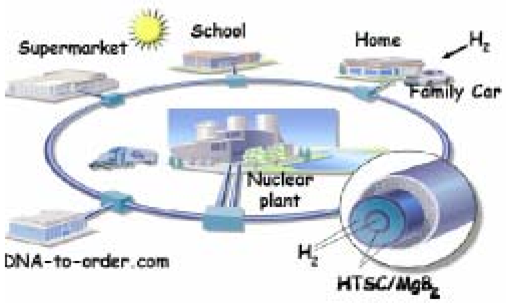
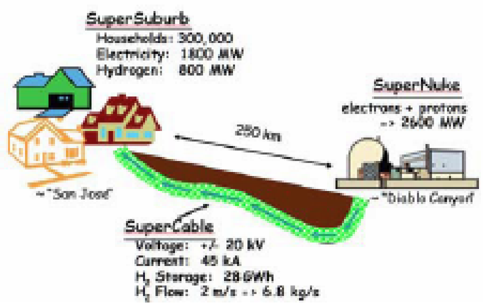
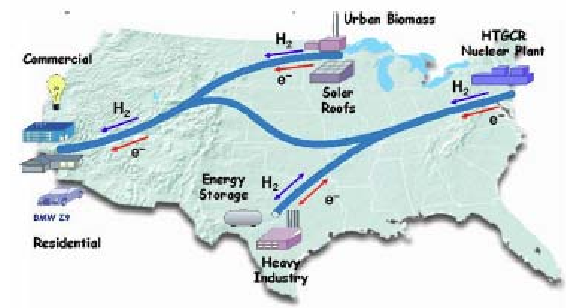
SuperCities, SuperSuburbs and SuperGrids

Superconducting Materials Challenges Confronting the Energy Society of the Future







Paul M. Grant
W2AGZ Technologies
San Jose, CA USA

www.w2agz.com

AGING IBM PENSIONER

MRS Spring Meeting
Moscone (West) Convention Center
25-29 April 2011, San Francisco, CA

2011 MRS SPRING MEETING

Session VV1.1 Room 2020
8:30 AM
Tuesday, 26 April 2011

Acknowledgements

Financial

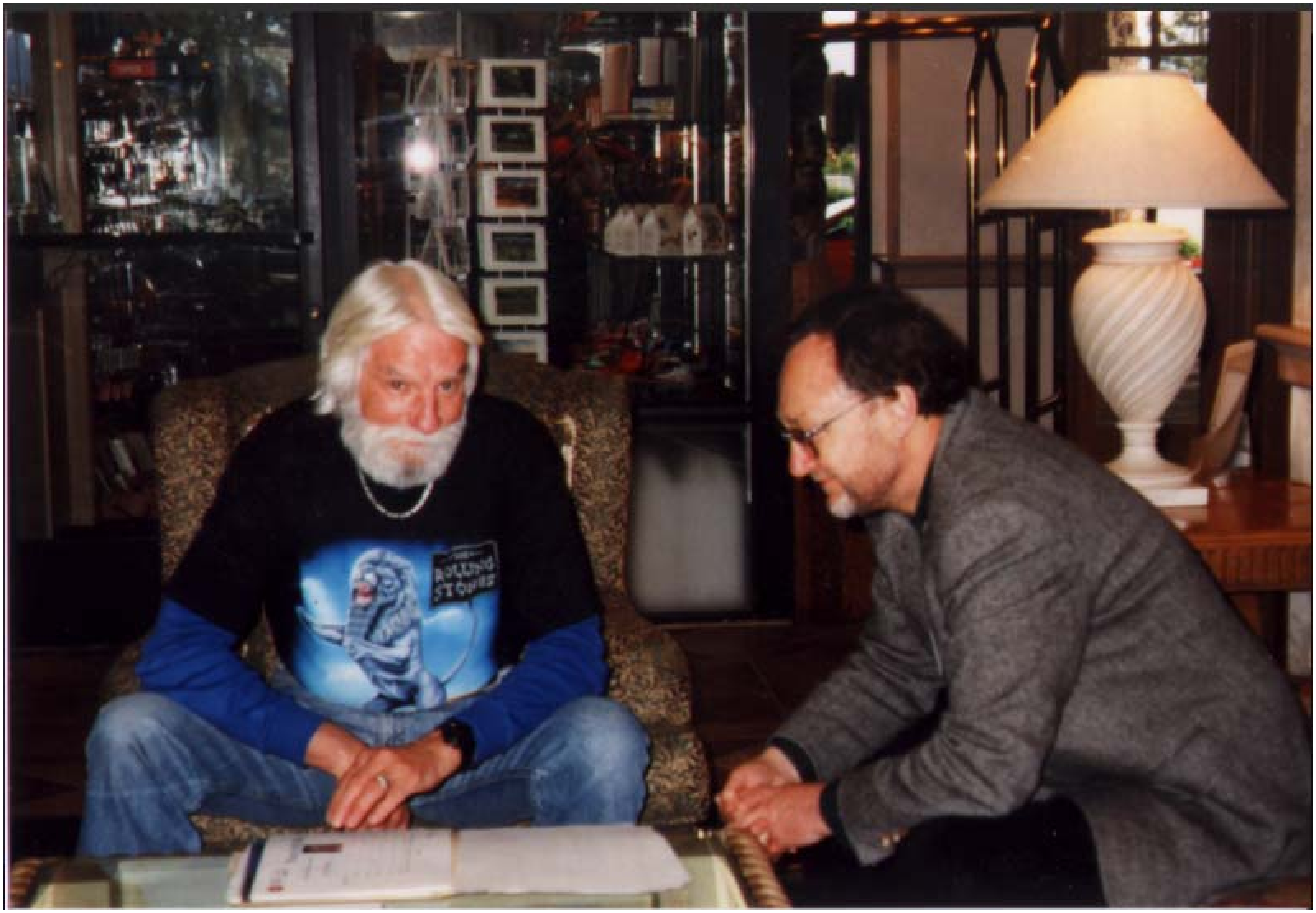
"IBM Retiree Pension Fund"

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.

Forgive me, Father, for I have sinned….



Grant, P.M., Superconductivity and Electric Power: Promises, Promises...Past, Present and Future, IEEE Trans. Appl. Supercon. (1997) 7 112-133

Discovery Anniversaries

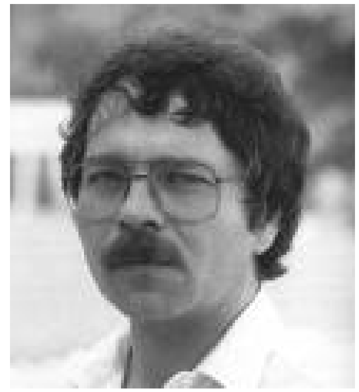
100

1911 (4.2 K)

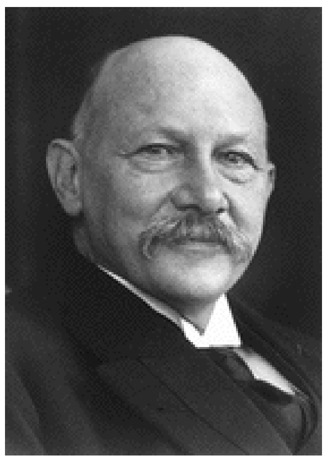
Gilles Holst

25

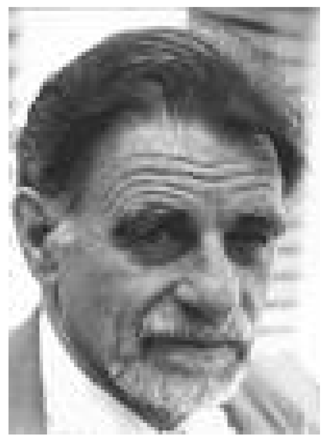
1986 (20-40 K)



