

Superconductivity in Power Applications

The Role of Cryogenics in Transforming the Power Enterprise Worldwide



“A Sober Assessment of Opportunities and Realities”

**Paul M. Grant
W2AGZ Technologies
San Jose, CA USA**

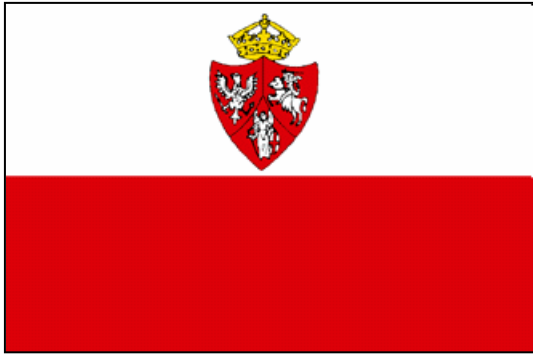
http://www.w2agz.com/BD_WROC10.htm

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.

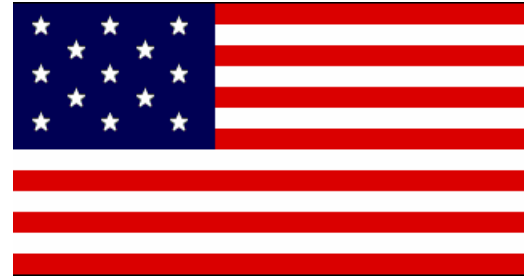
The Polish in America



1836



Thaddeus Kosciuszko



1777



Casimir Pulaski

The Journey

- History
- Wire
- Applications
- Marketing
- Vision

History

- Discovery
- Theory
- Type II Materials

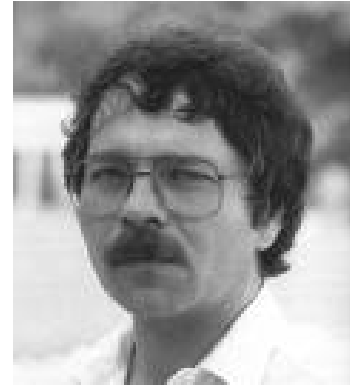
Discovery

1911 (4.2 K)



Gilles Holst

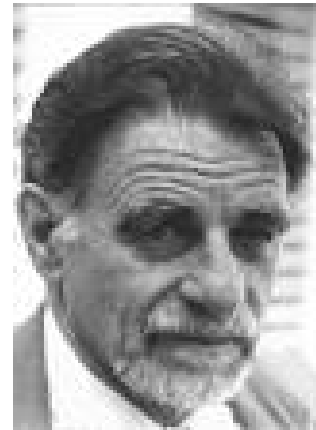
1986 (20-40 K)



Georg Bednorz

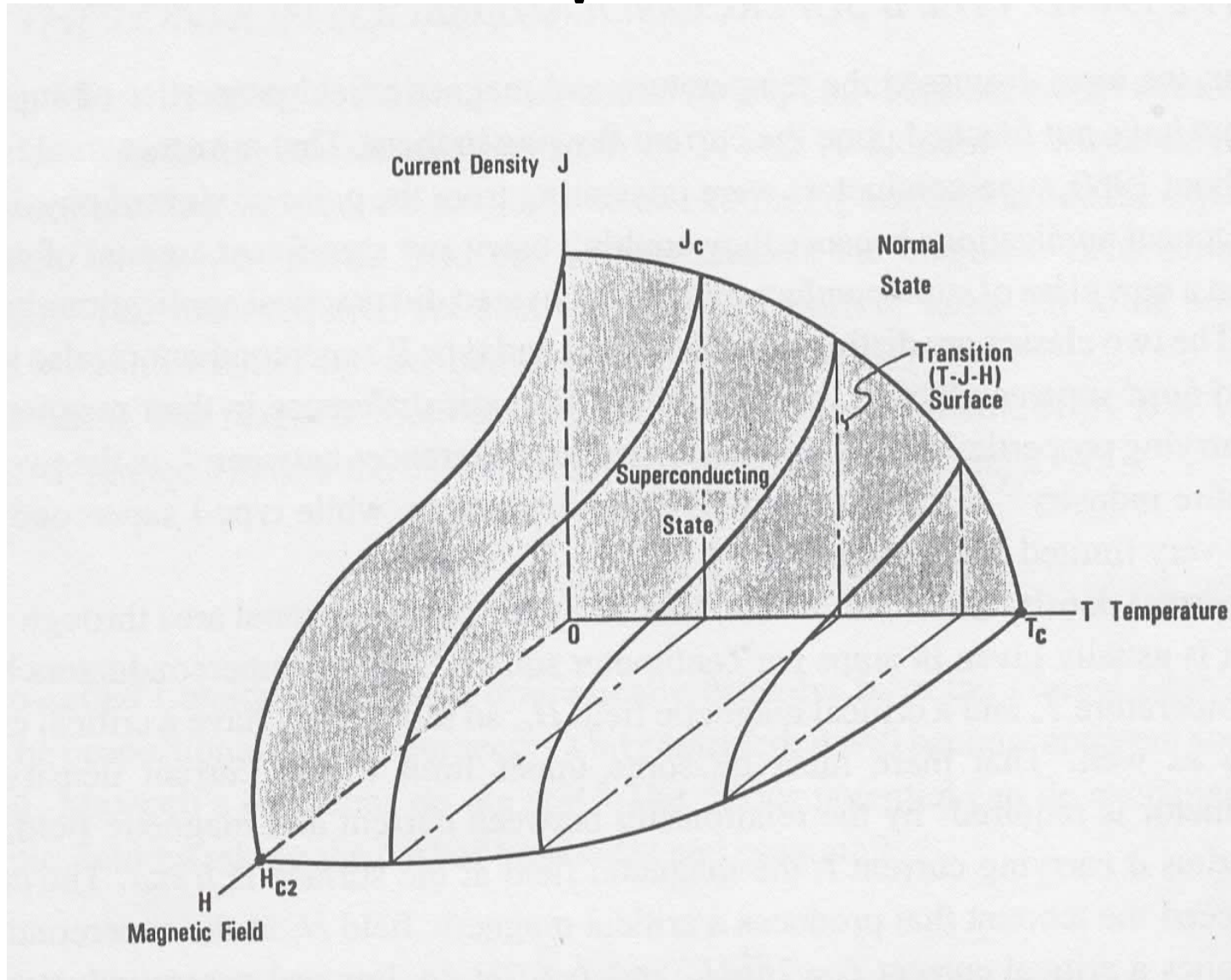


H. Kammerlingh-Onnes

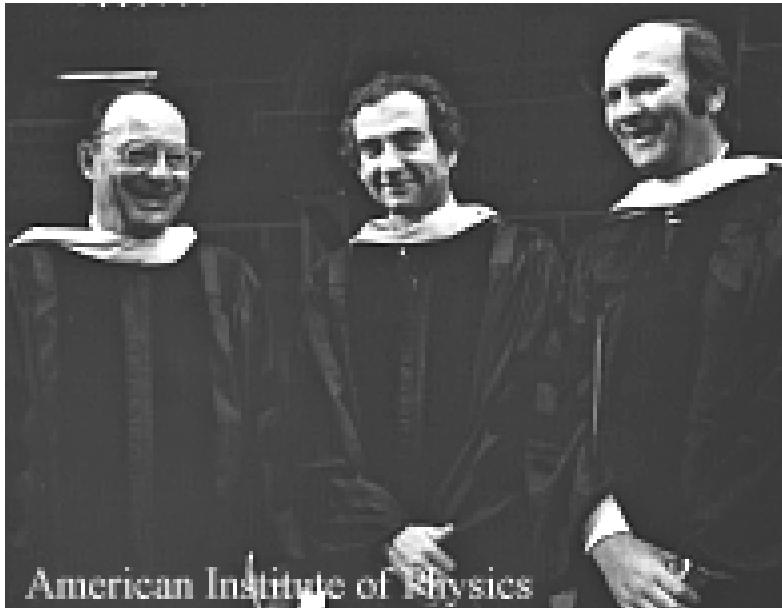


Alex Mueller

Properties

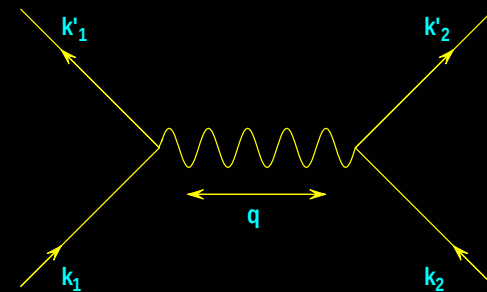


Theory (1956)



Bardeen-Cooper-Schreiffer (BCS)

Fermion-Boson Feynman Diagram



- 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)

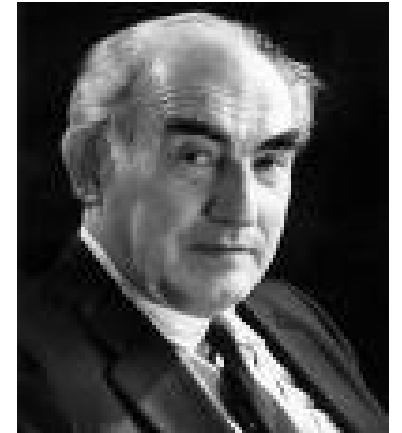
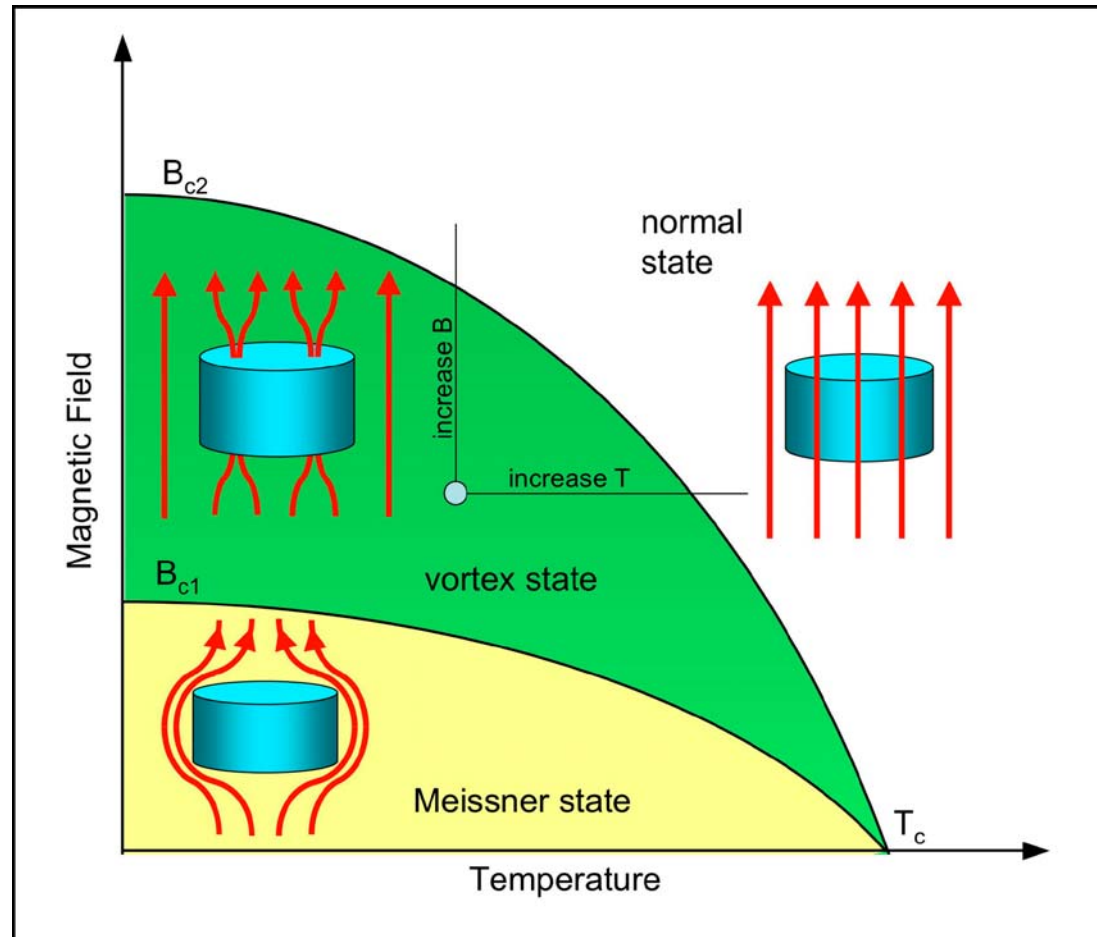
Type II (1930s +)



