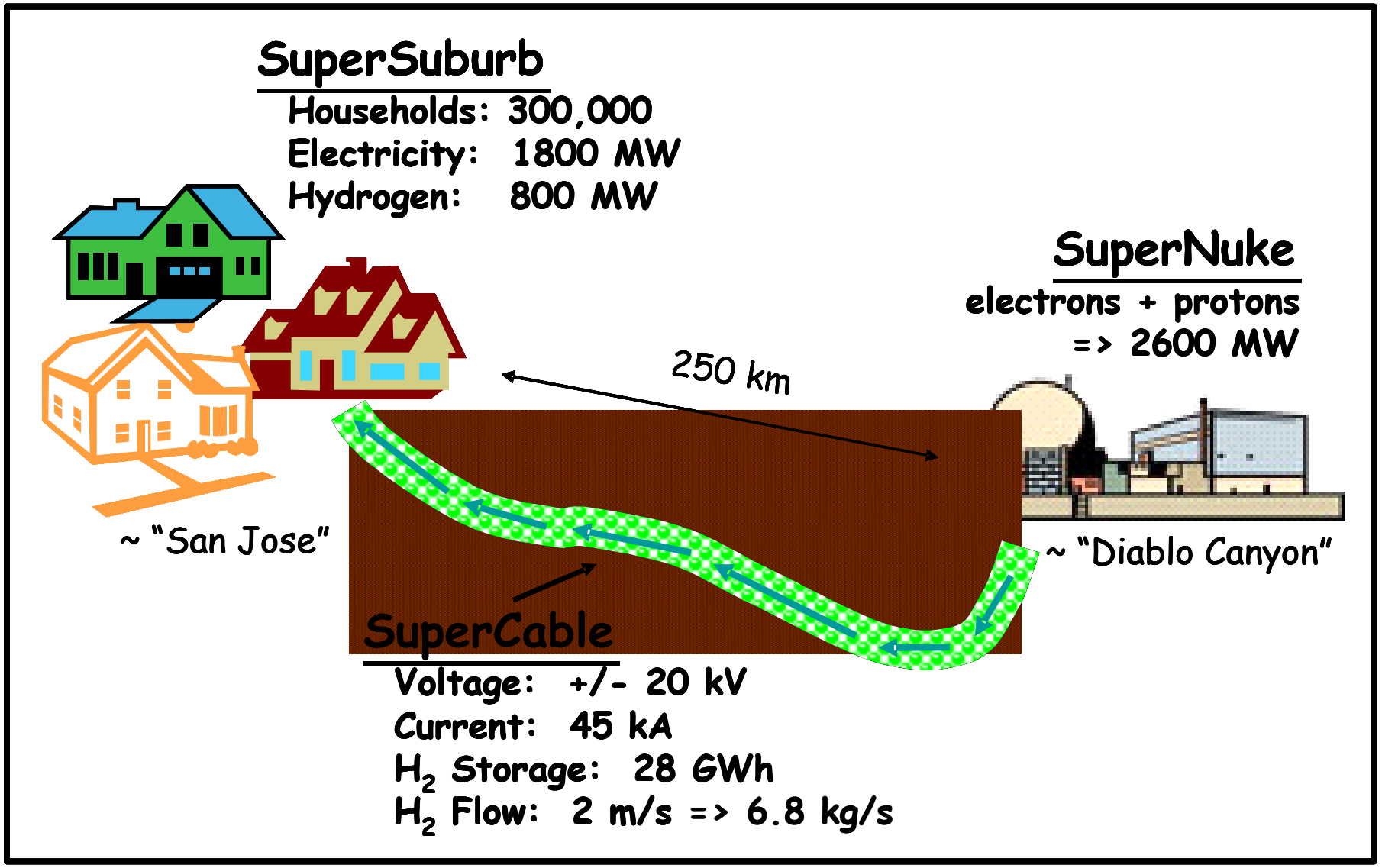
- Nuclear Power can generate both electricity and hydrogen – "Hydricity"
- Hydricity can be distributed in underground pipelines like natural gas
- The infrastructure can take the form of a **SuperGrid**
- ...or a **SuperCity**