Georg Bednorz

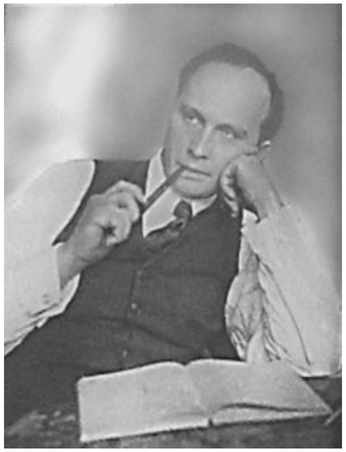


H. Kammerlingh-Onnes



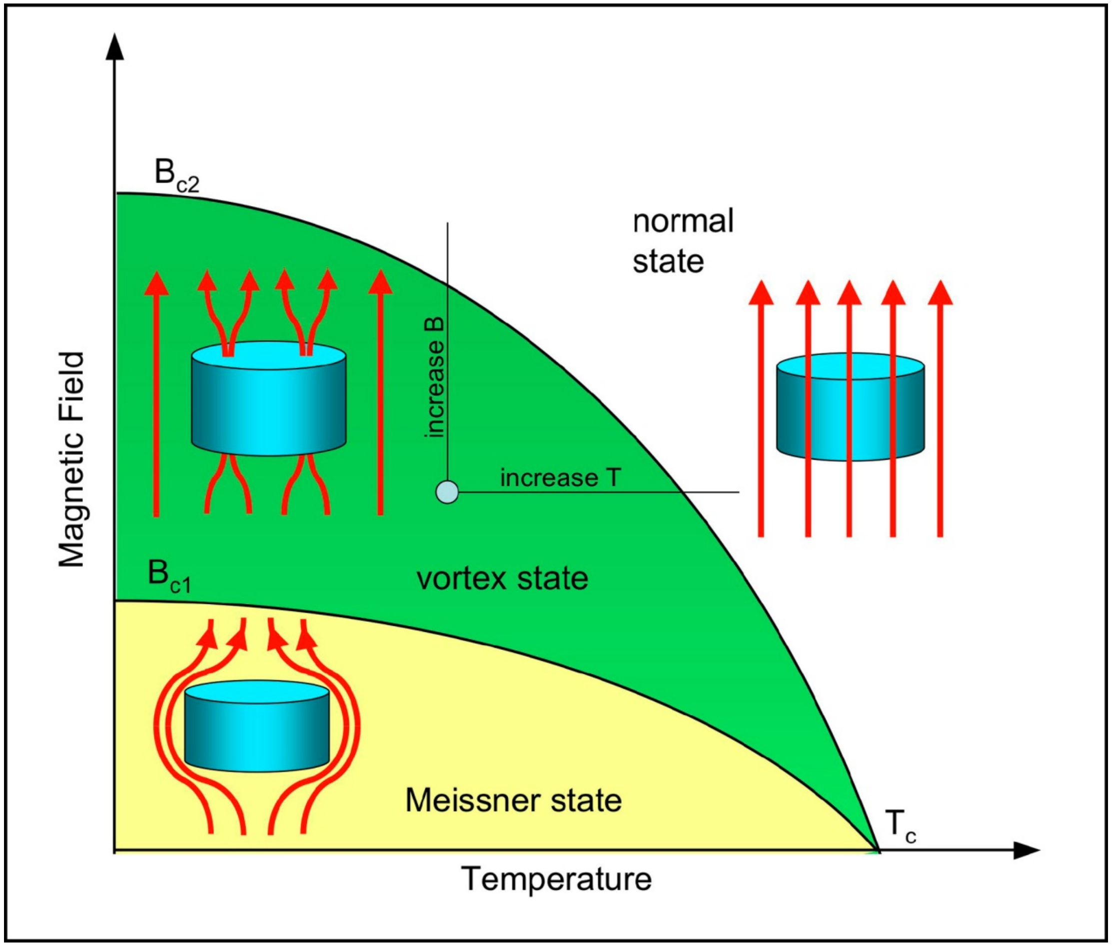
Alex Mueller

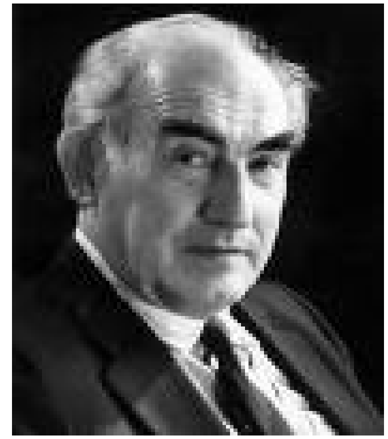
Type II (1930s +)



Lev Shubnikov

Lev Landau





“VL” Ginzburg

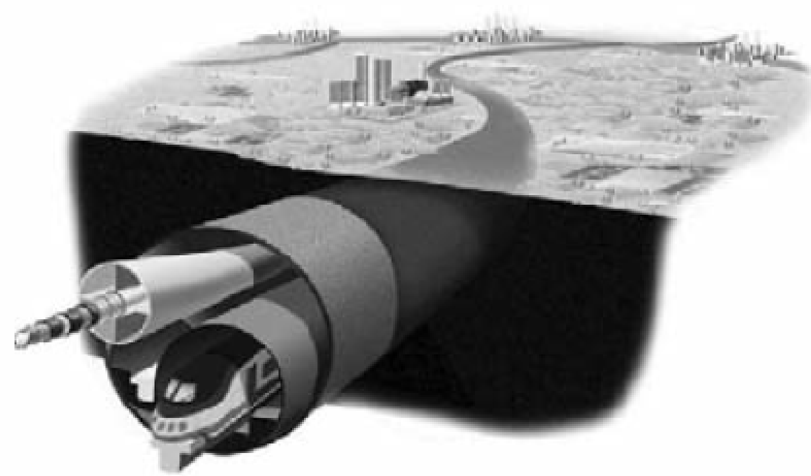
Aleksei Abrikosov

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.



Superconductivity: 100 years of history physicsworld.com

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

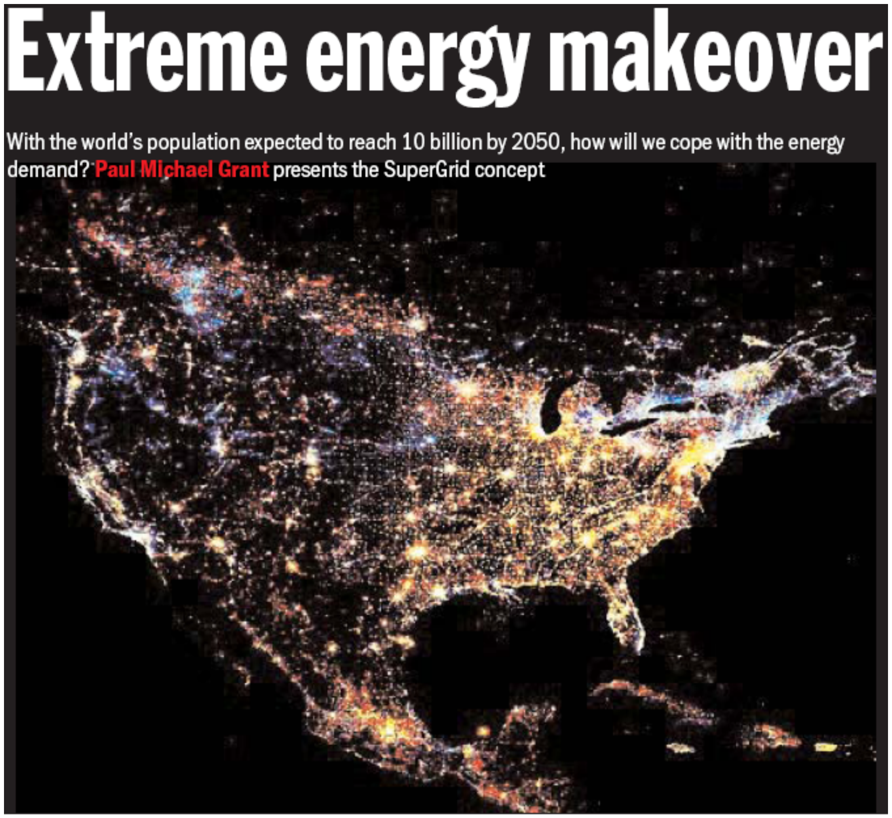
physicsworld.com Superconductivity: Top five applications

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

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

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…?

Warning!

Cuidado!

Achtung!