Lev Shubnikov



Lev Landau



"VL" Ginzburg



Aleksei
Abrikosov

GLAG

Ginzburg-Landau-Abrikosov-Gorkov

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

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

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

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

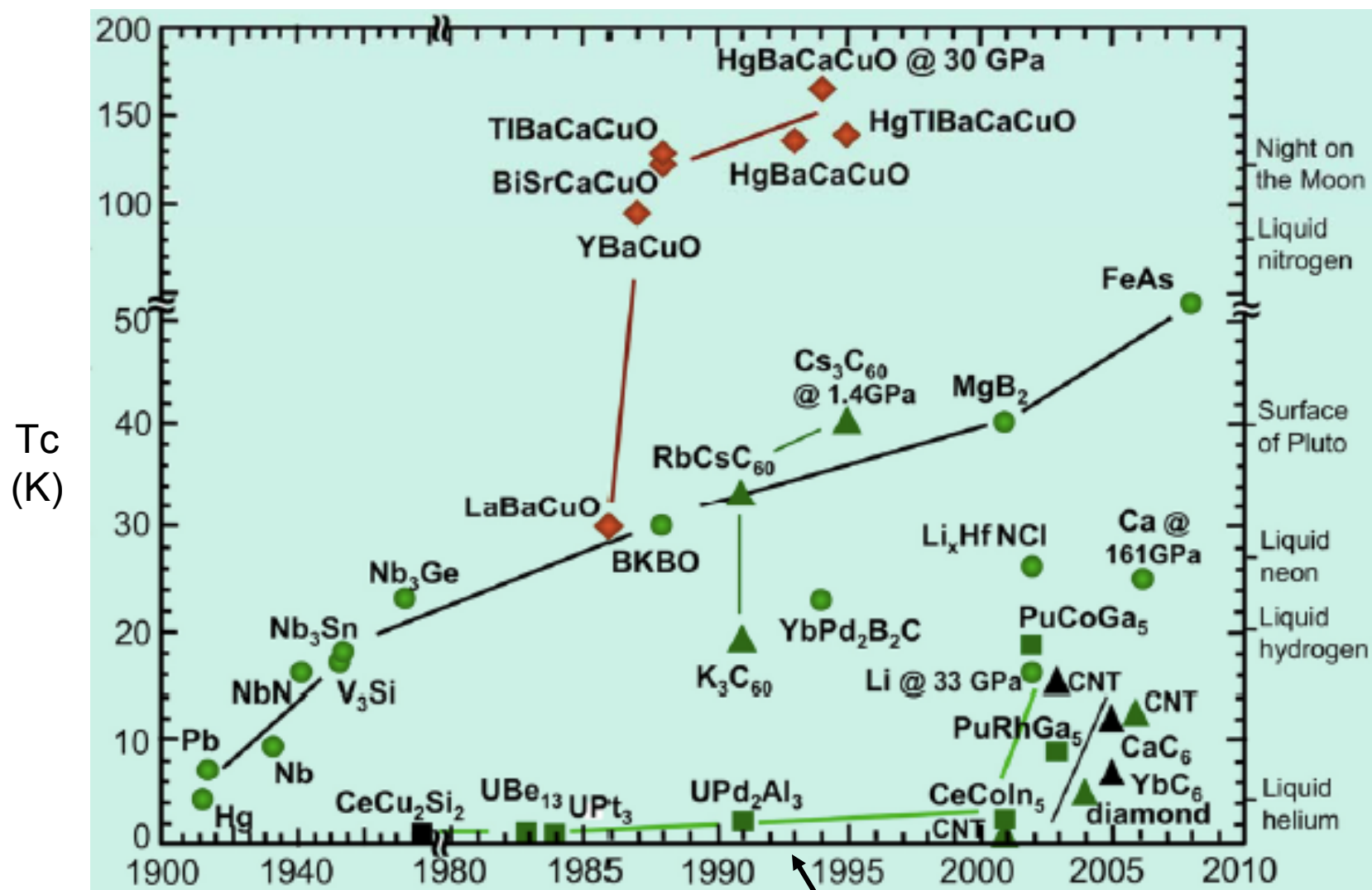
$$A = (\Phi_0 / 2\pi\xi) \mathcal{A}$$

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

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

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

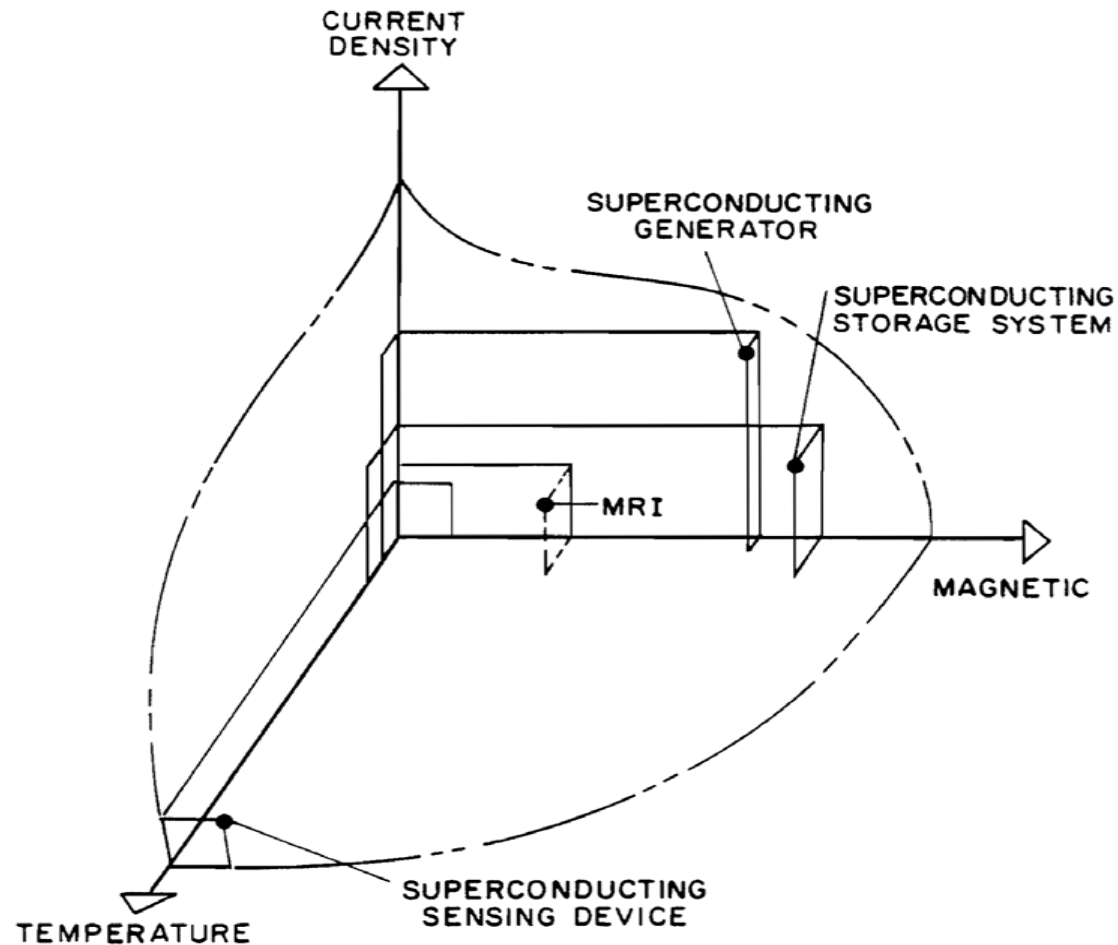
Today



Year

Non-Linear: Hockey Stick !

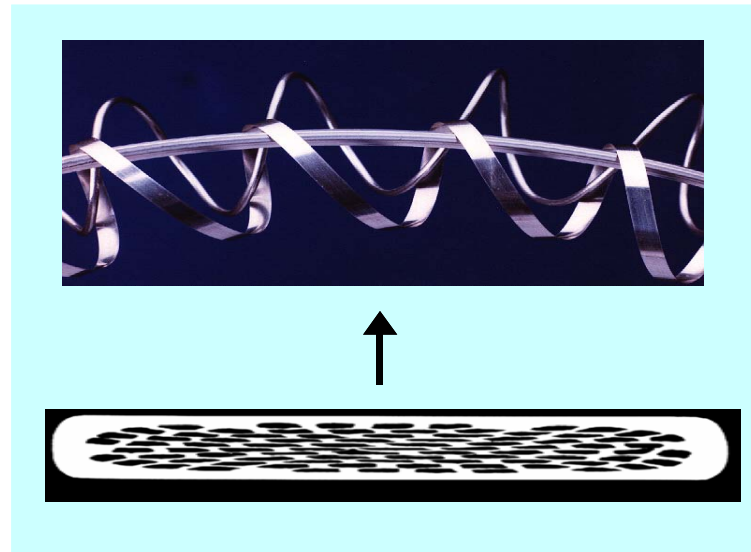
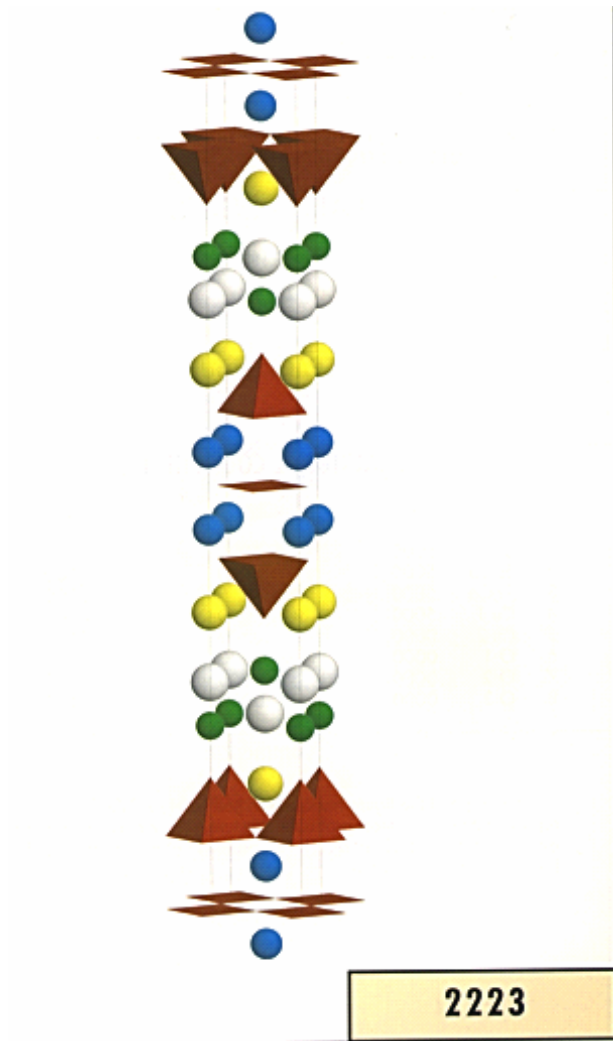
Applications Landscape



Wire

- Development and Embodiment
- Performance and Specifications

First HTSC "Wire"



Gen 1

Orientation Dependence of Grain-Boundary Critical Currents in $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ Bicrystals

D. Dimos, P. Chaudhari, J. Mannhart, and F. K. LeGoues

*Thomas J. Watson Research Center, IBM Research Division,
Yorktown Heights, New York, 10598*

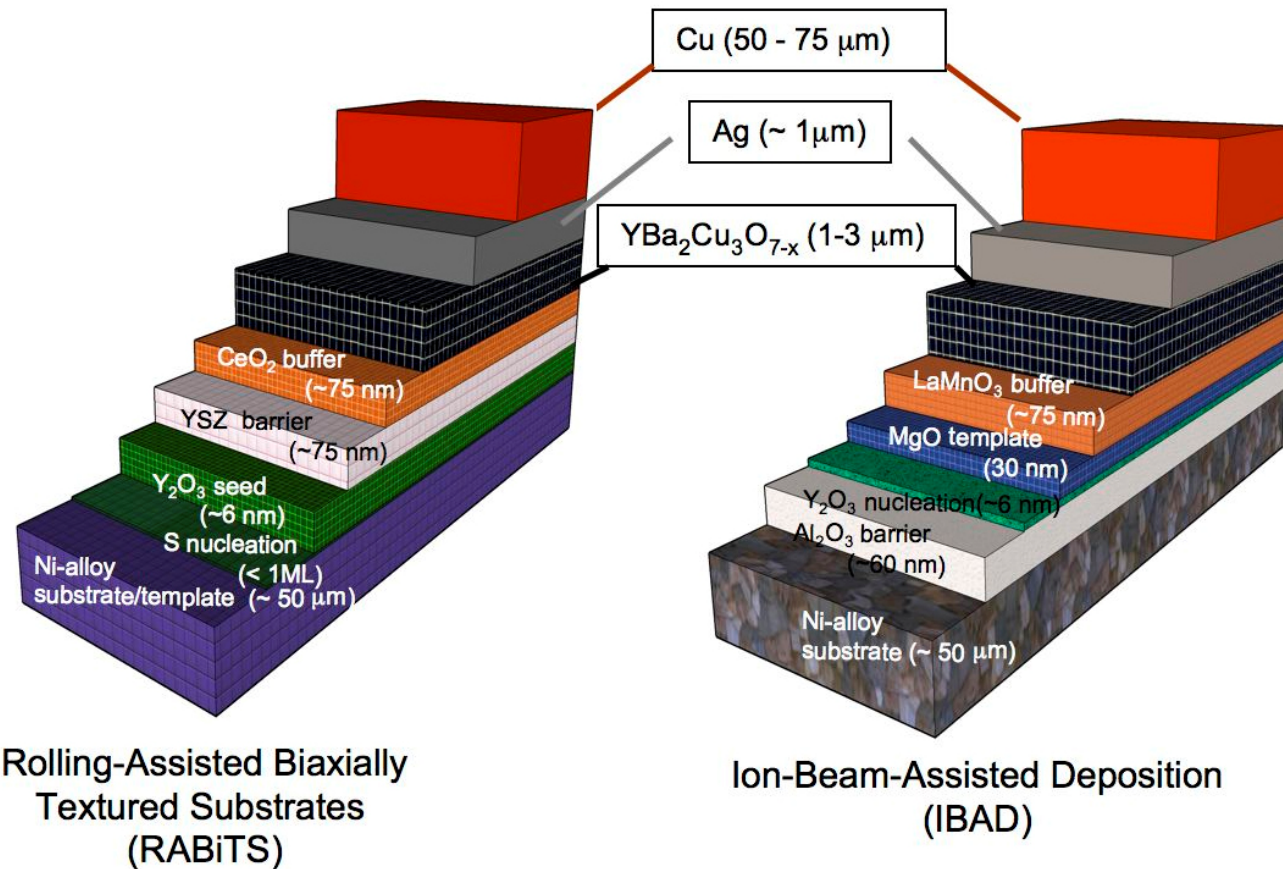
(Received 4 May 1988)



Praveen Chaudhari, 1937 - 2010

[Physics Today, p.64, April 2010](#)