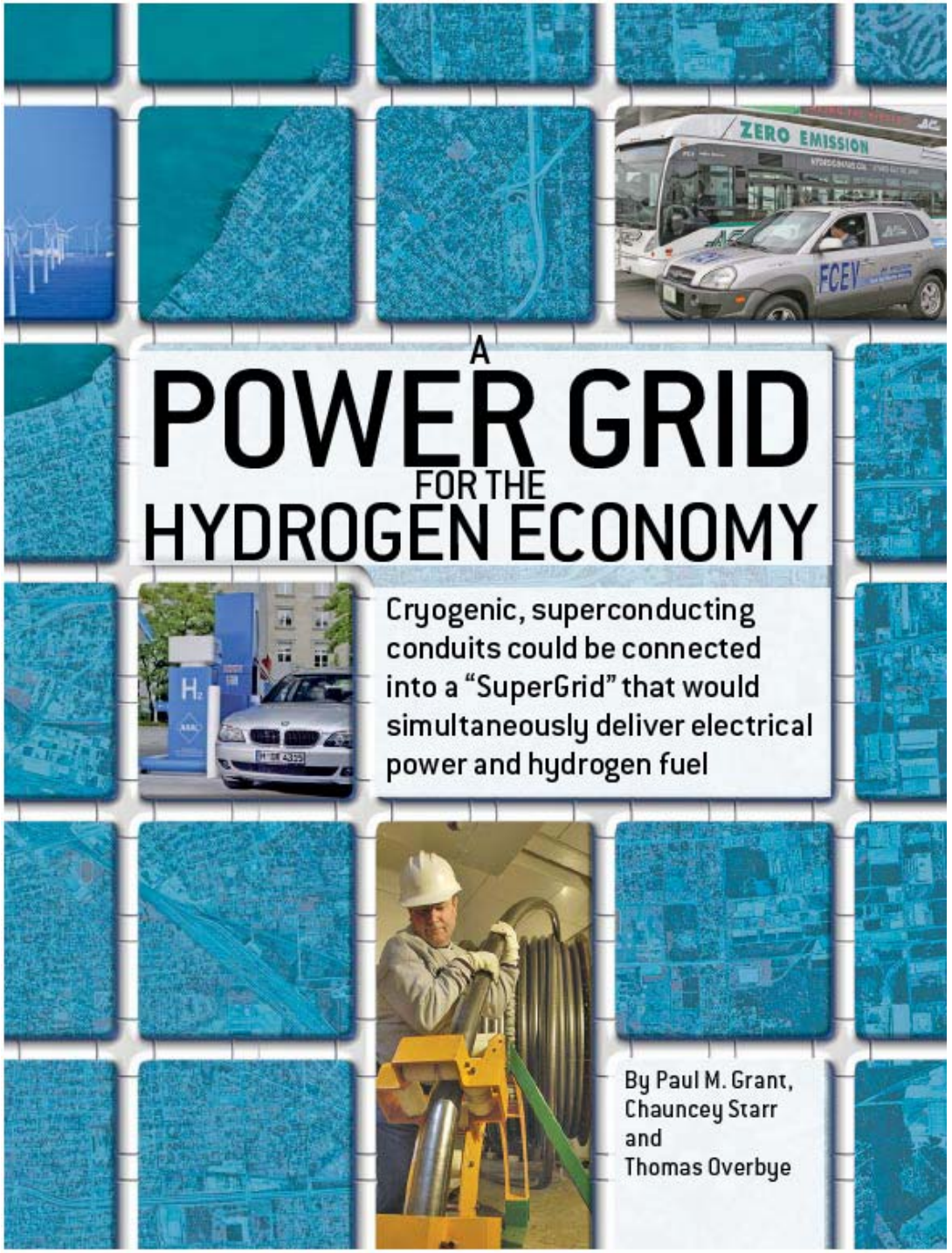
SuperGrid



EPRI White Paper, 2006

SuperSuburb





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

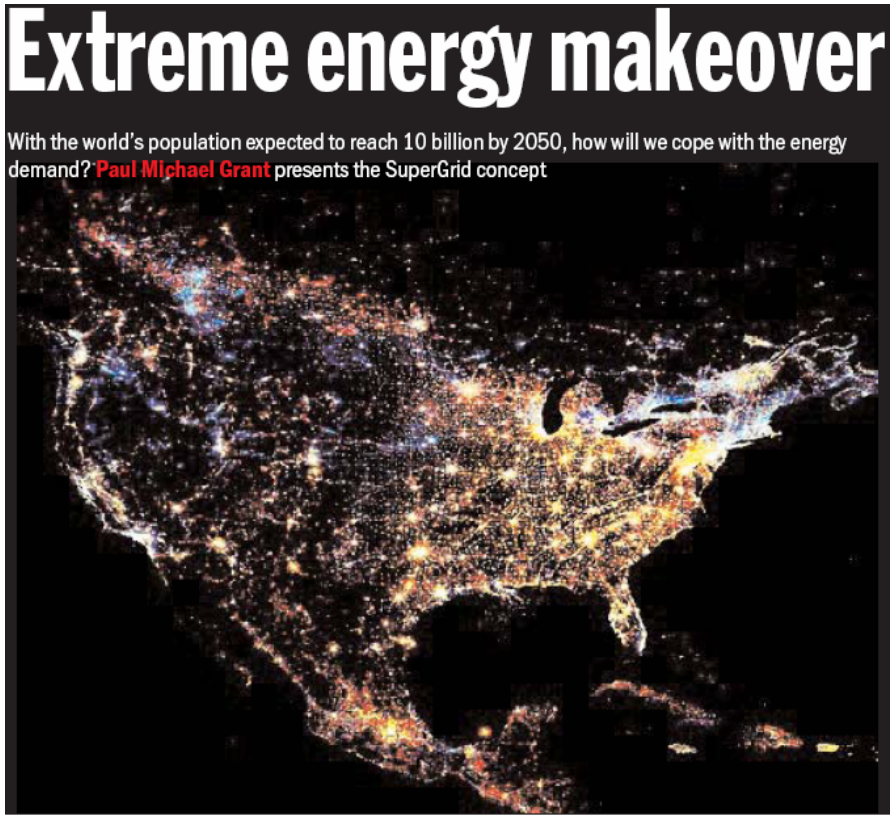
July, 2006

"System Crash"

Omni Productions, Vancouver, BC

CBC Broadcast October, 2008

Physics World, October 2009



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…?

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!"

Dziękuję

za uwagę

http://www.w2agz.com/BD_WROC10.htm

w2agz@w2agz.com