This presentation will:

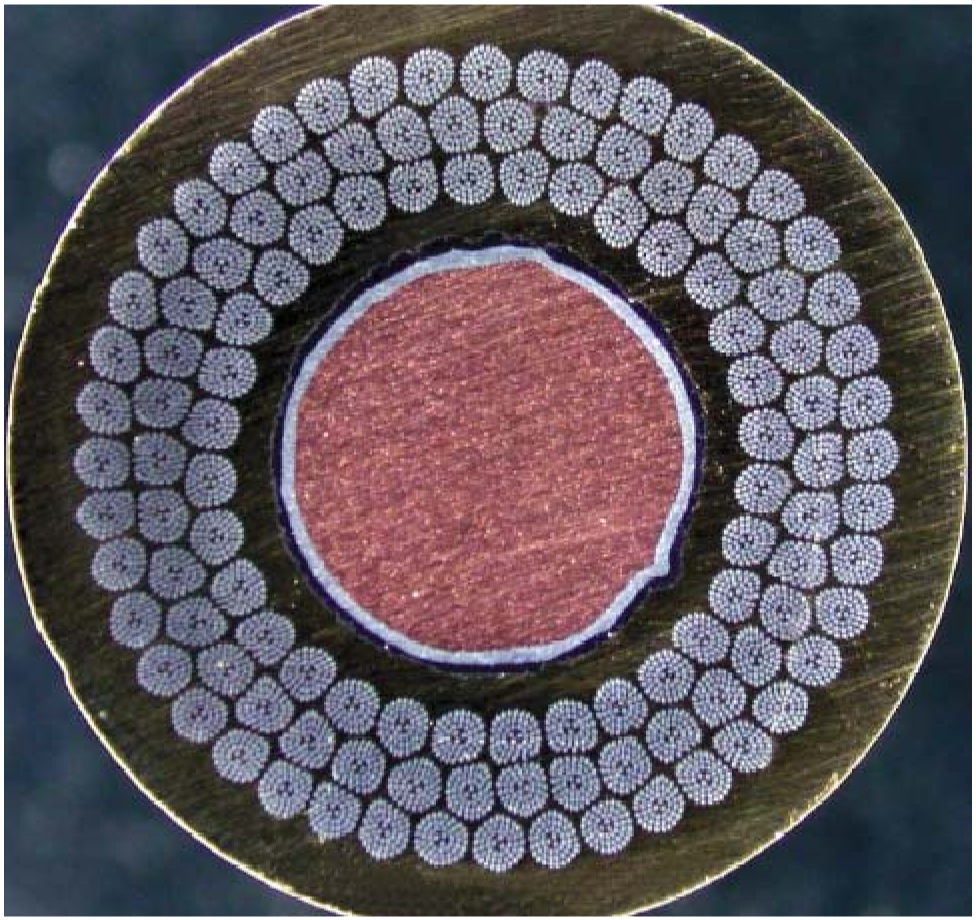
1. Be iconoclastic
2. Have little to do with materials science (however, see talk VV4.2 tomorrow morning!)

Wire

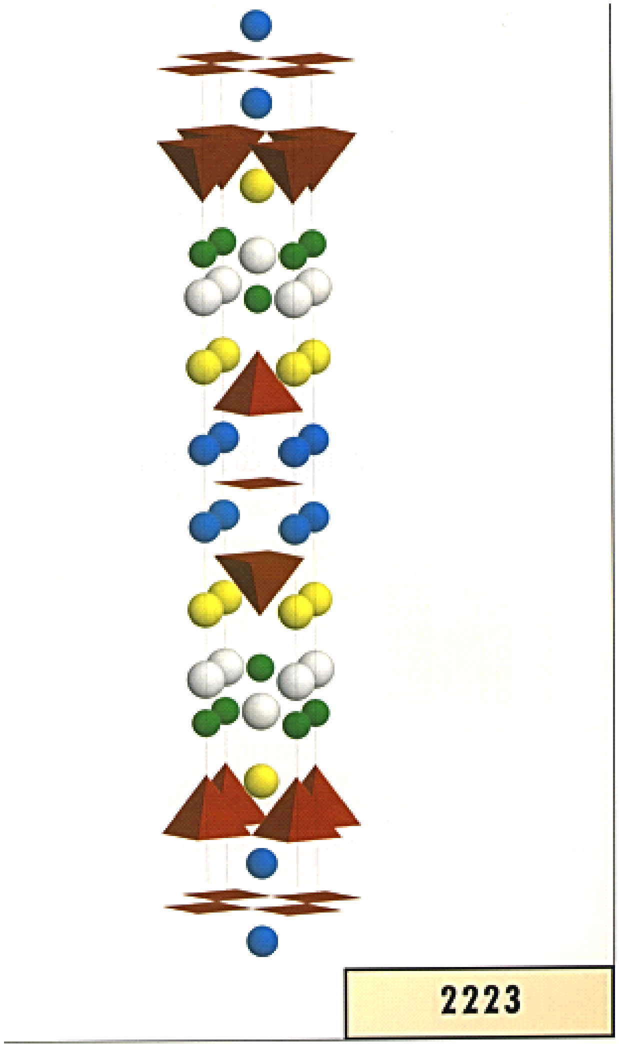
NbTi

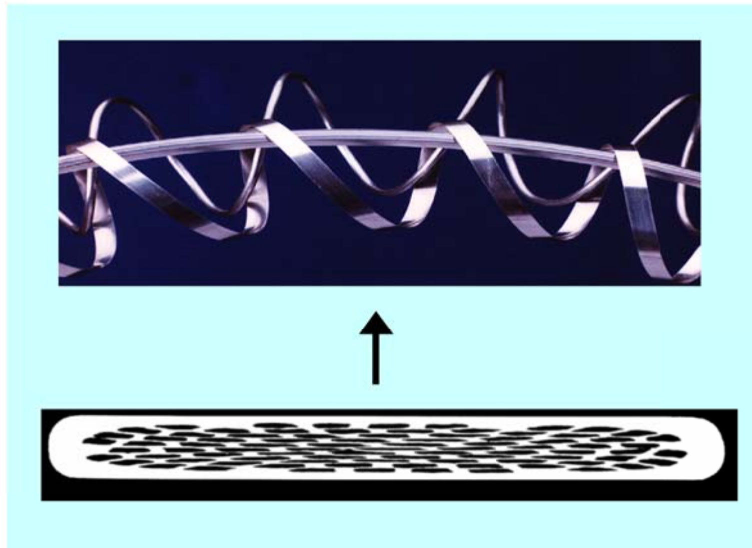
Nb_3Sn

- The Workhorse Wires -



First HTSC "Wire"