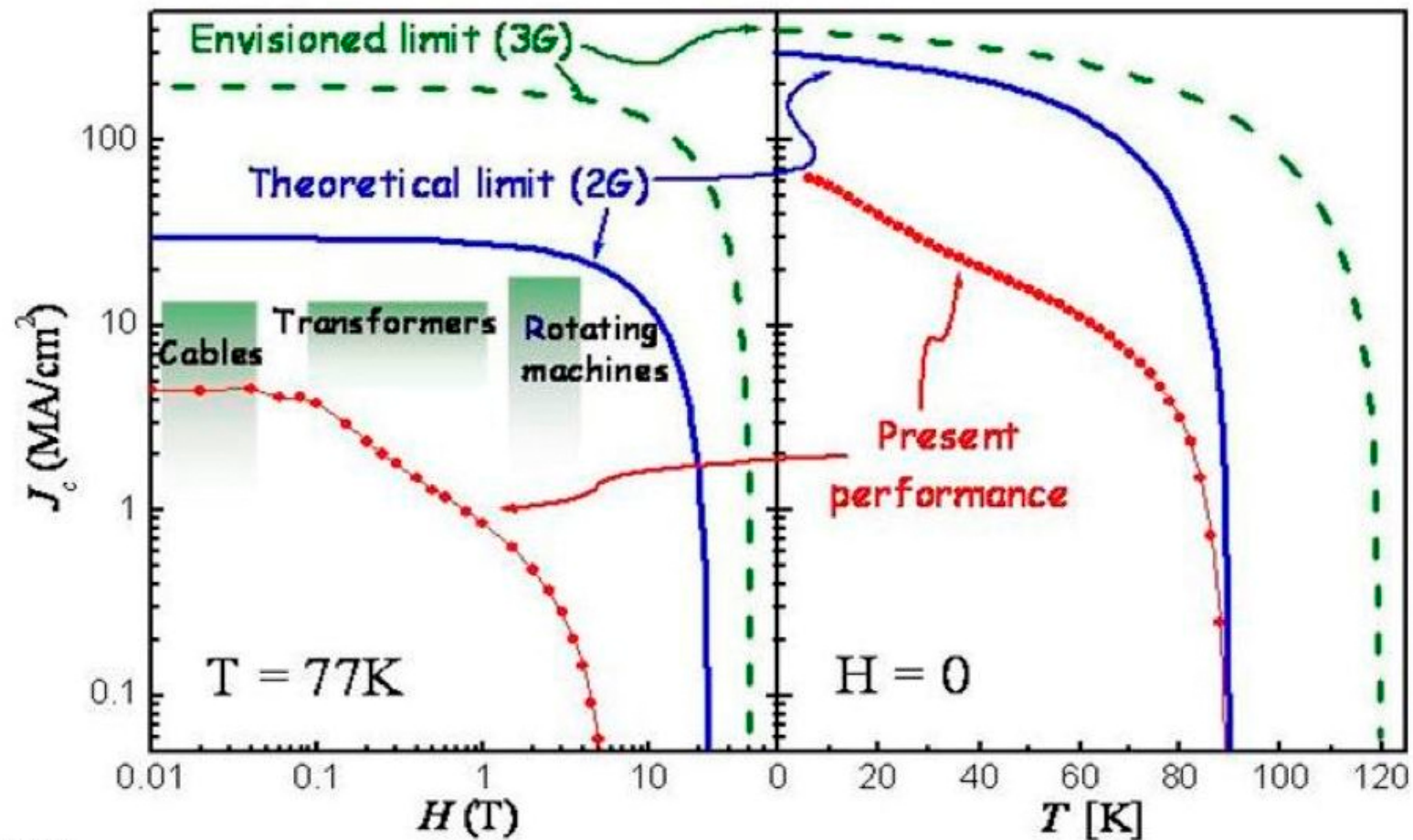
Gen II Coated Conductor



American Superconductor

SuperPower

Wire Performance

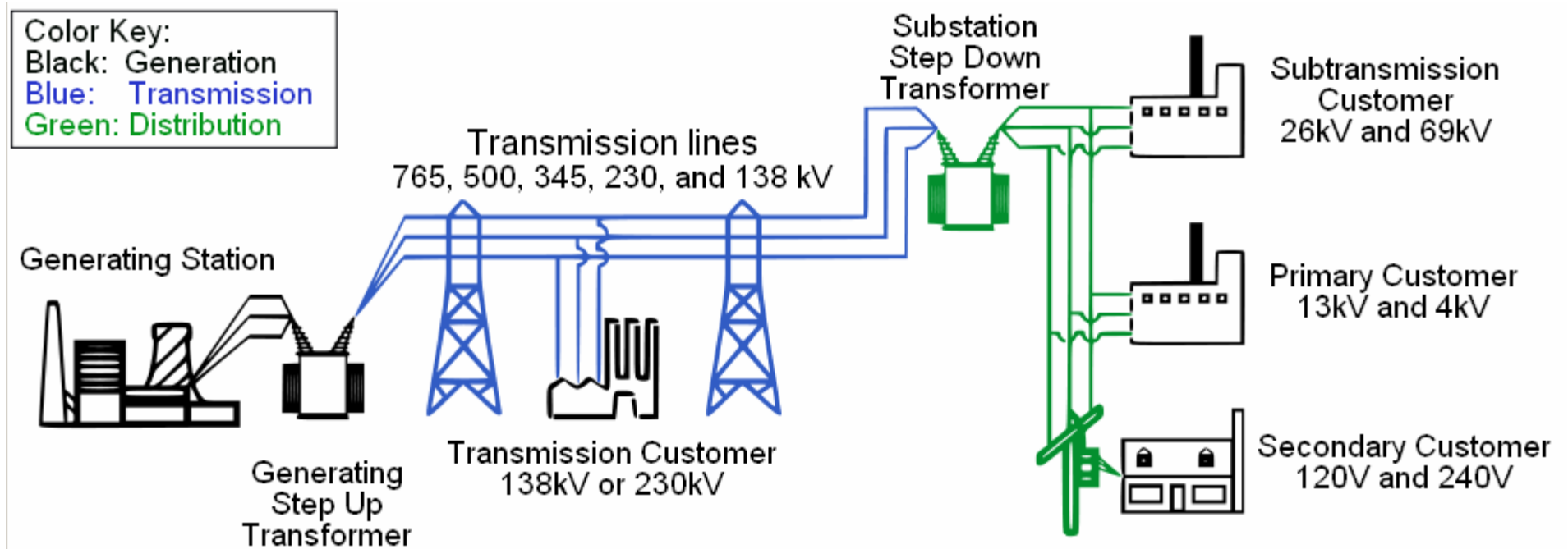


Applications

- 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!)

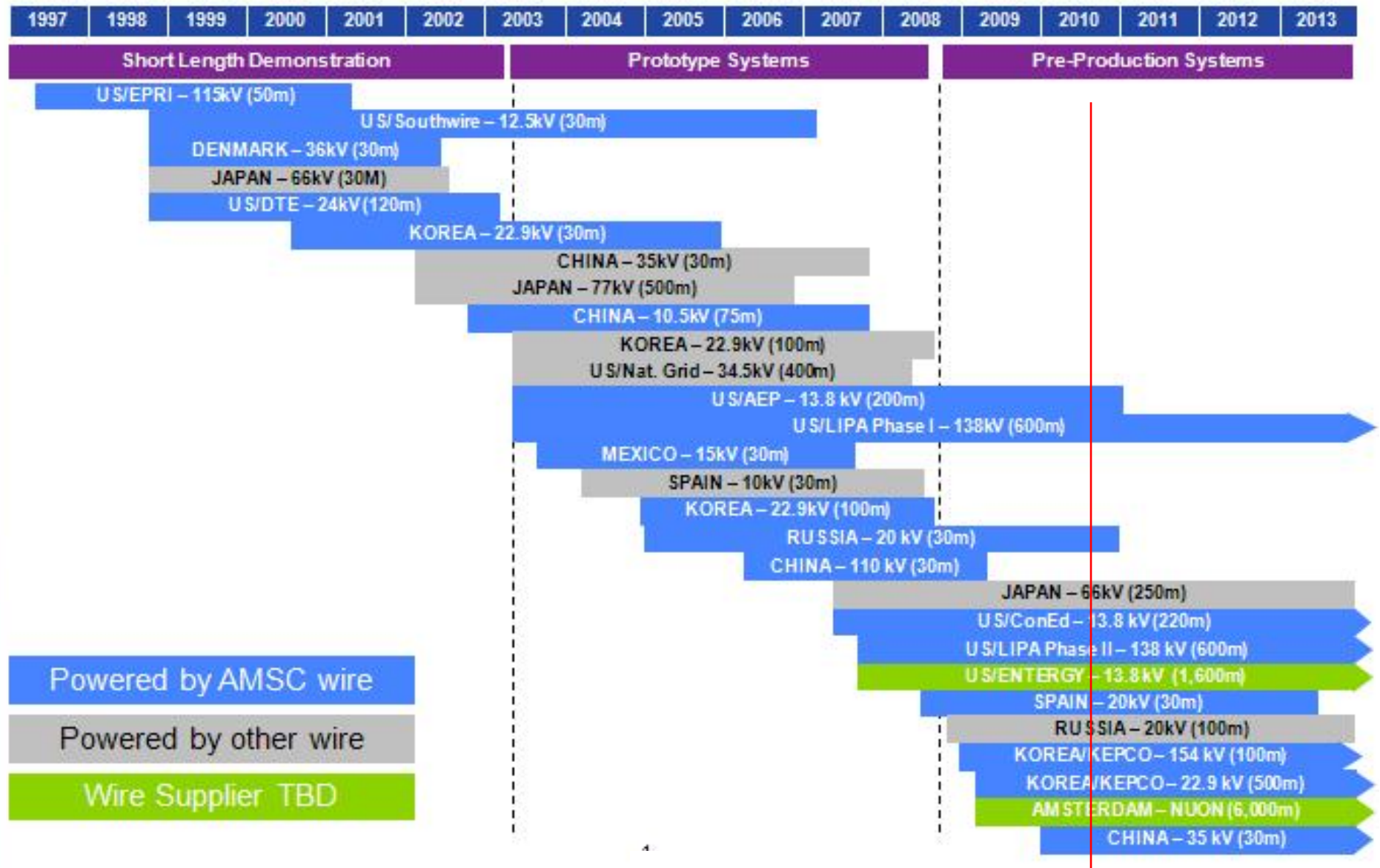
Where Can We Apply Superconductivity to Electric Power?



Potentially Everywhere

HTSC Cable Projects Worldwide

Past, Present...Future?





U.S. HTS Cable Installations

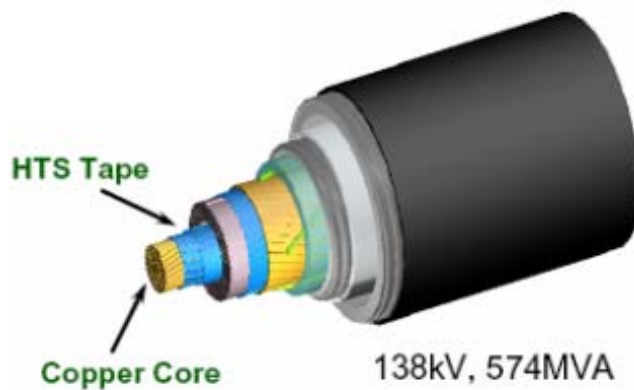


Various ac HTSC Cable Designs

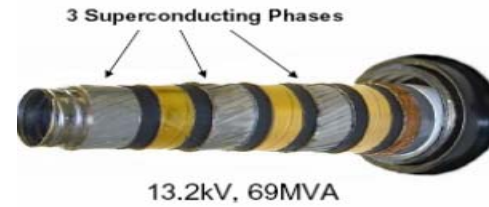


Cable configuration: 3 phases in 1 common cryostat

Sumitomo



Nexans-AMSC

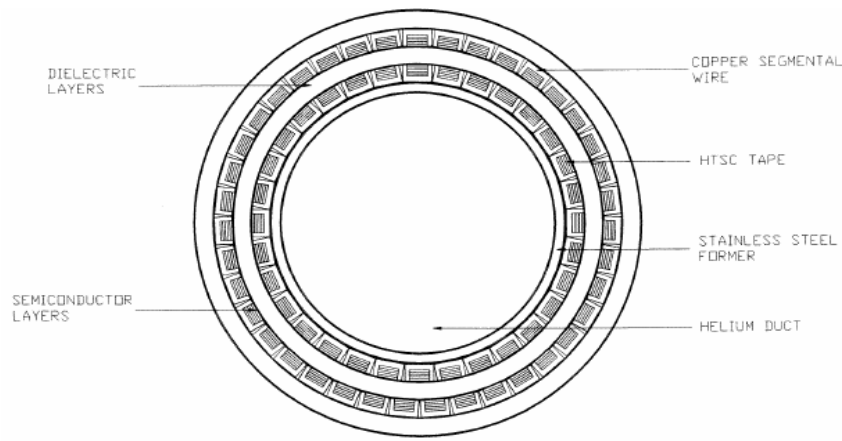


Ultera-ORNL

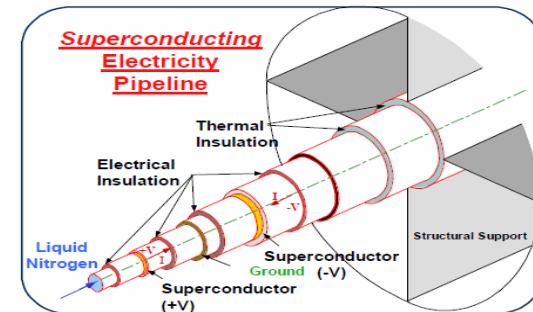
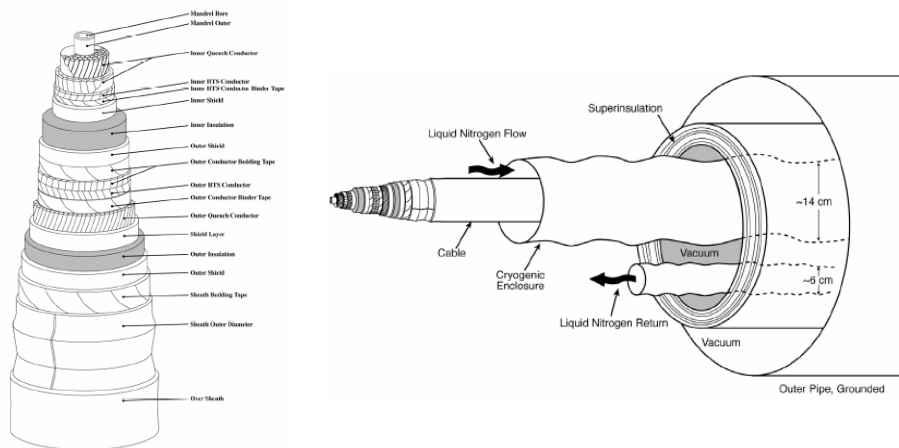


Pirelli

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

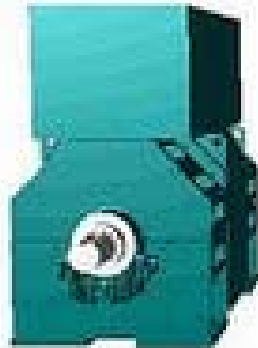
EPRI: Hassenzahl, Gregory, Eckroad, Nilsson, Daneshpooy, Grant (2009)
+/- 50 kV, 100 kA, 10 GW

Example: Long Island Power Authority



Superconducting Motors

HTS Motor

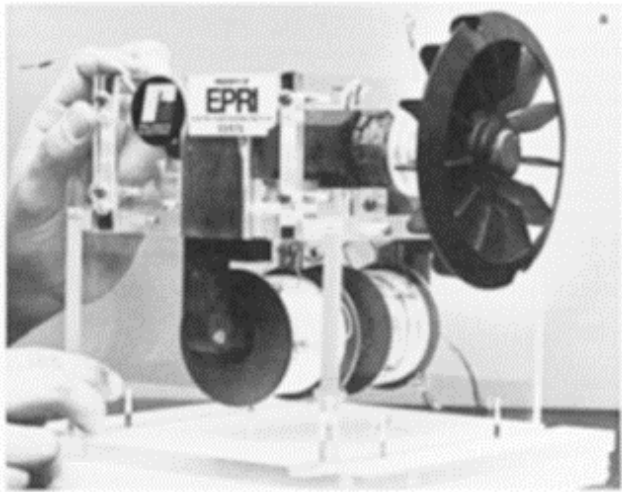


- Efficiency = 98.6%
 - 43% of the loss in the conventional motor
- Smaller volume
 - 47% of the volume of the conventional motor

High Efficiency Conventional



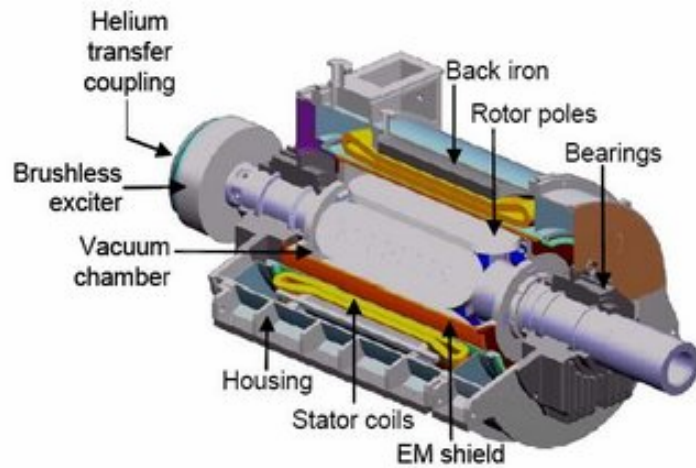
- Efficiency = 96.8%
 - 230% of the loss in the HTS motor
 - Annual energy costs to operate may be \$50,000 more than HTS motor.
- Larger volume



EPRI 1 hp (1988)



USN-AMSC
49,000 hp
(2008)

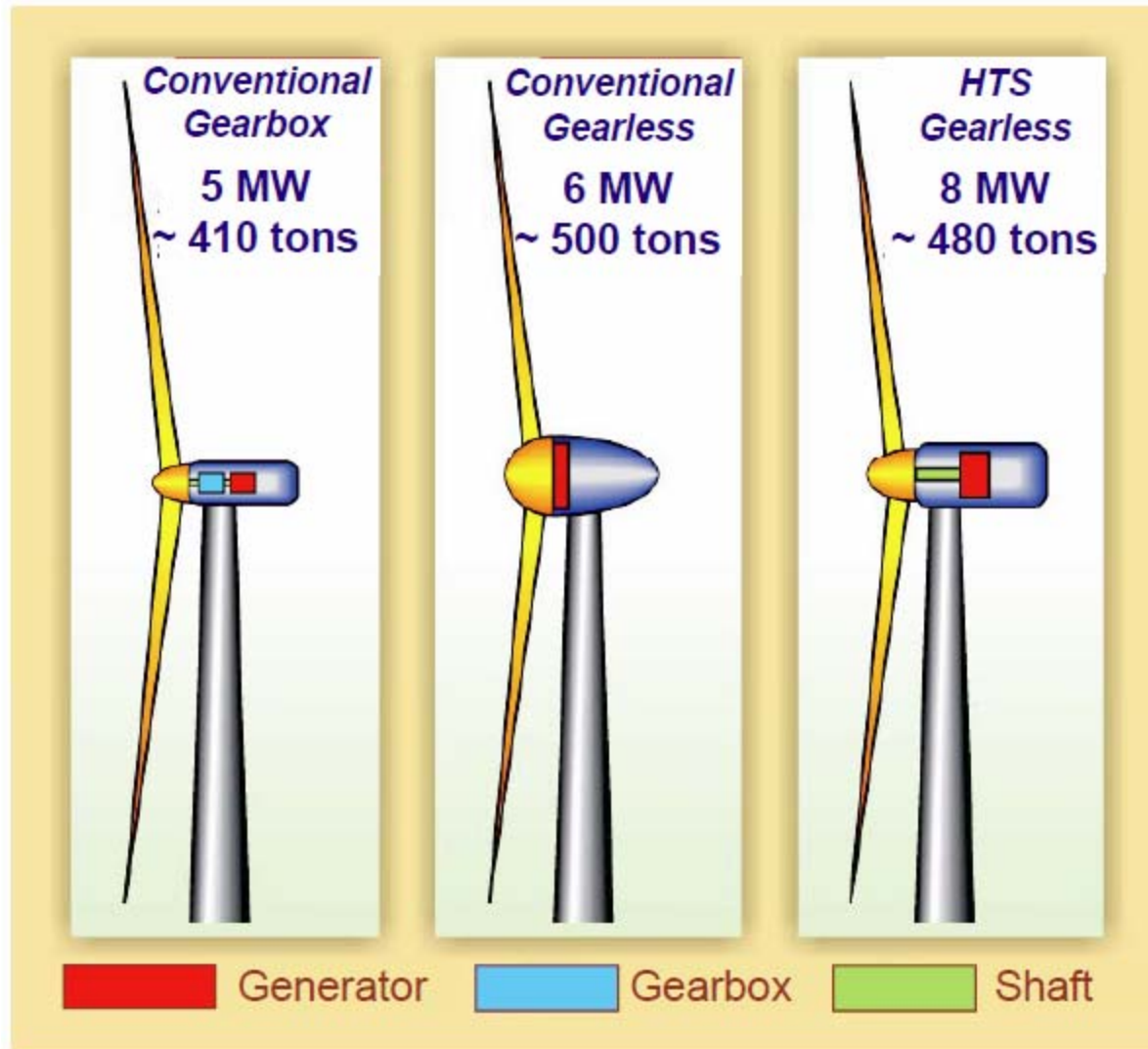


AMSC 7000 hp
(2003)



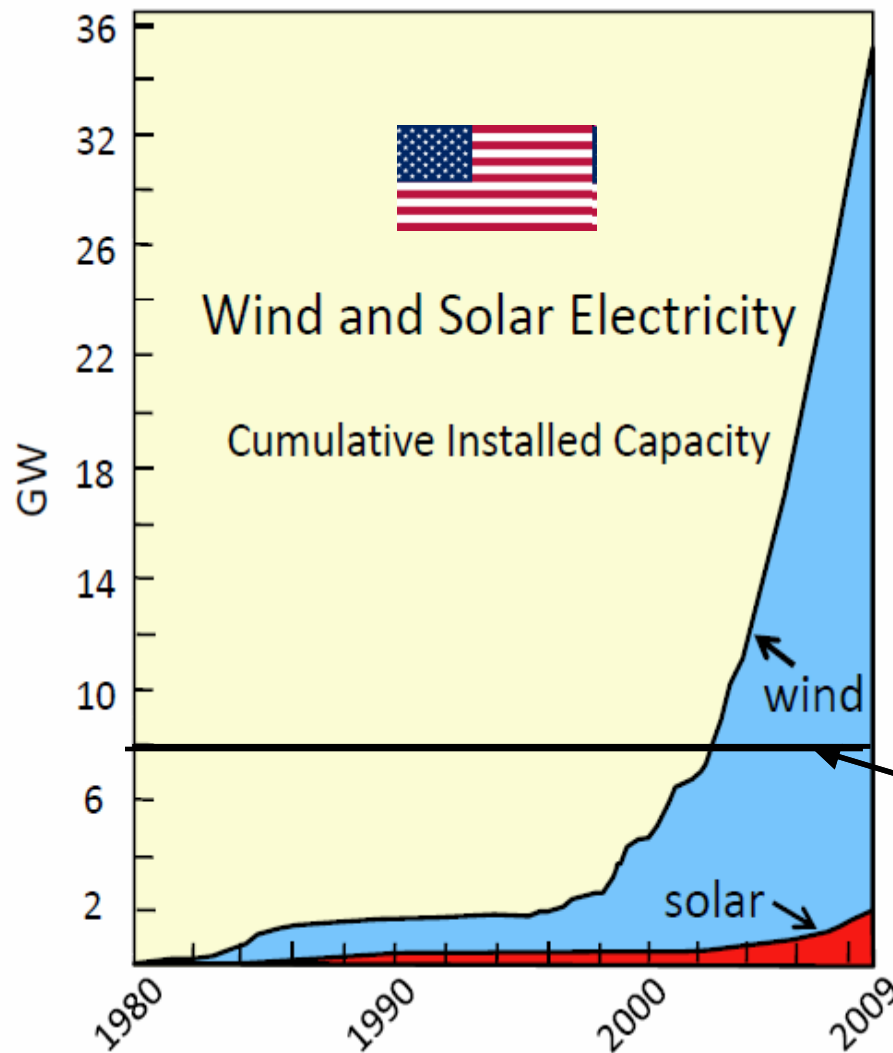
Sumitomo 70-460 hp
(2009)

Rotating Machinery - Wind Generators



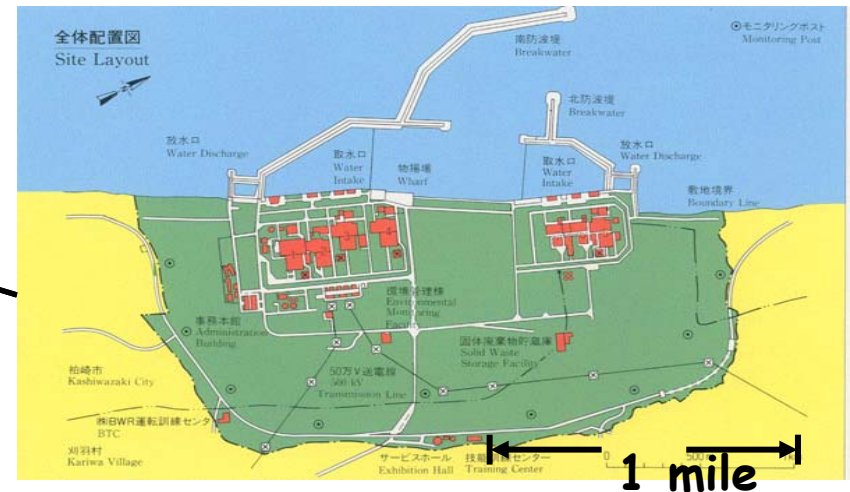
Matthews, Physics Today **62**(4), 25 (April 2009)

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



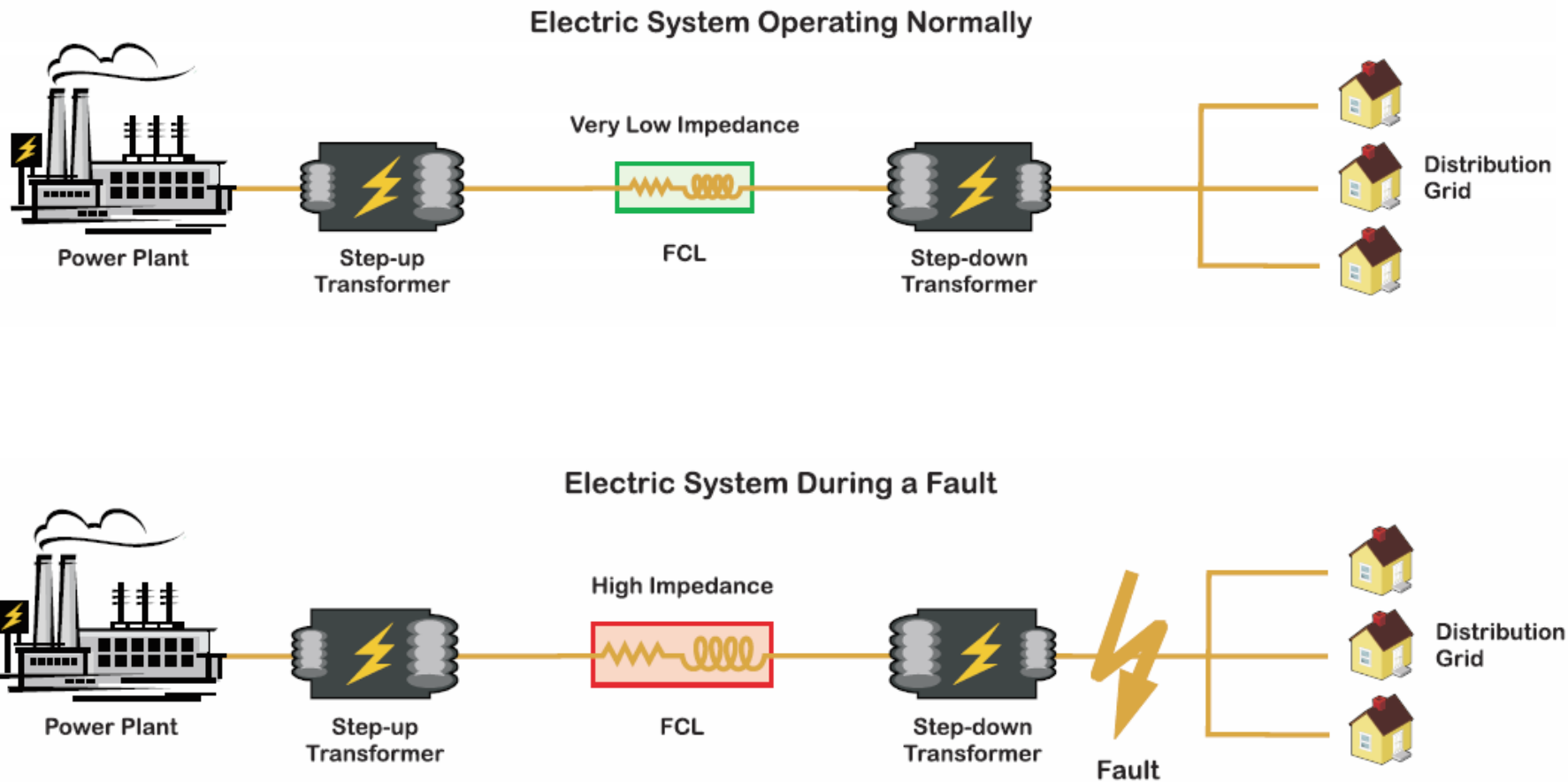
Bruker 2 MJ SMES



AMSC D-Var

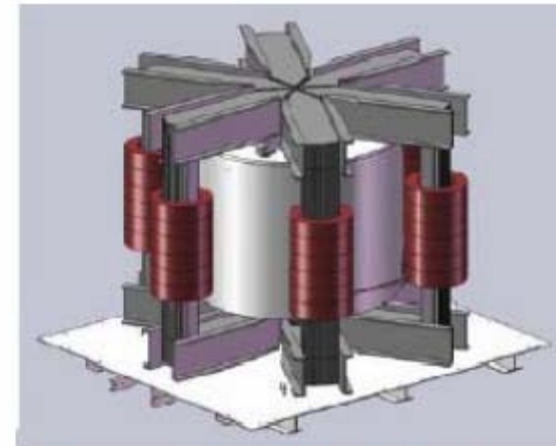
- “Orthogonal” to SMES...stores reactive power in an ordinary coil
- Great for intermittent generation...like wind

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



Schematic of 3- Φ FCL unit



Actual installed device in Southern California Edison grid NY

**Nom. 2G tape length requirements
10 to 100 km**



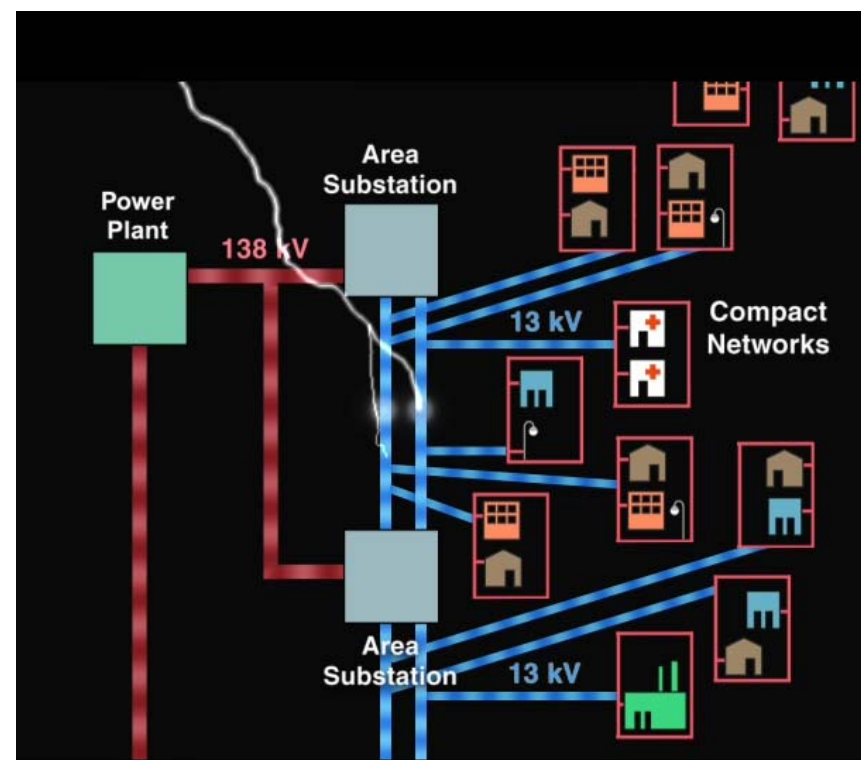
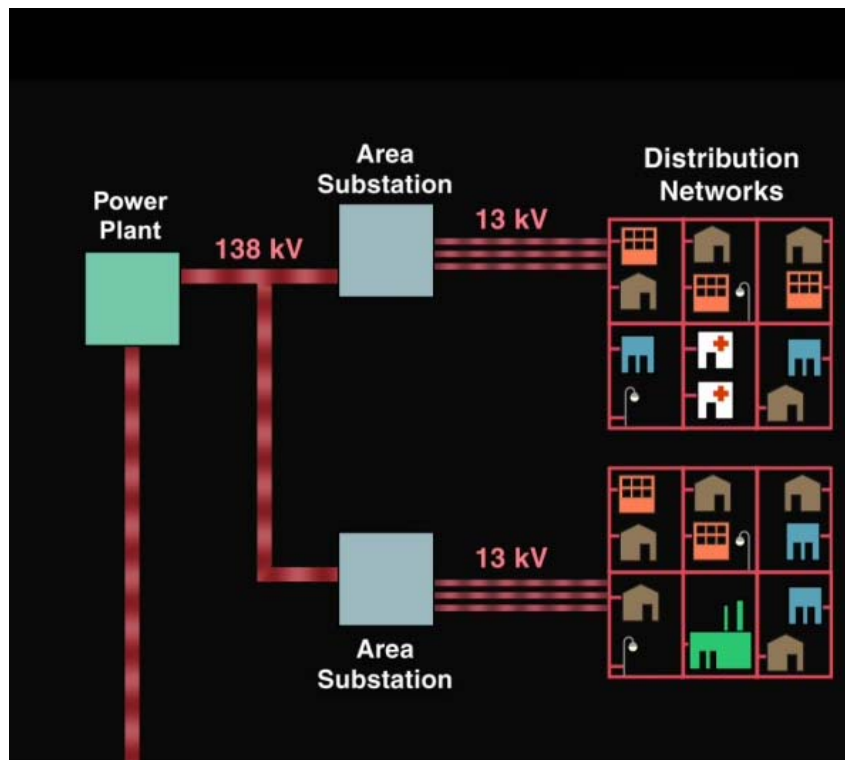
*Fault Current Limiting Equipment Overview at
2010 Workshop on High Temperature Superconducting Wires*