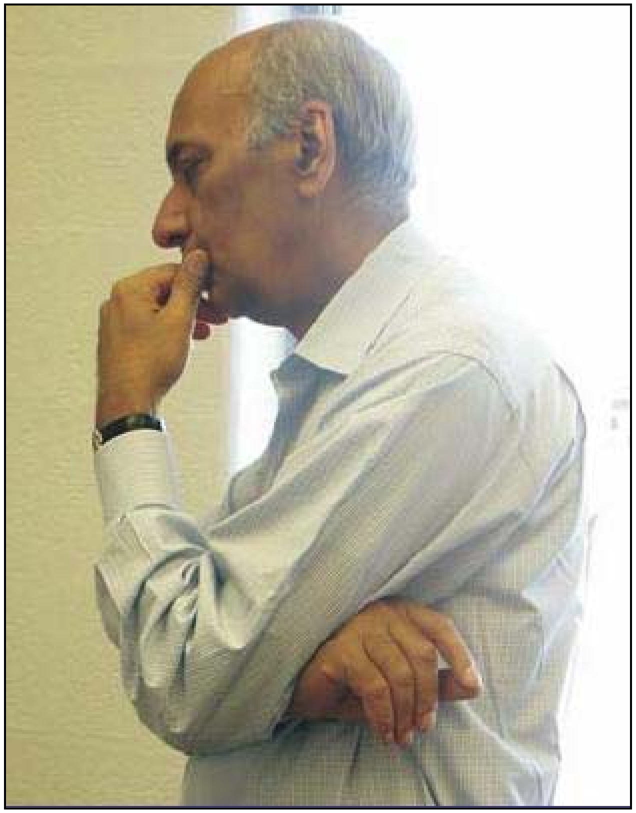




Gen 1

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

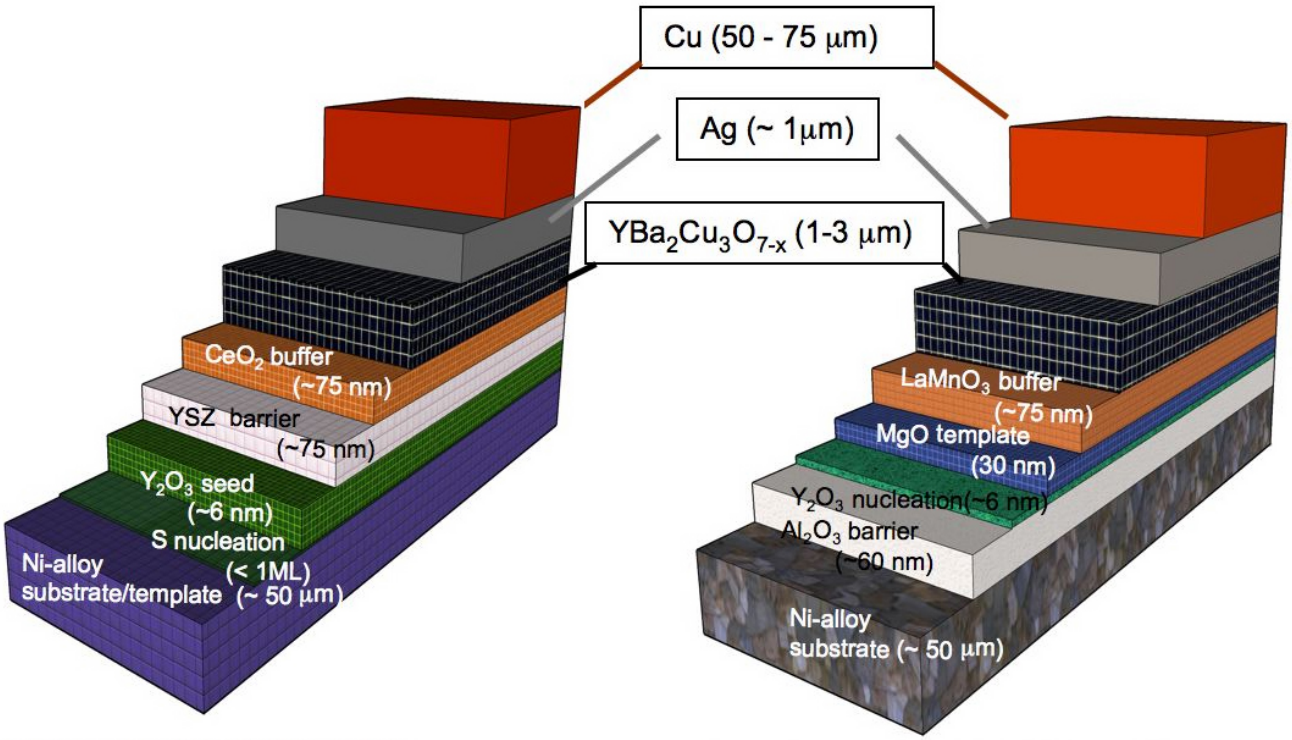
D. Dimos, P. Chaudhari, J. Mannhart, and F. K. LeGoues
Thomas J. Watson Research Center, IBM Research Division, Yorktown Heights, New York, 10598
(Received 4 May 1988)



Praveen Chaudhari, 1937 - 2010

Physics Today, p.64, April 2010

Gen II Coated Conductor



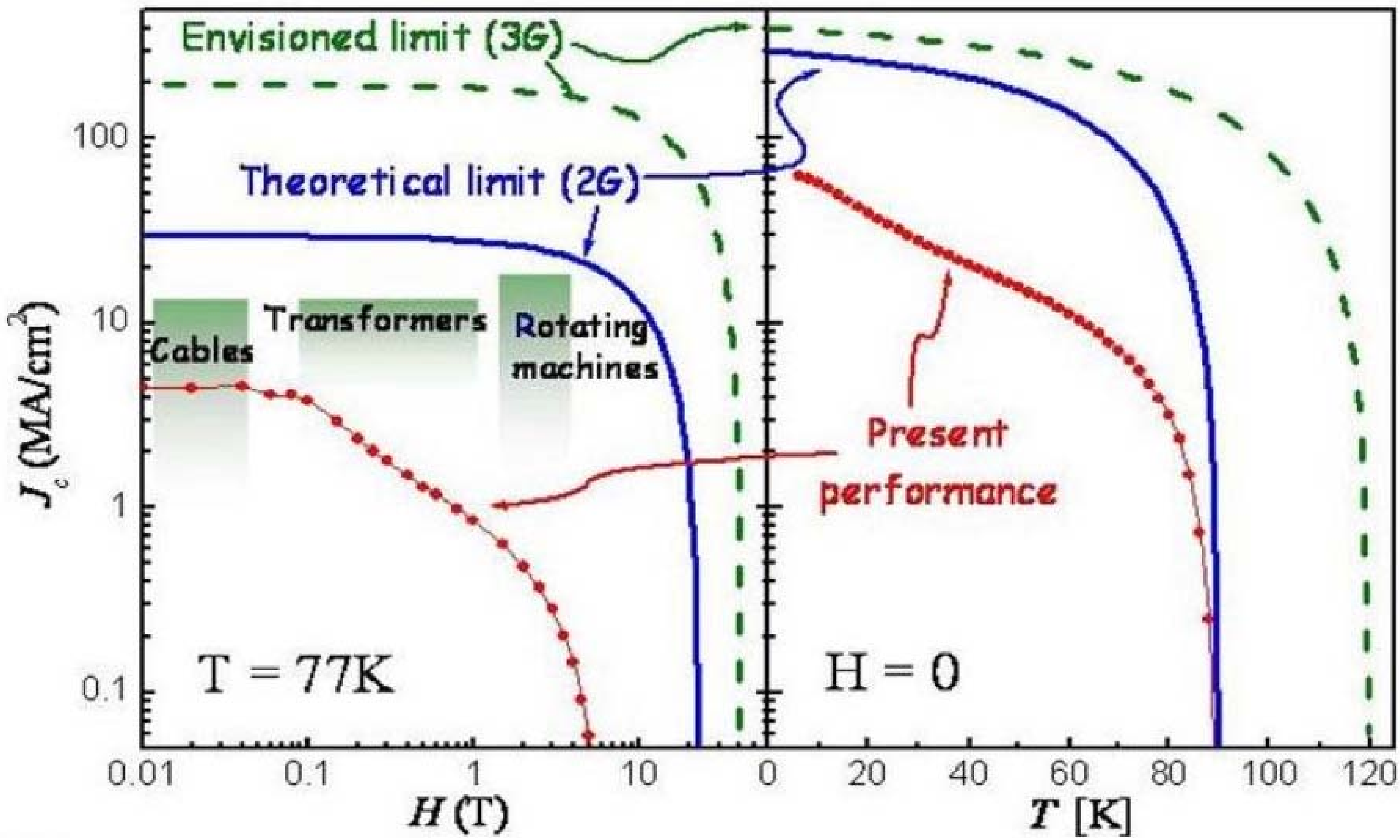
Rolling-Assisted Biaxially Textured Substrates (RABiTS)

Ion-Beam-Assisted Deposition (IBAD)

American Superconductor

SuperPower

Wire Performance



Cable Design Anthology

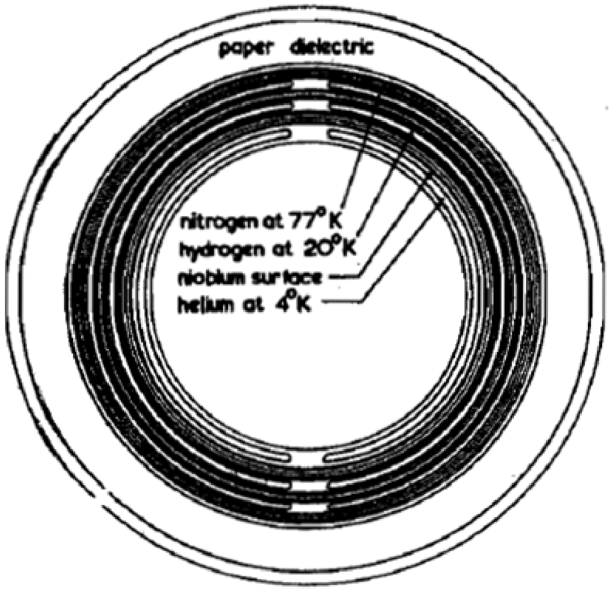


Fig. 2

Superconducting thin-walled niobium core cooled internally by liquid He and protected externally by liquid H_2 and liquid N_2