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

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 (10³ USD)

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

Research and Development
 High Temperature Superconductivity
 Visualization and Controls
 Energy Storage and Power Electronics
 Renewable and Distributed Systems Integration
 Clean Energy Transmission and Reliability
 Smart Grid Research and Development
 Energy Storage
 Cyber Security for Energy Delivery Systems
 SUBTOTAL Research and Development

 Permitting, Siting, and Analysis
 Infrastructure Security and Energy Restoration
 Program Direction
 Congressionally Directed Activities
 American Recovery and Reinvestment Act, 2009
 Use of prior year balances

TOTAL

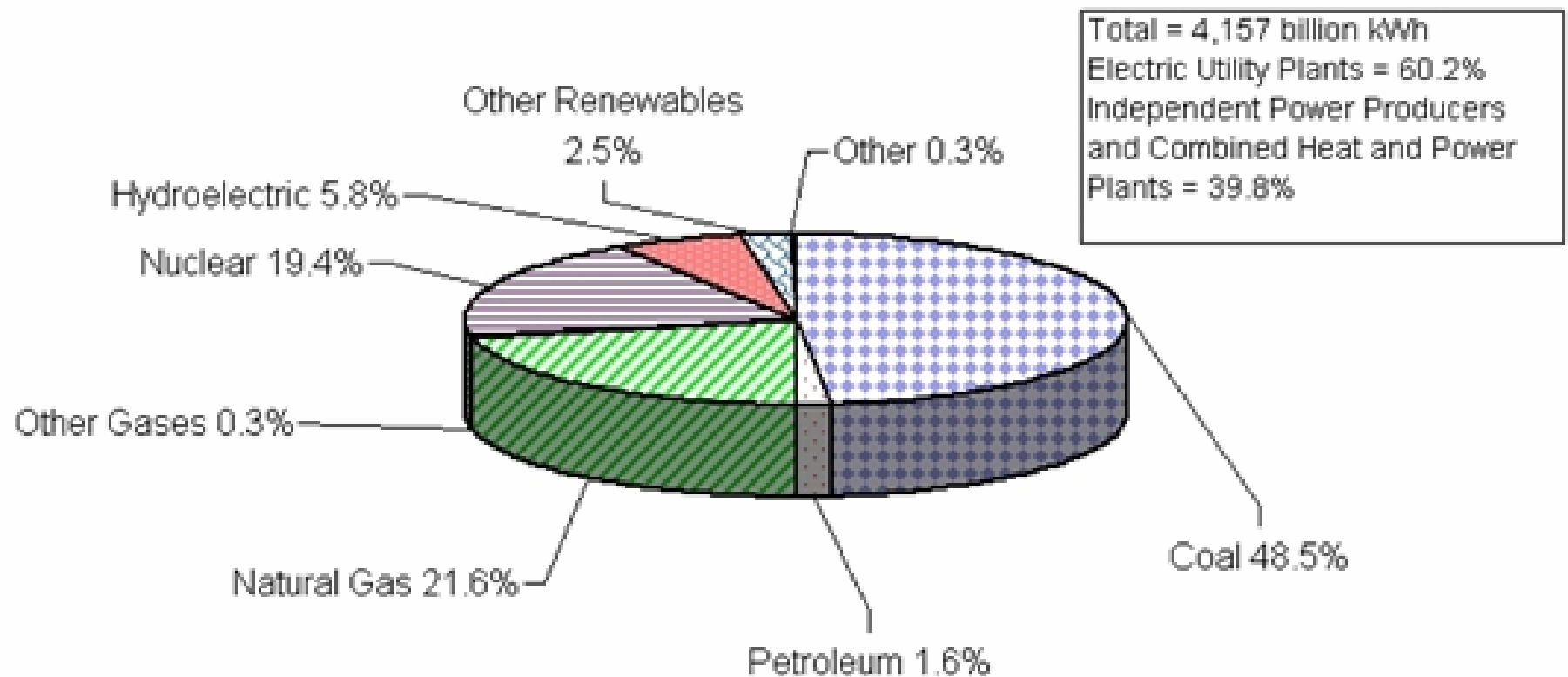
FY 2009		FY 2010	FY 2011
Current Appropriation	ARRA Appropriation	Current Appropriation	Congressional Request
23,130		?	?
24,461			
6,368			
29,160			
		38,450	35,000
		32,450	39,293
		14,000	40,000
		40,000	30,000
83,119		124,900	144,293
5,271		6,400	6,400
6,180		6,187	6,188
21,180		21,420	29,049
19,648		13,075	
	4,495,712		
-769			
134,629	4,495,712	171,982	185,930

WOW ! “Obama Cash”

Marketing

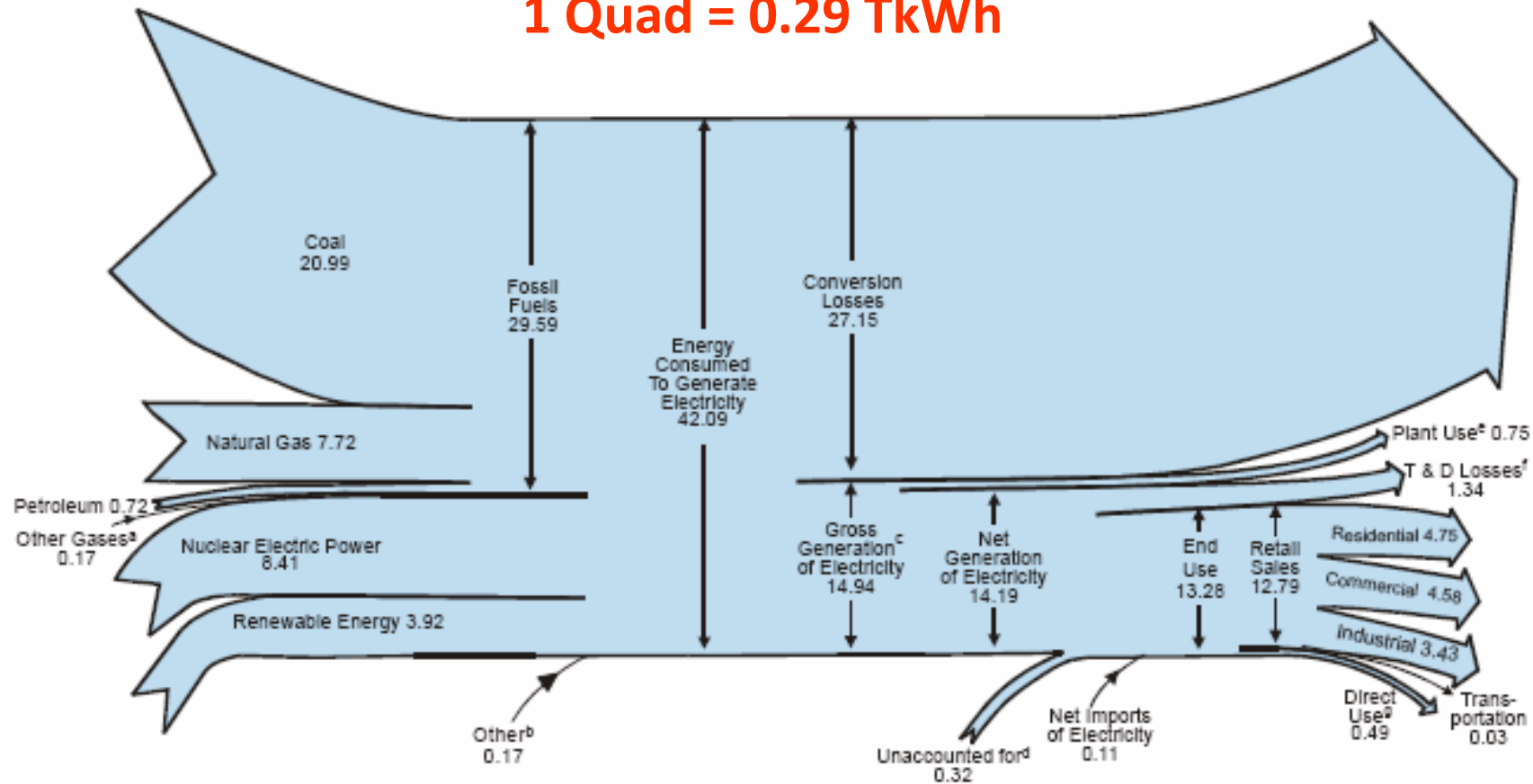
- Insertion and Deployment
- Compelling Needs?
- Killer Apps?

US Electricity Generation Sources



US Electricity Flow - 2007

1 Quad = 0.29 TkWh



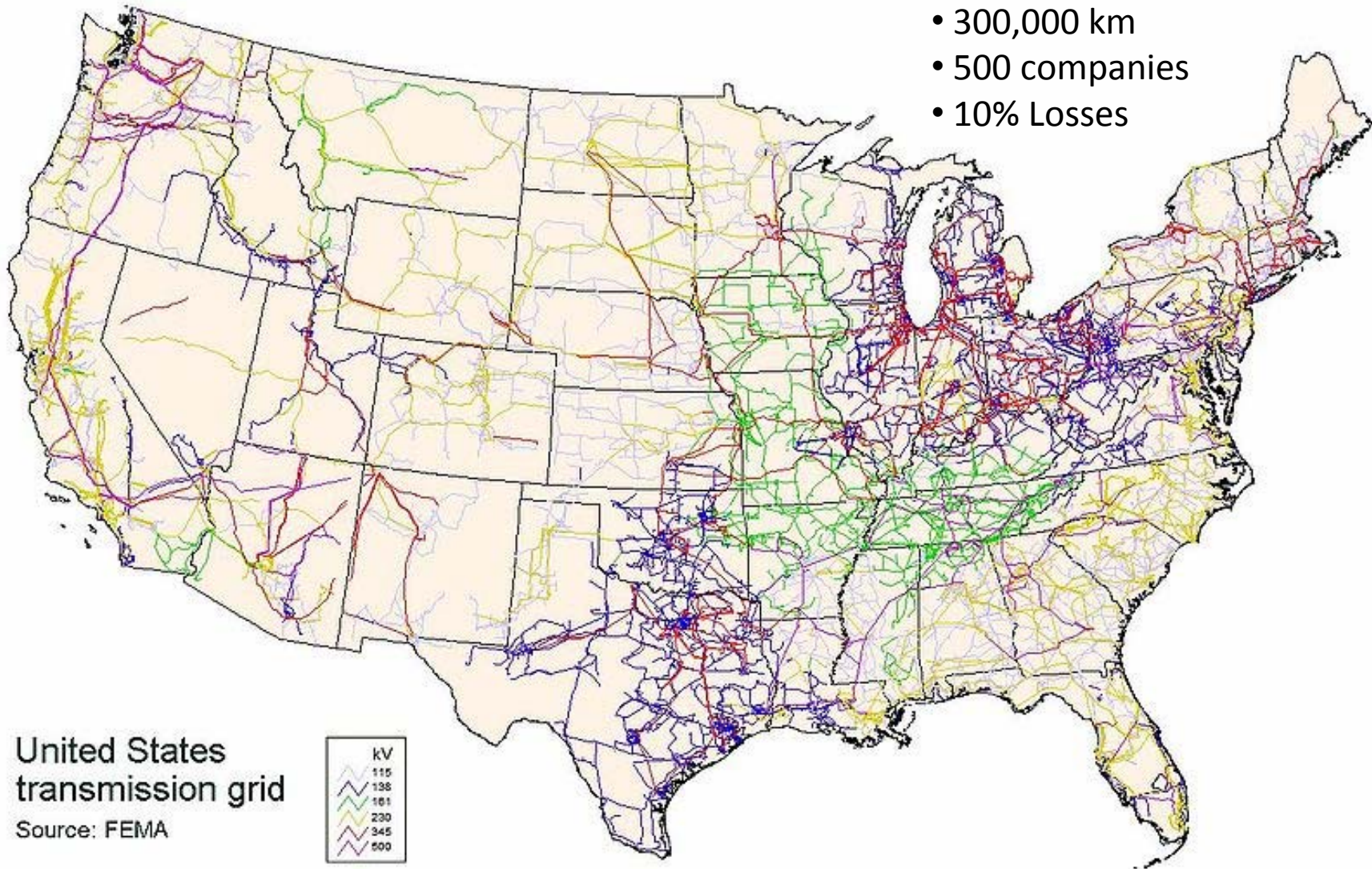
US Generation Capacity = 1.1 TW

Gross Generation = 4.33 GkWh

$(T\&D \text{ Losses}) / (\text{End Use}) = 10\%$

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”

Blackouts

Texas '03

Detroit '00

Northern California '01

San Francisco '00

Delaware '99

New Orleans '99

Chicago '99

New York '99

Northeast '03

West Coast '96

Atlanta '99



The Big Blackout

Northeast 8/14/03



As Night Falls...



The Party Begins...



...and Continues...



Mary Altaffer / AP

It Gets Better...



David Friedman / MSNBC.com

and Better...



George Widman / AP

The Morning After



Gregory Bull / AP

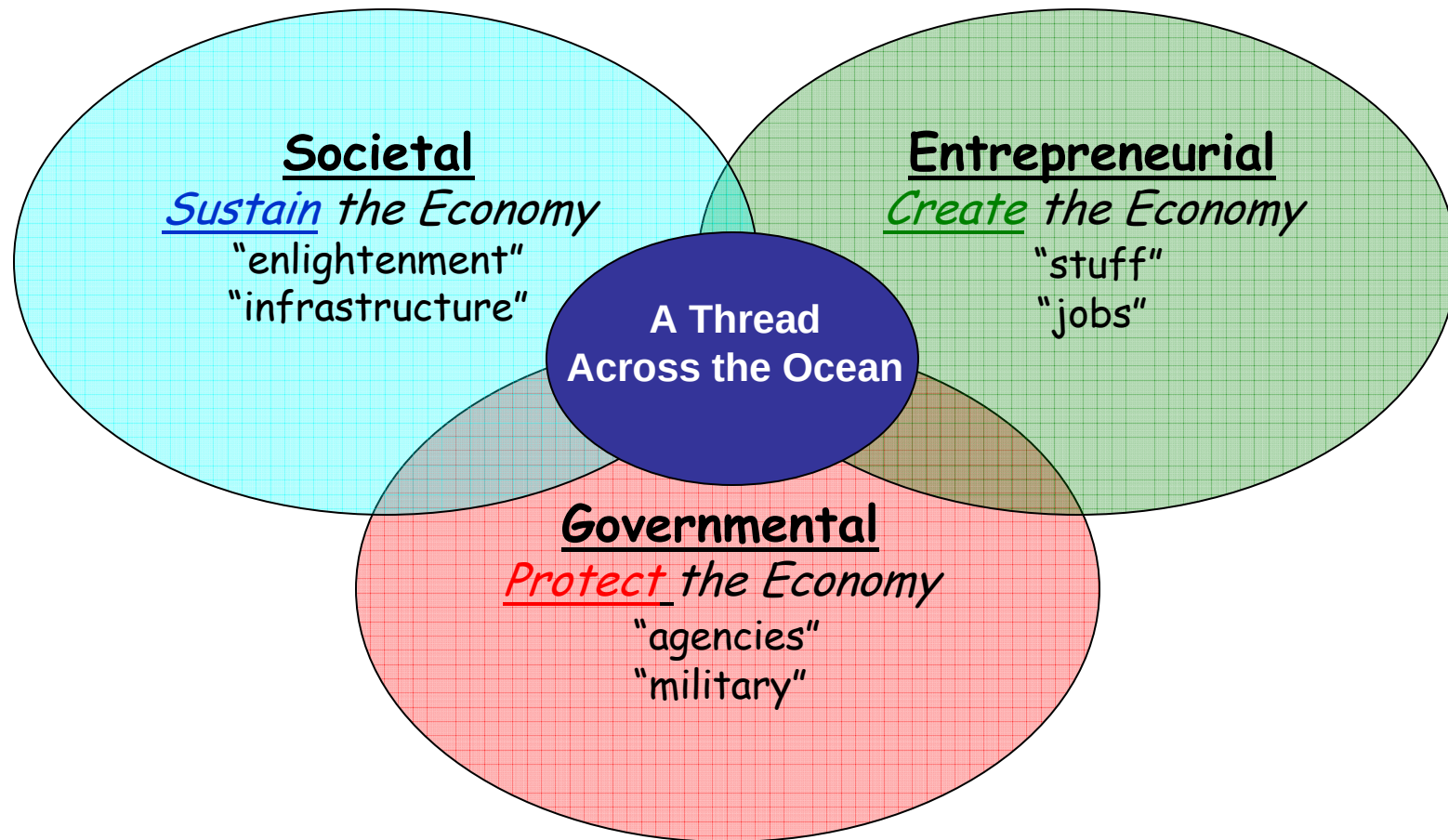
Viva New York!



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



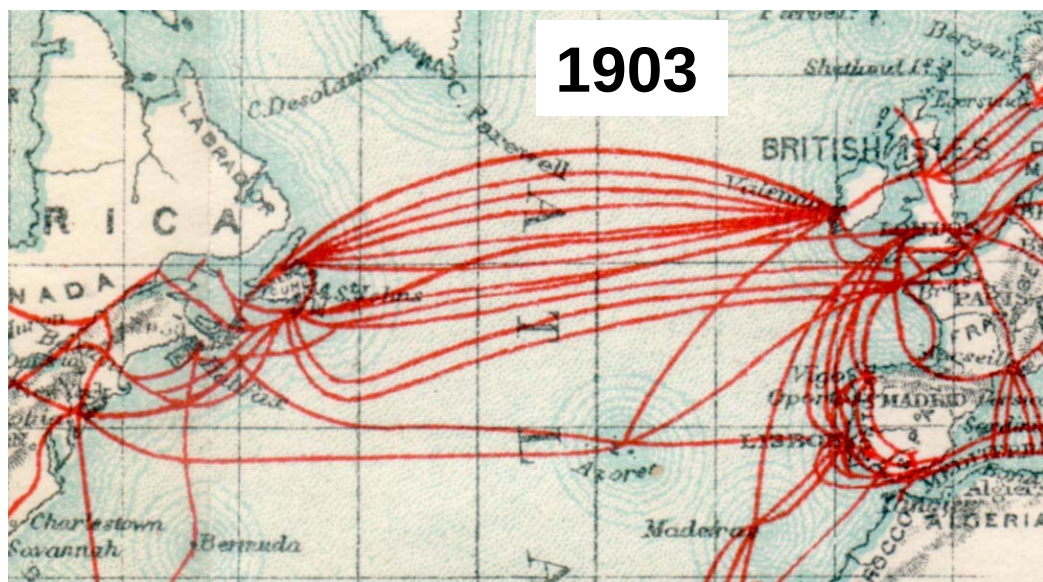
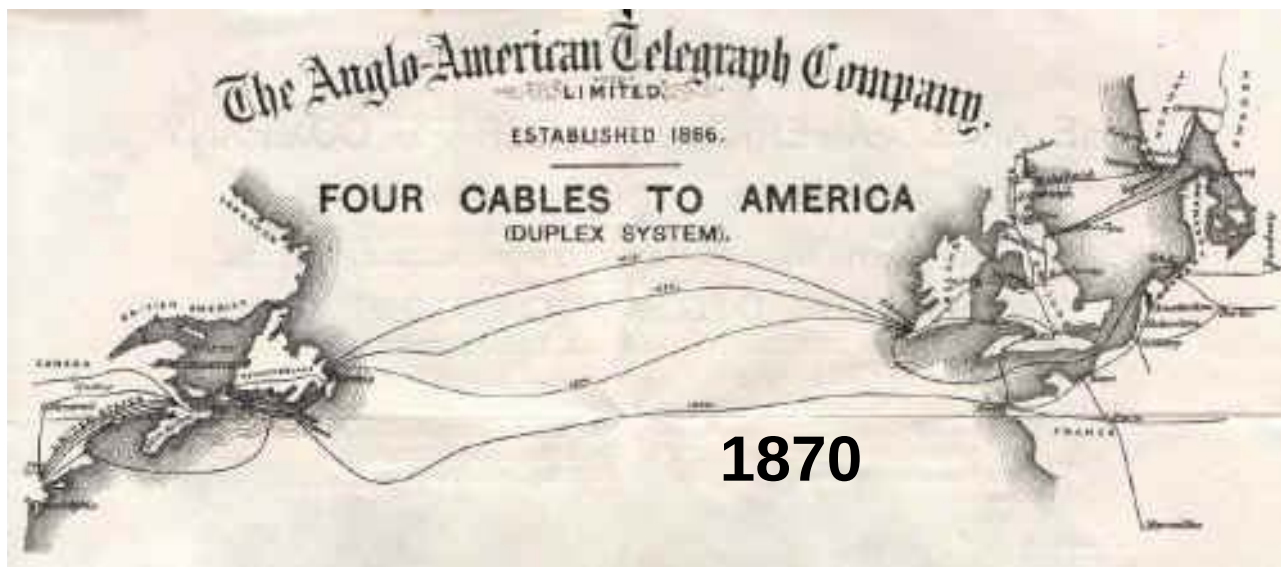
William Thomson
Irish Physicist

John Steele Gordon

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?

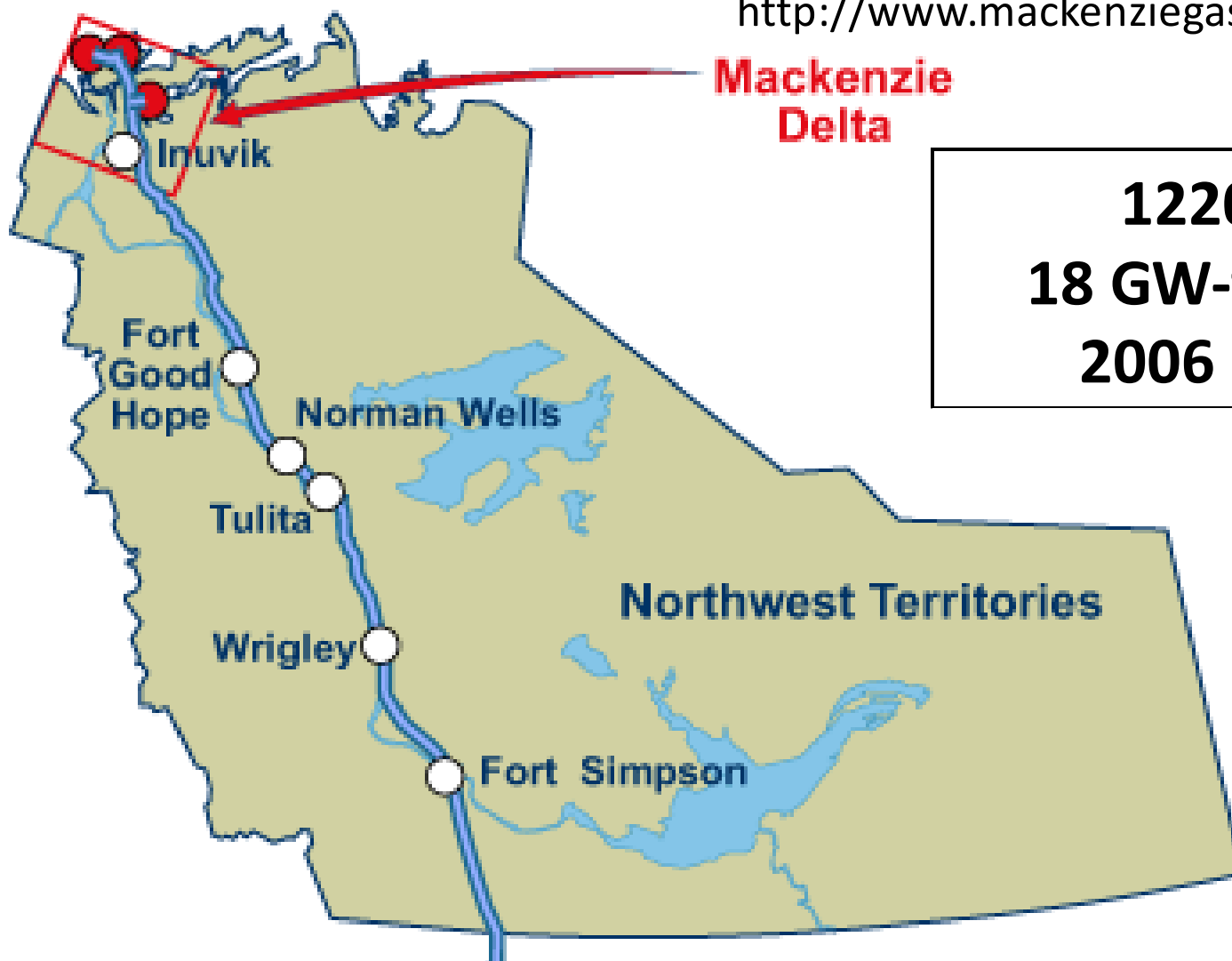
- What's the analogy to the Erie Canal, Railroads, REA, TVA, Interstate Highways that opened the country to economic development?
 - Capacity? Possibly
 - Reliability? Maybe
 - Power Quality? Nah