Wilkinson, 1966

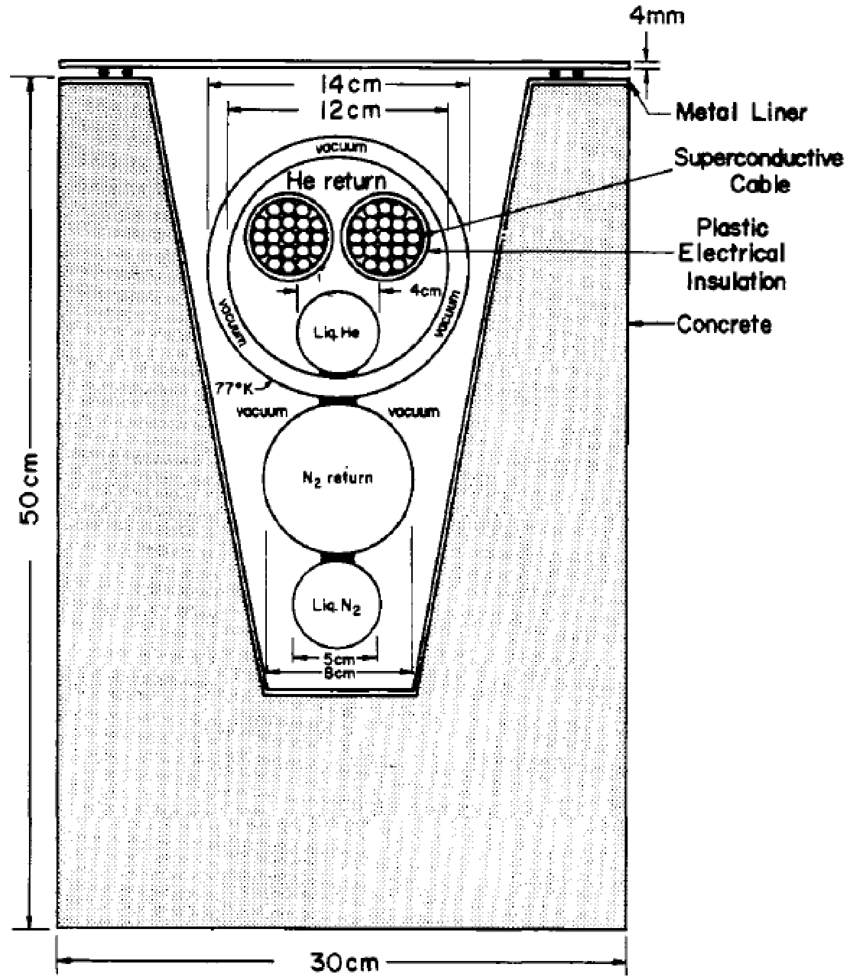


Fig. 1. Cross section of the 100-GW line.

Garwin-Matisoo, 1967

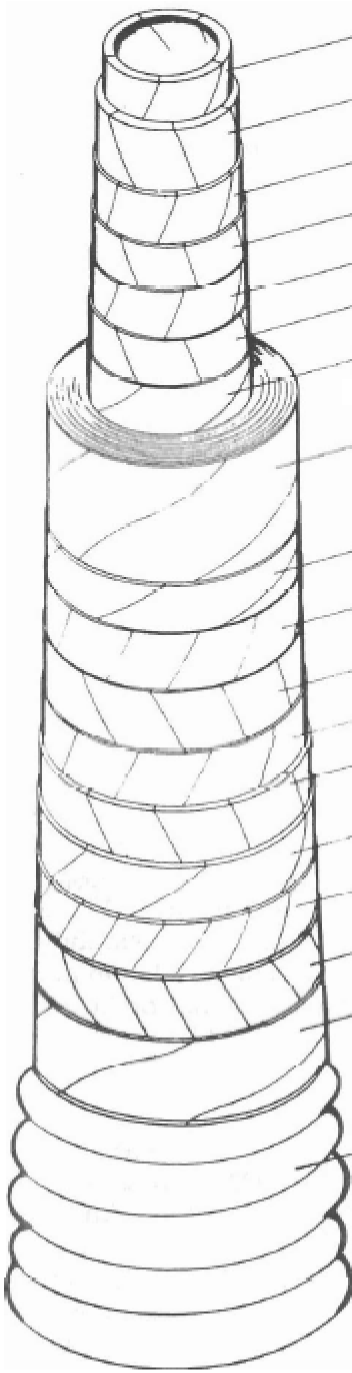


Table 1 Characteristics of the 1000 MVA test system

Number of cables	2
Length of each cable (m)	115
Cable outer diameter (over armour) (cm)	**5.84**
Inner conductor diameter (cm)	2.95
Enclosure outer diameter (cm)	40
Maximum operating temperature (K)	9
Operating pressure (MPa)	1.55
Cooldown time (h)	100
Rated voltage (3-phase) (kV)	138
Rated impulse withstandability (kV)	650[a]
Maximum steady state power rating (MVA)	980
Emergency power level (MVA) (1 h)[b]	1430
Surge impedance load (MVA)	872
Surge impedance (Ω)	25
Current-dependent loss at rated power, 3-3-phase (7.5K) (Wm^{-1})	0.8
Voltage-dependent loss at rated power, 3-phase (7.5 K) (Wm^{-1})	0.15
Enclosure heat in-leak, 3-phase (7.5 K) (Wm^{-1})	0.45

Brookhaven – Late 70s, Early 80s

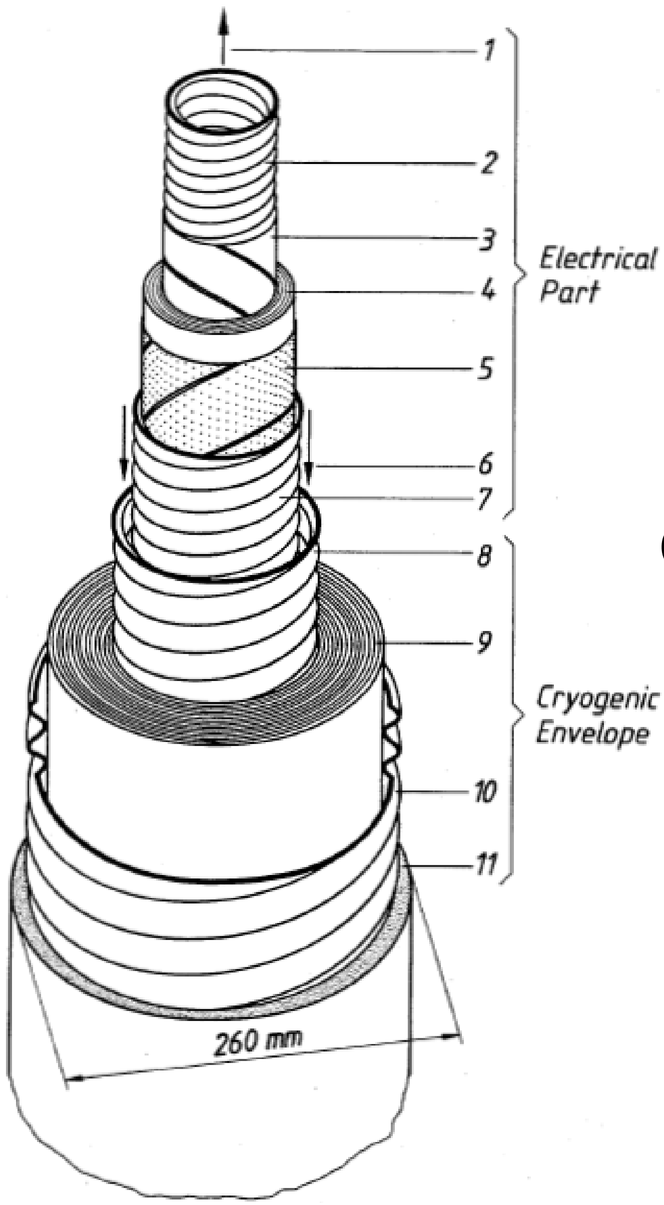
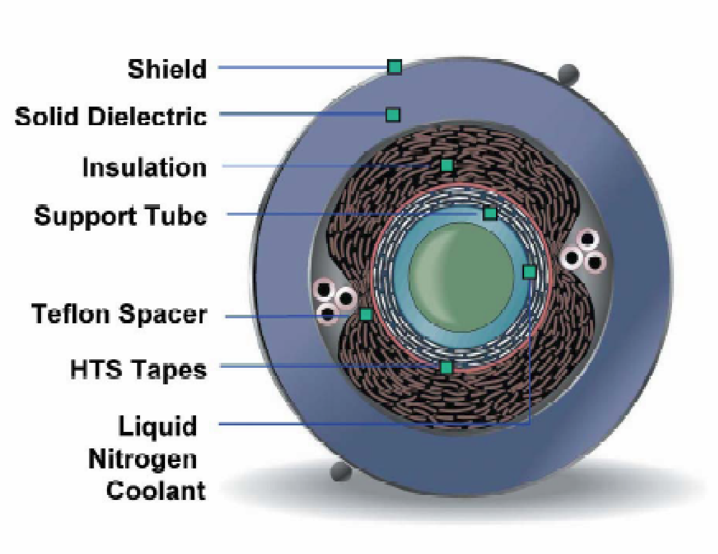