A Canadian's View of the World



The Mackenzie Valley Pipeline

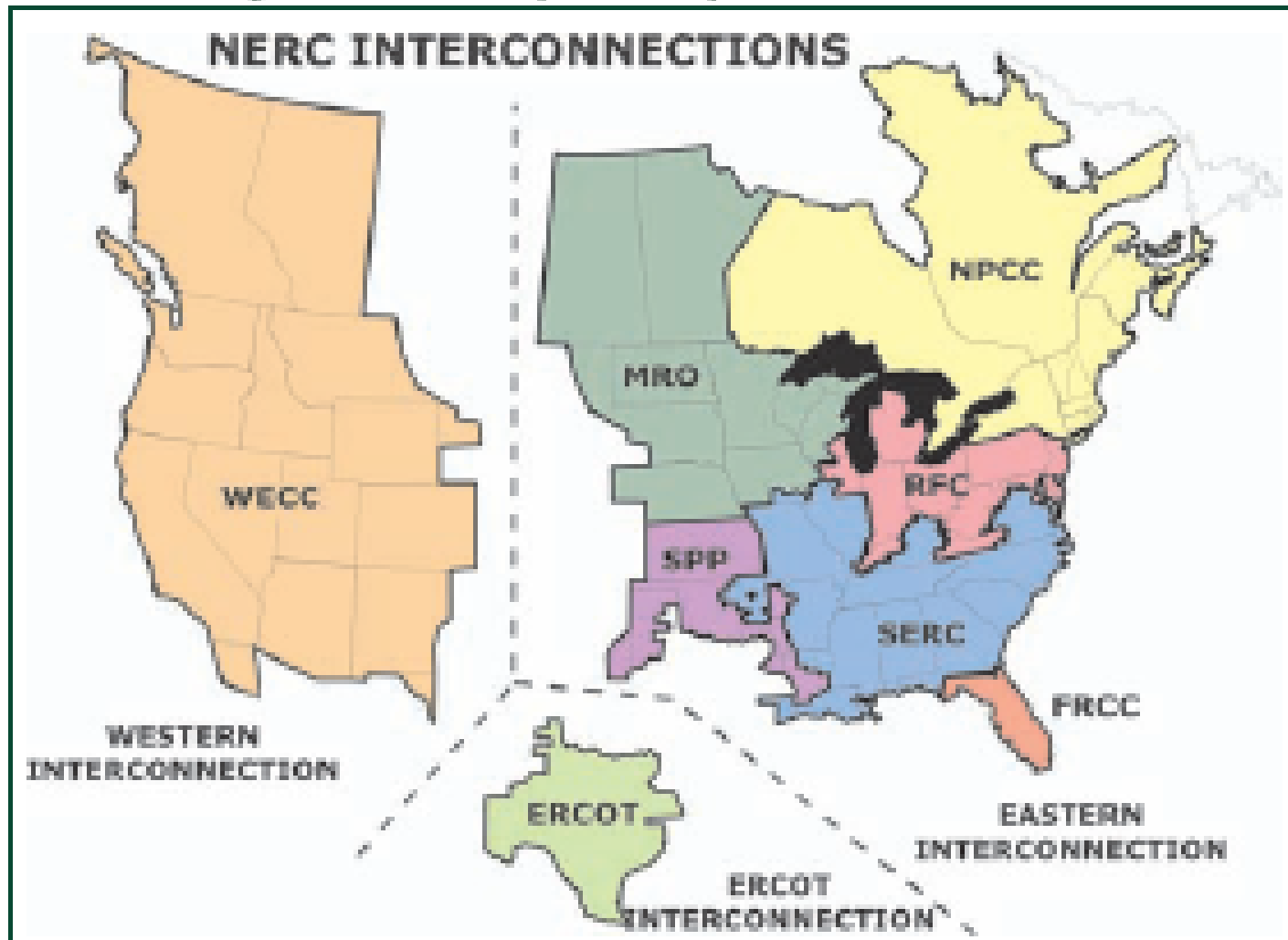
<http://www.mackenziegasproject.com>



**Mackenzie
Delta**

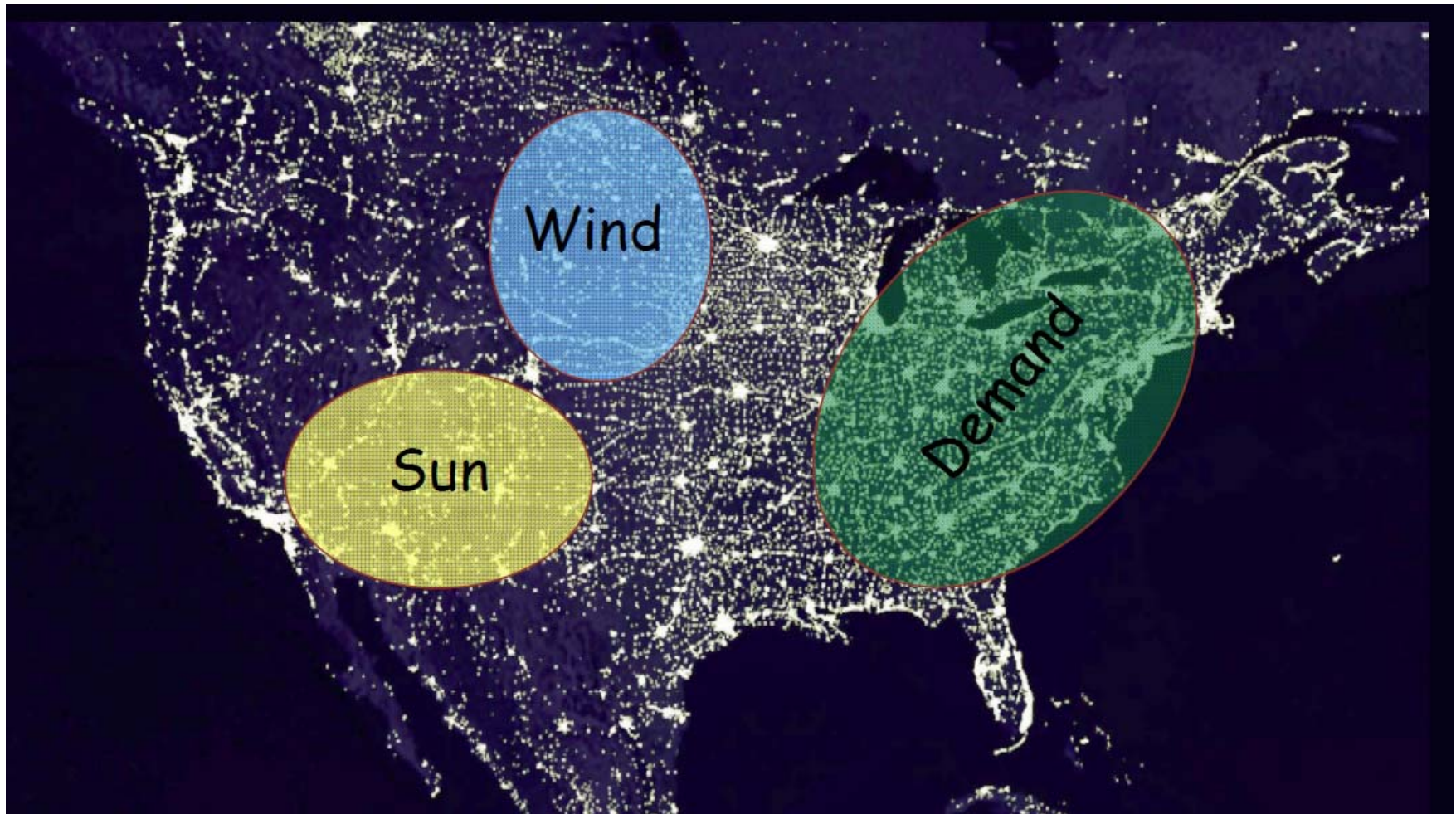
**1220 km
18 GW-thermal
2006 - 2010**

NERC Interconnects



Source: DOE 2006 National Electric Transmission Study

The "Green" Energy Economy

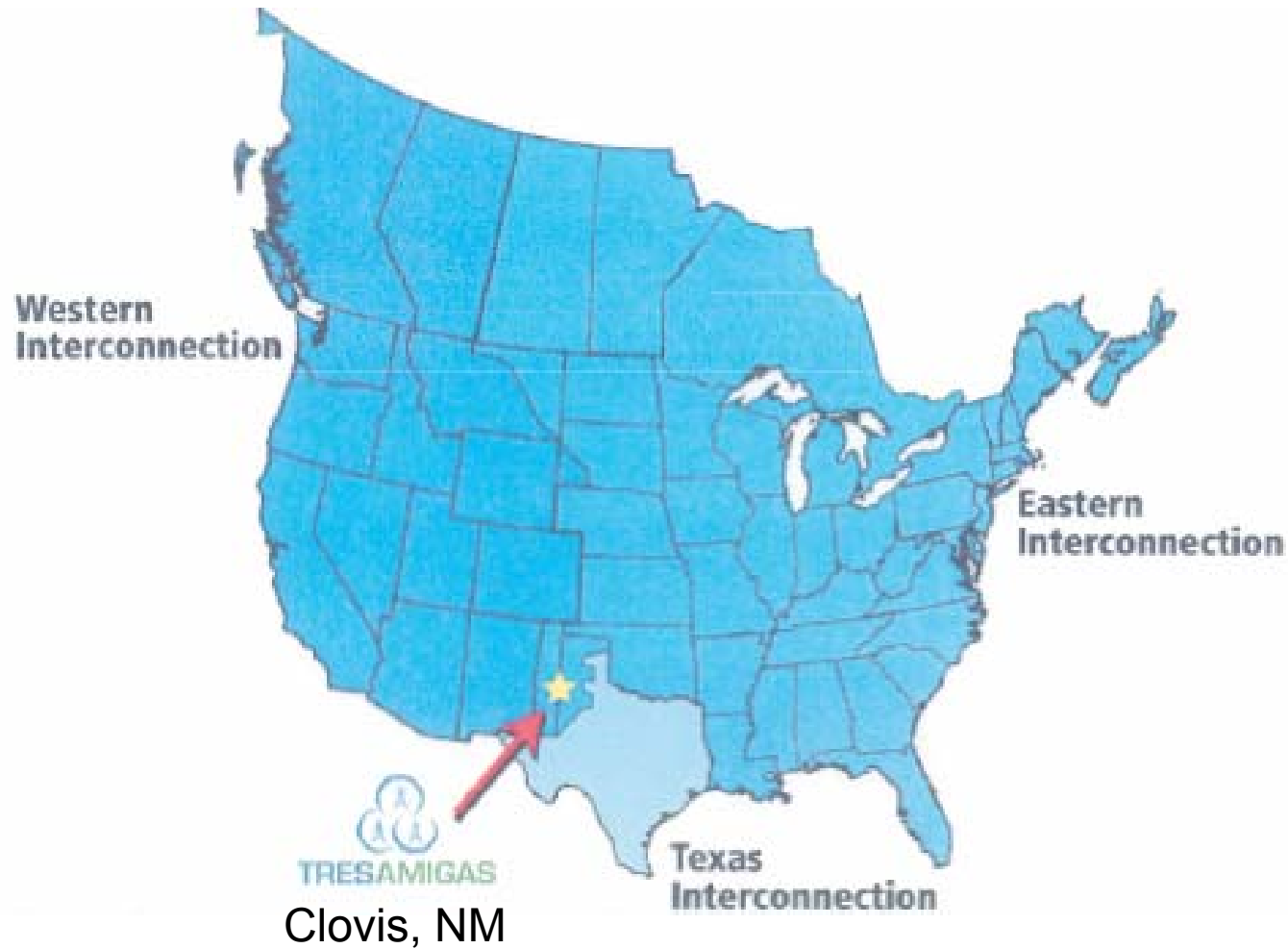


THE TRES AMIGAS PROJECT

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"

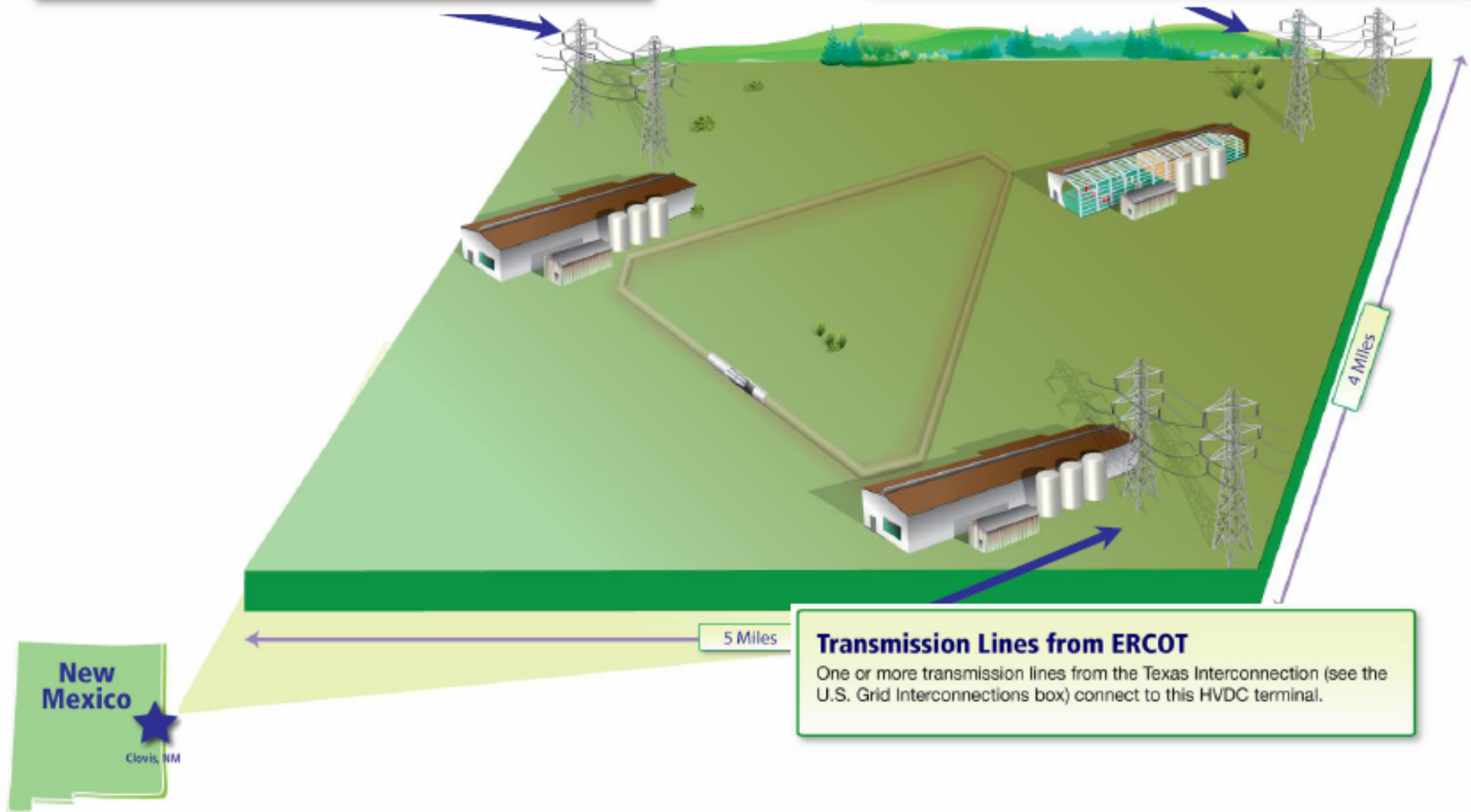


The Tres Amigas SuperStation



Transmission Lines from Western Interconnection

Transmission Lines from Eastern Interconnection



DC Superconductor Ring

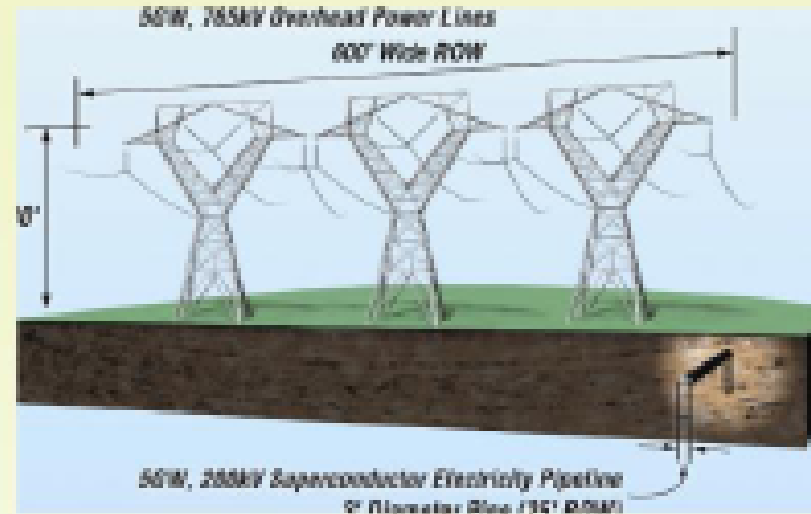
Key to the Tres Amigas SuperStation is an underground pipeline of direct current (DC) superconductor cables less than three feet in diameter capable of carrying more than 5,000,000,000 watts (5 gigawatts) of electricity with no electrical losses; enough electricity to power 2.5 million homes. Superconductor 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 CO2 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).

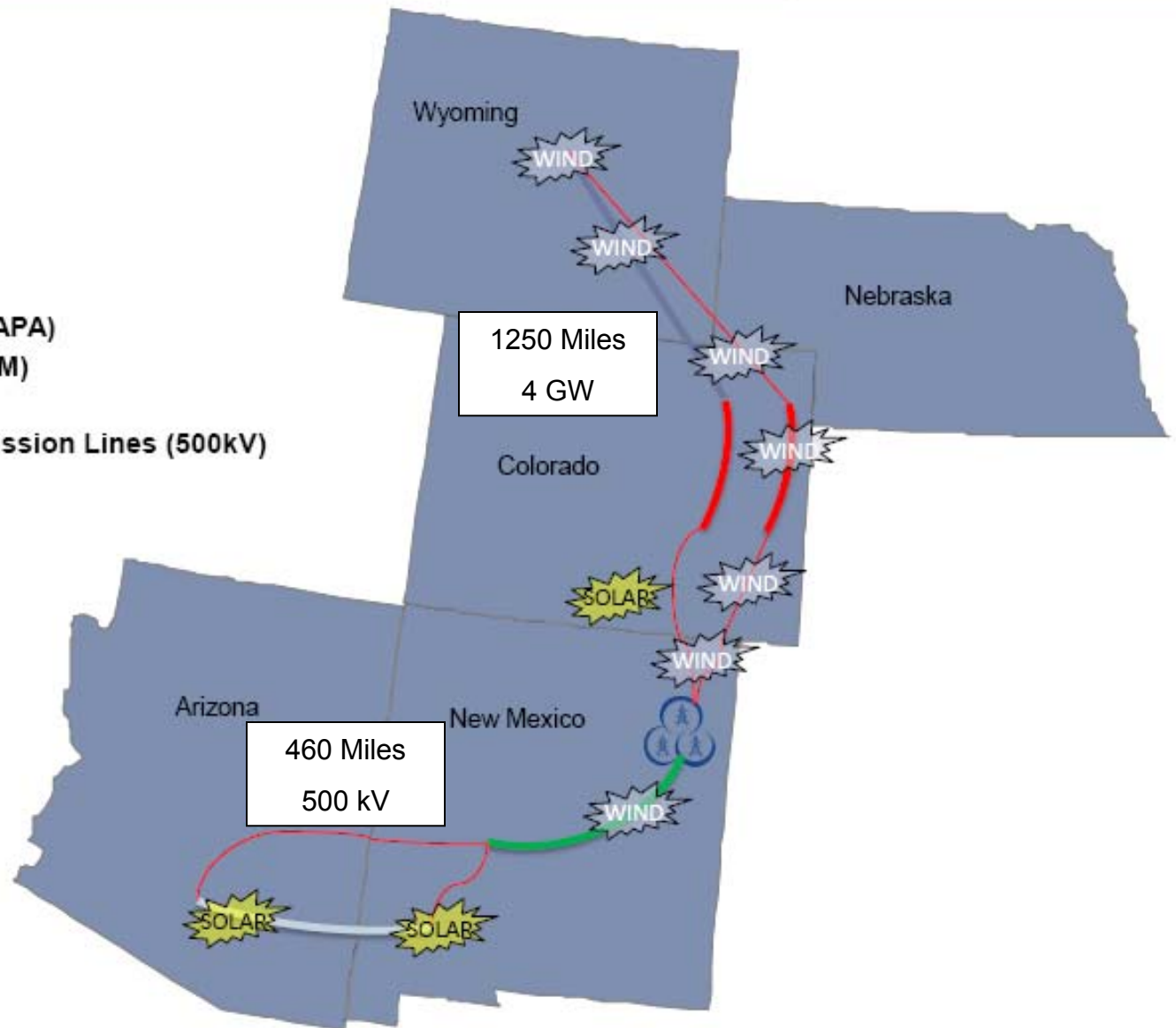
Increase power security: Unlike overhead lines, underground cables are virtually immune to weather-related outages, the most common cause of power disruptions. Similarly, underground placement makes them less subject to vandalism and other forms of willful attack.



Potential Beneficiaries in WECC



- WCI (TE/WIA/WAPA)
- FPTP (Tri-State/Xcel/WAPA)
- NM Wind Collector (PNM)
- SunZia
- HPX Proposed Transmission Lines (500kV)



(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

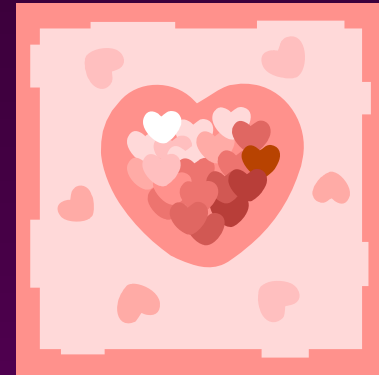


Miss Same Old Technology



Together Forever?