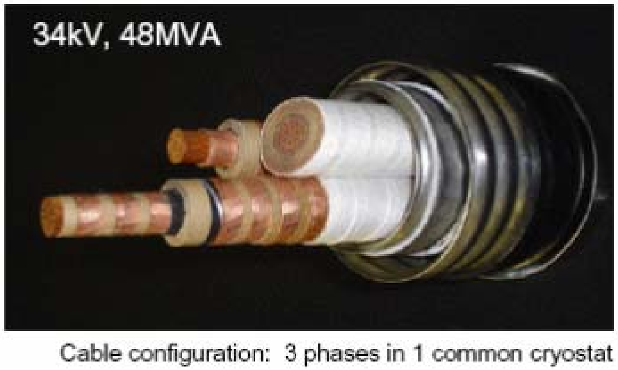
Fig. 5. Fully Flexible Superconducting Cable for 1/3 GW / 110 kV (Design Klaudy-Kabelmetal). 1-Cooling helium 2-Corrugated copper tube with superconducting niobium layer as the phase conductor 3-Smoothing compound 4-Helium impregnated paper tape insulation 5-Electrostatic screen 6-Cooling helium 7-Corrugated copper tube with niobium layer as the shield conductor 8-Inner corrugated tube of the cryogenic envelope 9-Superinsulation in vacuum 10-Outer corrugated tube of the cryogenic envelope 11-PVC-sheath.

Graz, Austria – Late 70s

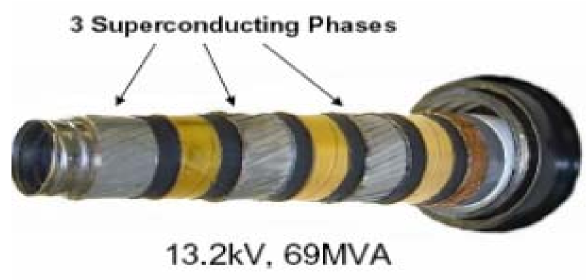


Pirelli – Detroit Edison Demo: 1999-2001
Successful Superconductivity Performance!

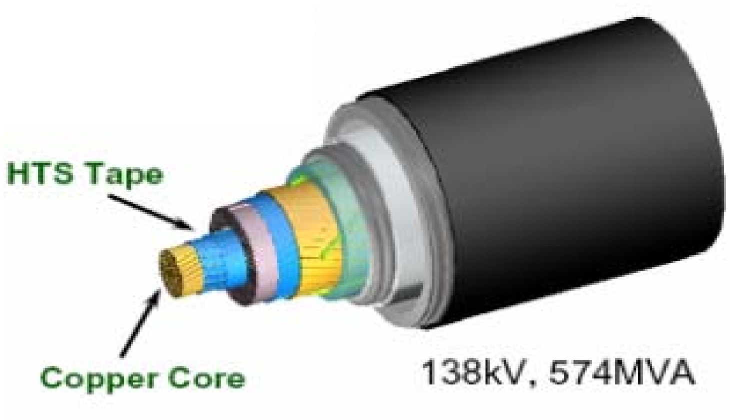
Various ac HTSC Cable Designs



Sumitomo



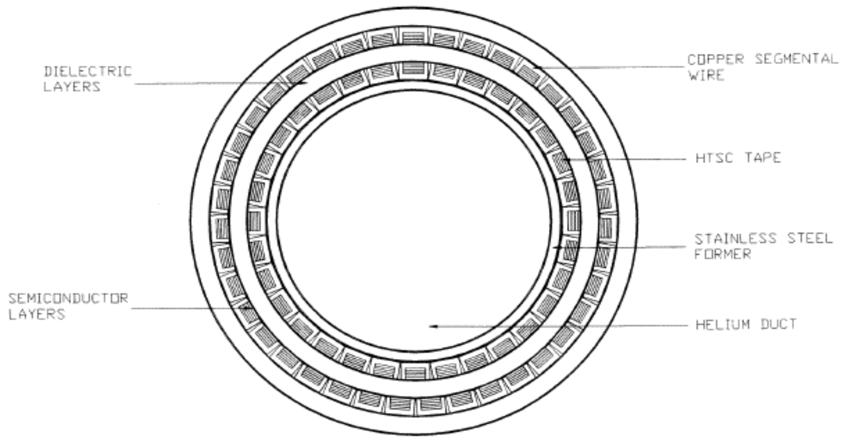
Ultera-ORNL

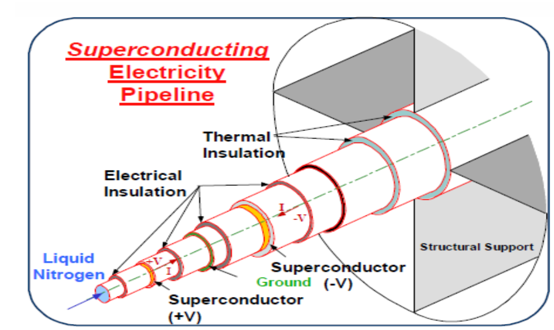


Nexans-AMSC

Pirelli

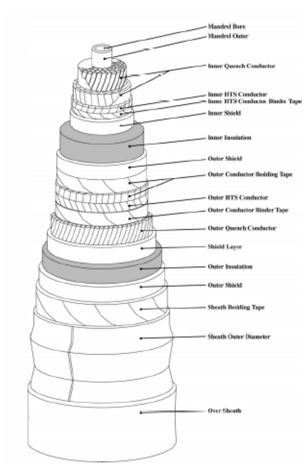
Various dc HTSC Cable Designs

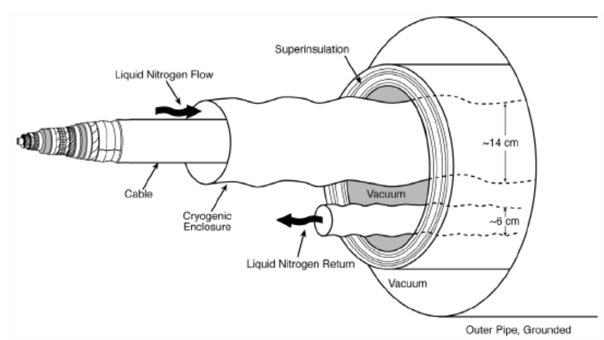




EPRI: Schoenung, Hassenzahl, Grant (1997)
+/- 50 kV, 50 kA, 5 GW

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



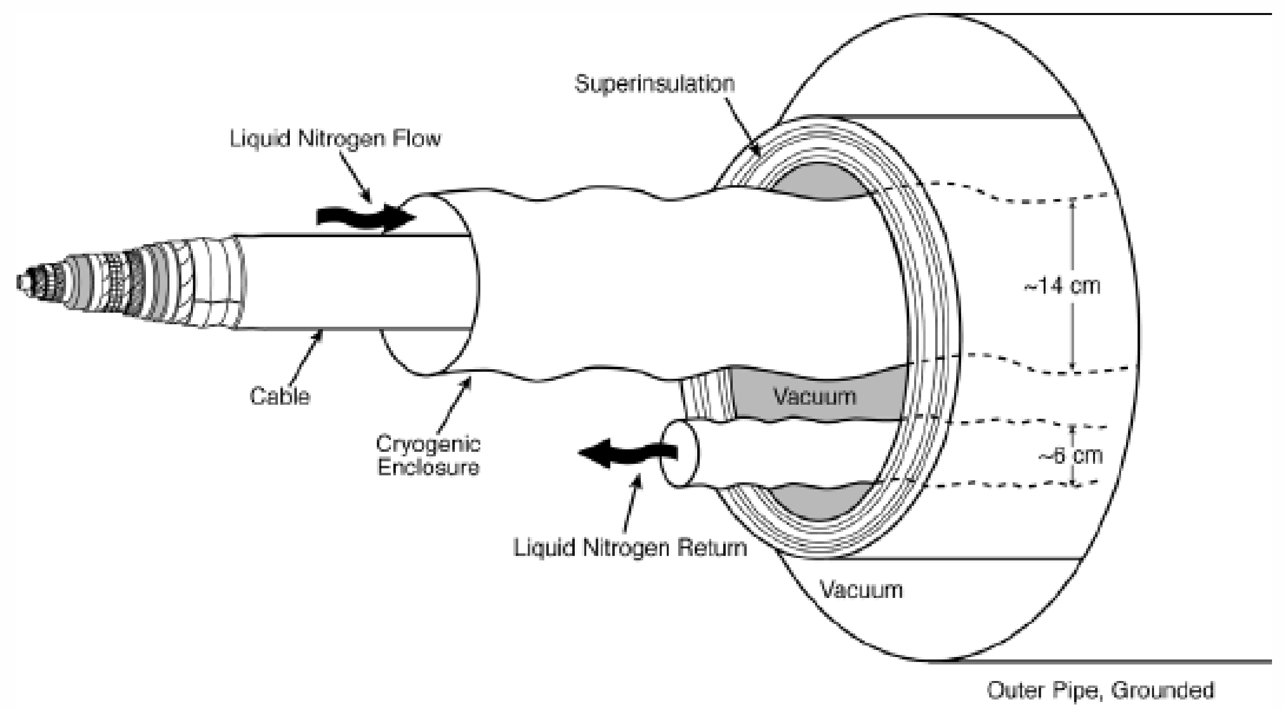


EPRI: Hassenzahl, Gregory, Eckroad, Nilsson, Daneshpooy, Grant (2009)
+/- 50 kV, 100 kA, 10 GW