“Al Gore” – He’s Available !

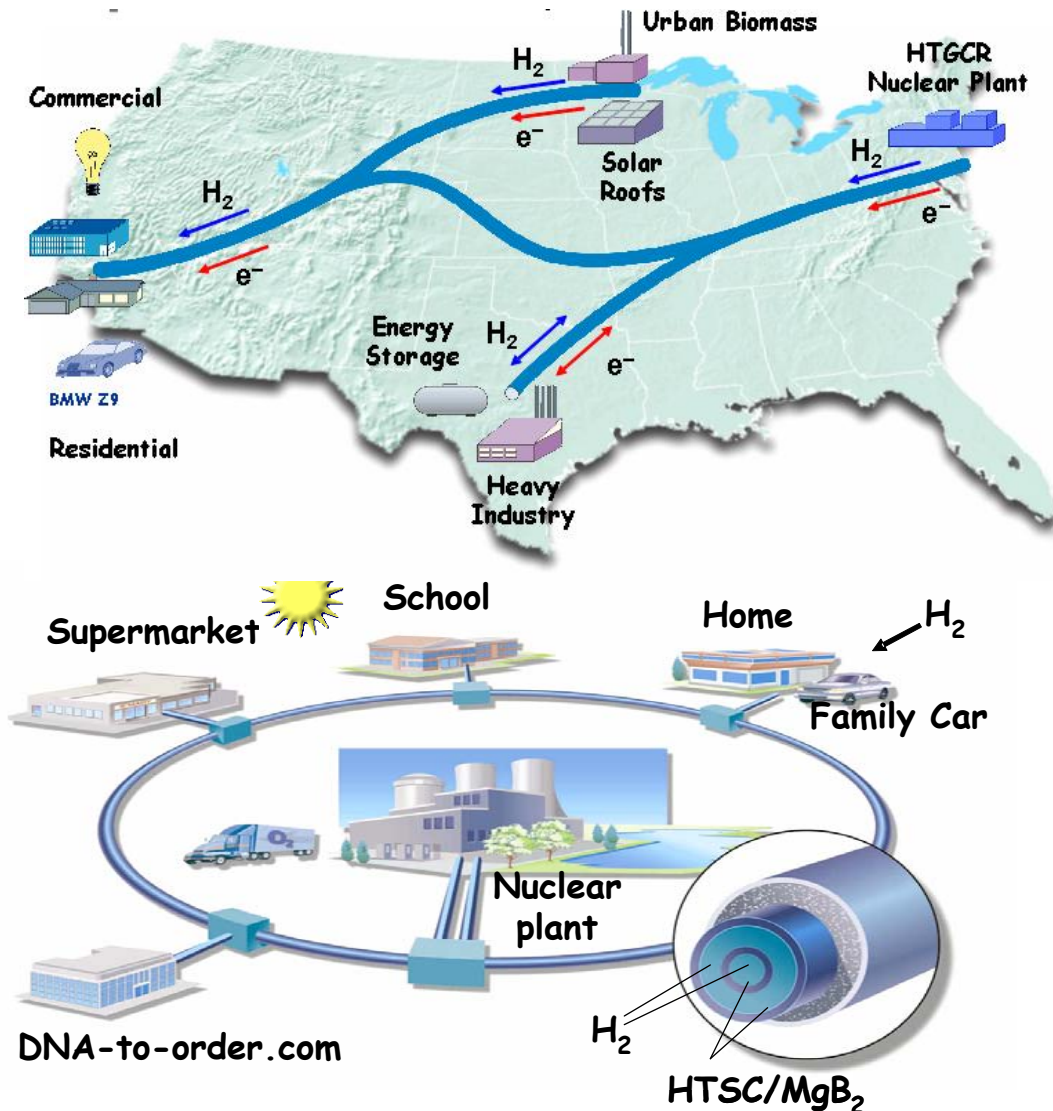


Vision

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

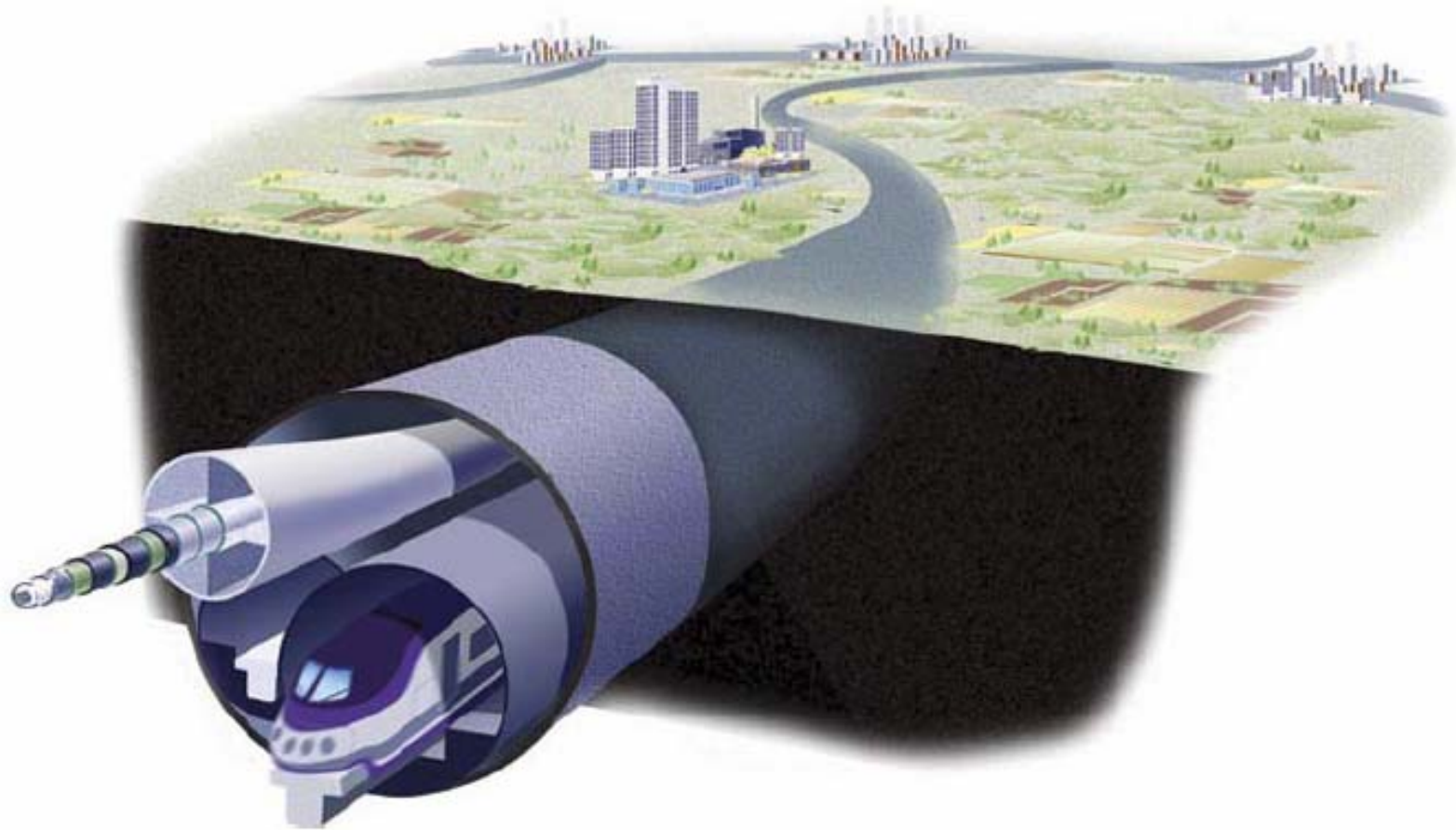
Extreme Energy Makeover

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

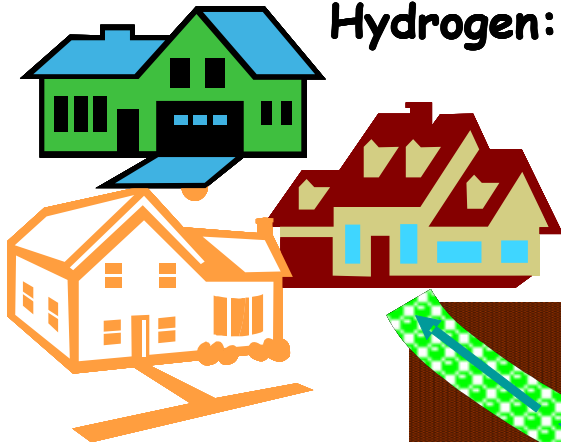
SuperSuburb

SuperSuburb

Households: 300,000

Electricity: 1800 MW

Hydrogen: 800 MW



~ "San Jose"

250 km

SuperCable

Voltage: +/- 20 kV

Current: 45 kA

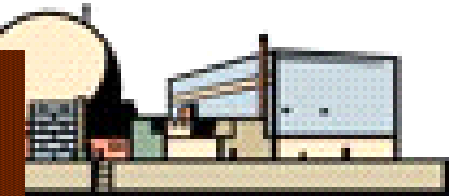
H₂ Storage: 28 GWh

H₂ Flow: 2 m/s => 6.8 kg/s

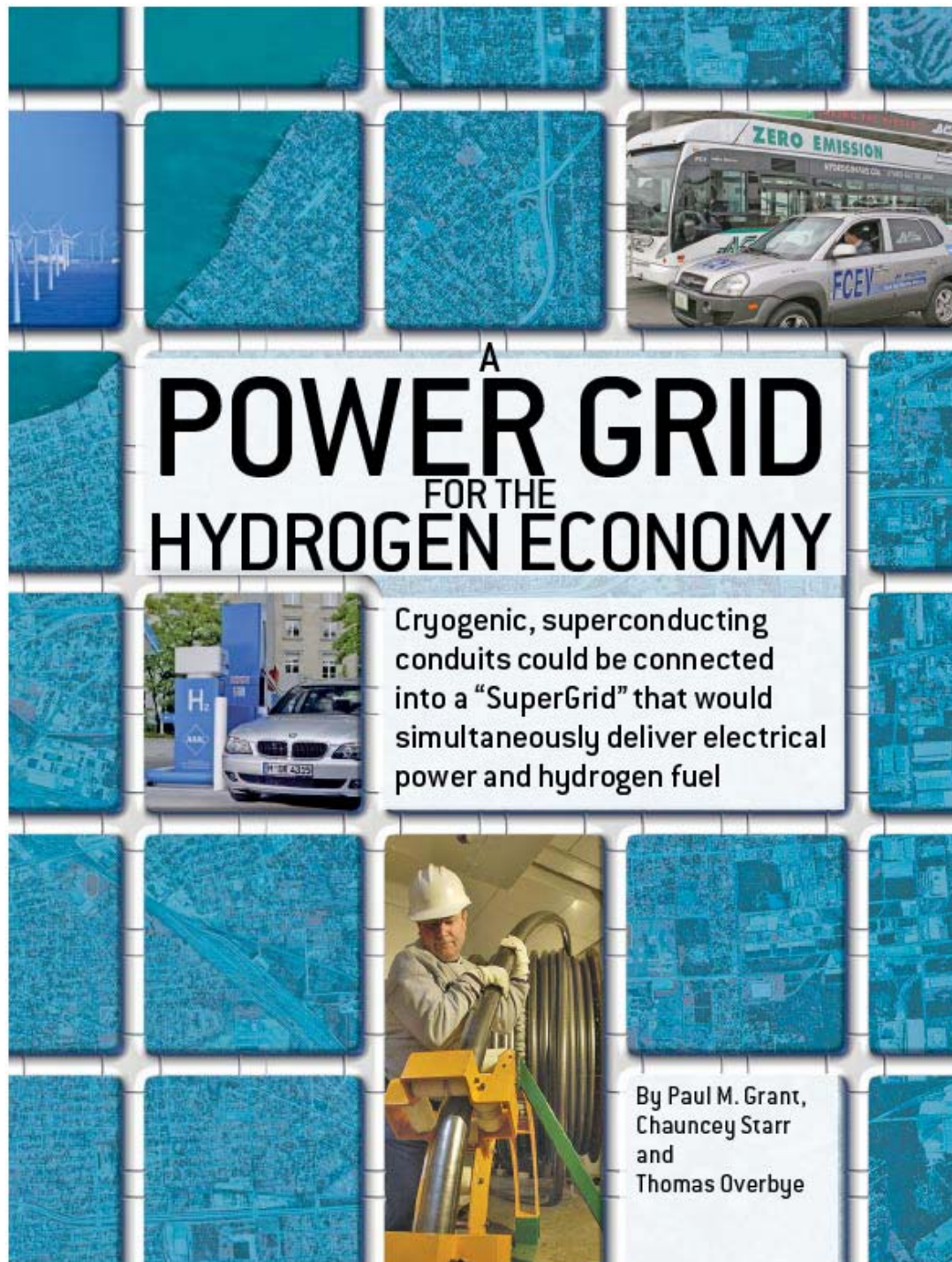
SuperNuke

electrons + protons

=> 2600 MW



~ "Diablo Canyon"

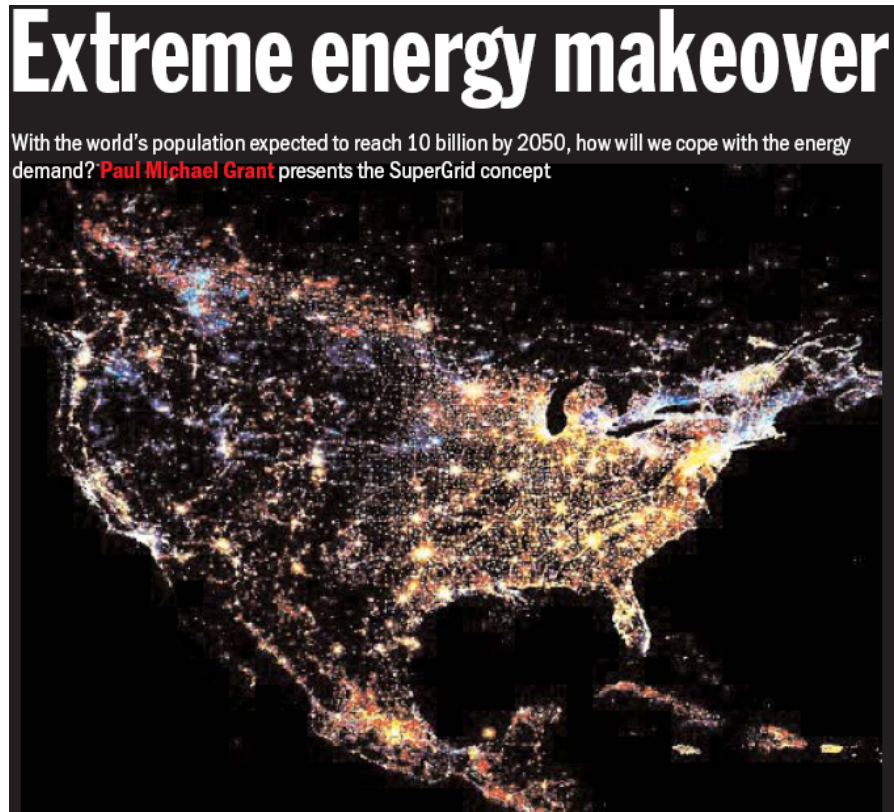


On the afternoon of August 14, 2003, electricity failed to arrive in New York City, plunging the 10 million inhabitants of the Big Apple—along with 40 million other people throughout the northeastern U.S. and Ontario—into a tense night of darkness. After one power plant in

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