A Superconducting dc Cable

EPRI Report 1020458 (2009)

Hassenzahl, Gregory, Eckroad, Nilsson, Daneshpooy, Grant

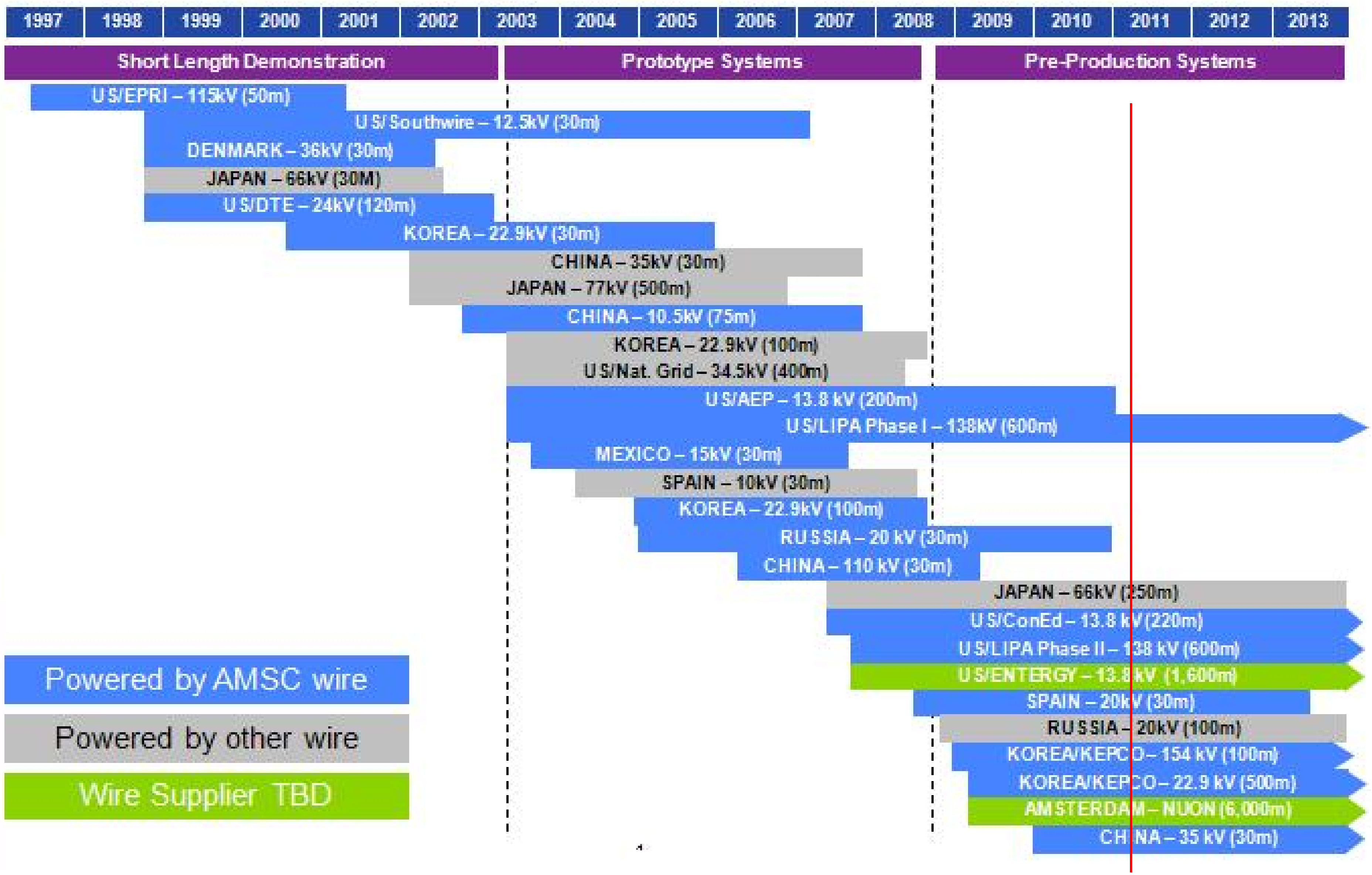


<u>Monopole Specs</u>

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

US HTSC Cable Demonstrations

HTSC Cable Demonstration Projects Worldwide Past, Present…Future?

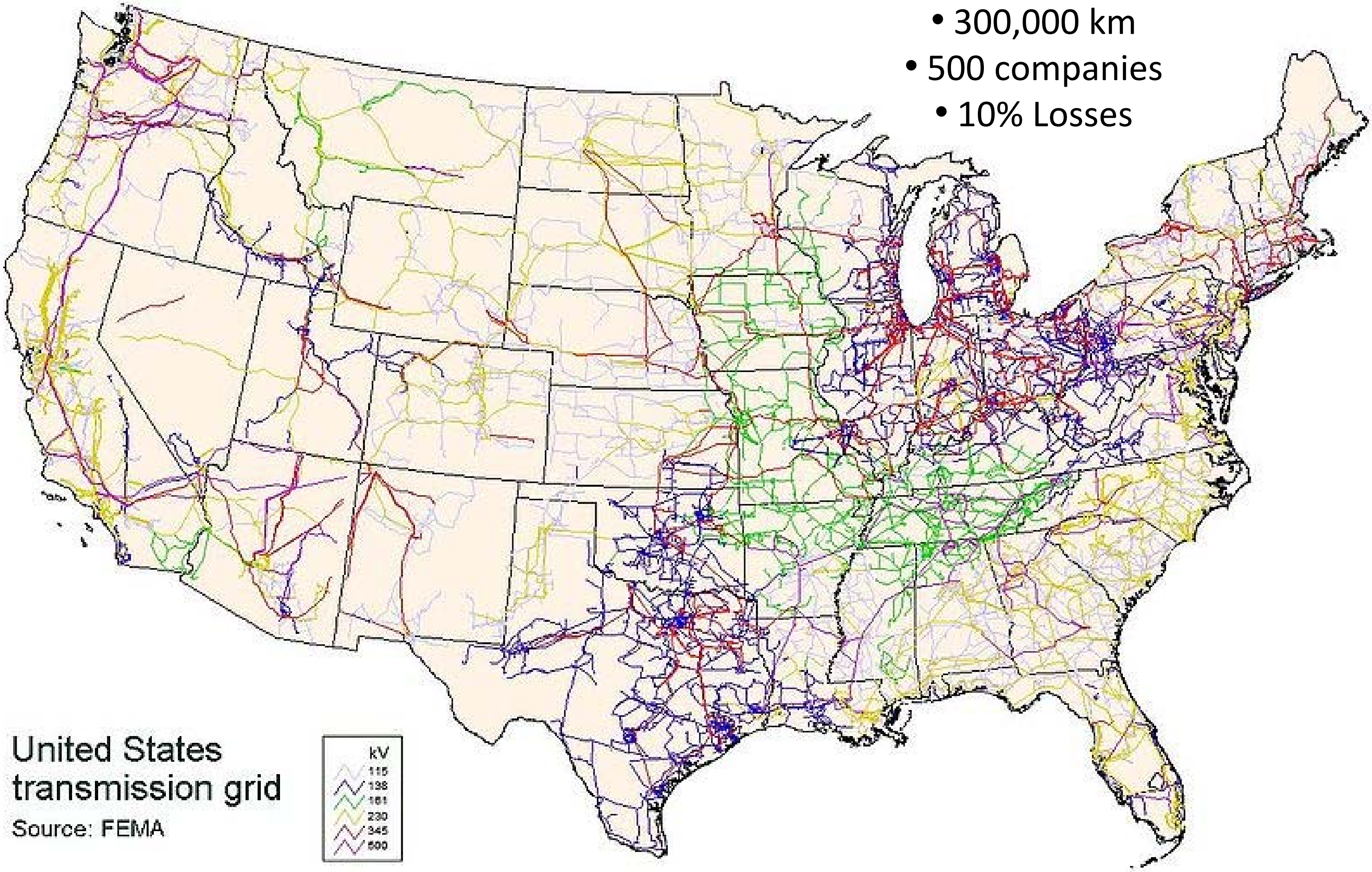


HTSC Cables

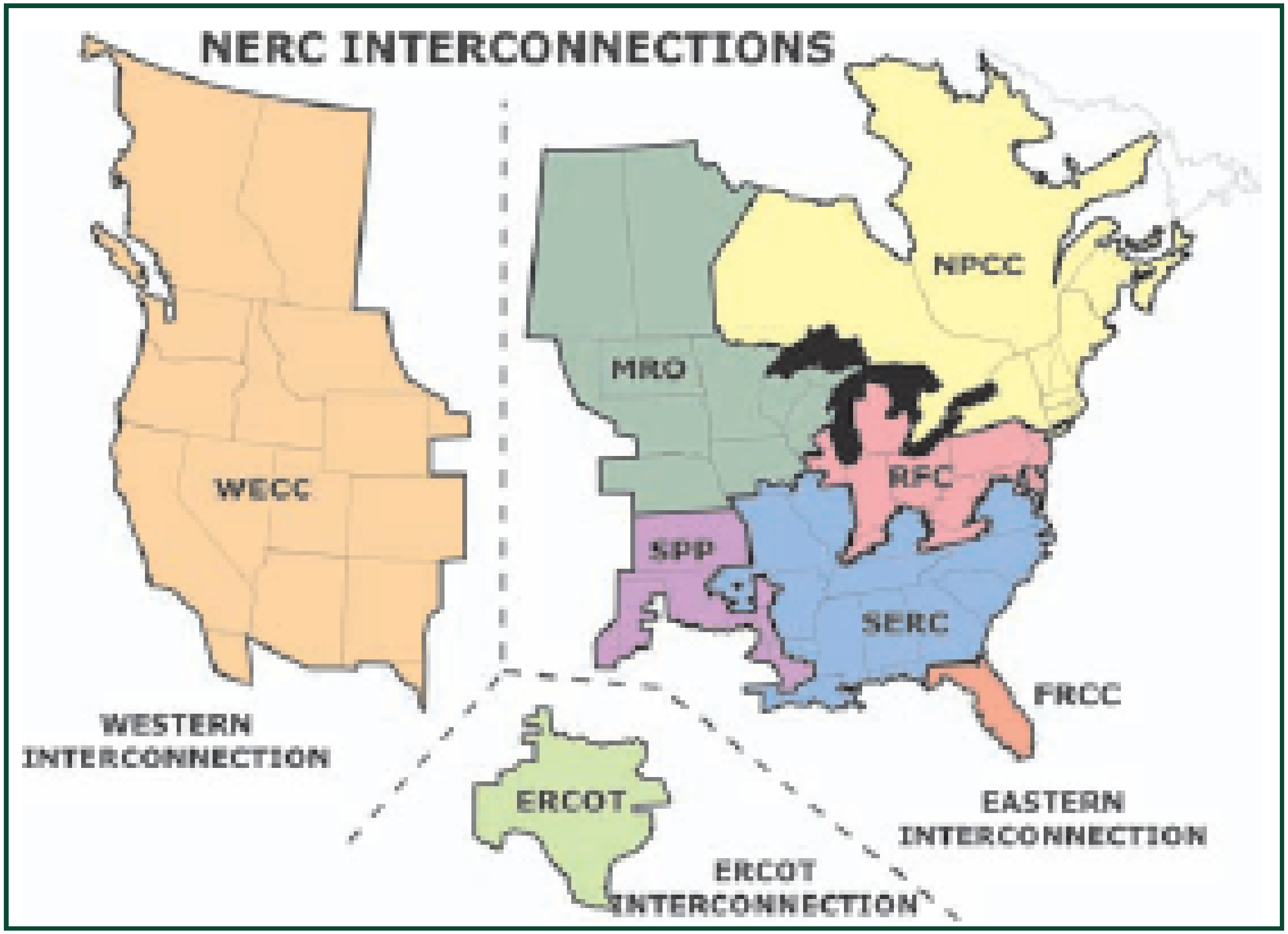
- Deployment Opportunities -

The US Transmission Grid(s)

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



NERC Interconnects



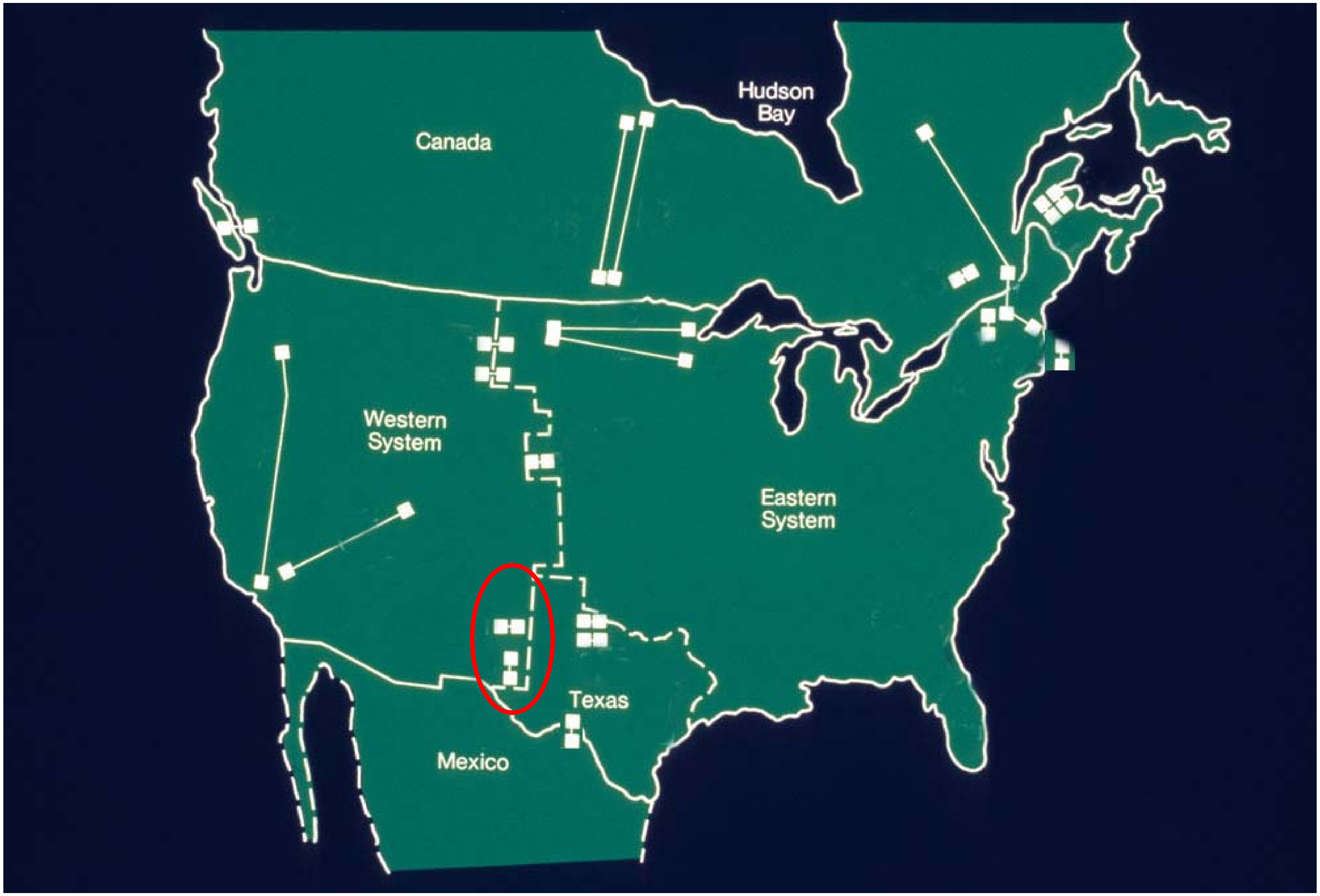
Source: DOE 2006 National Electric Transmission Study

Pacific Intertie

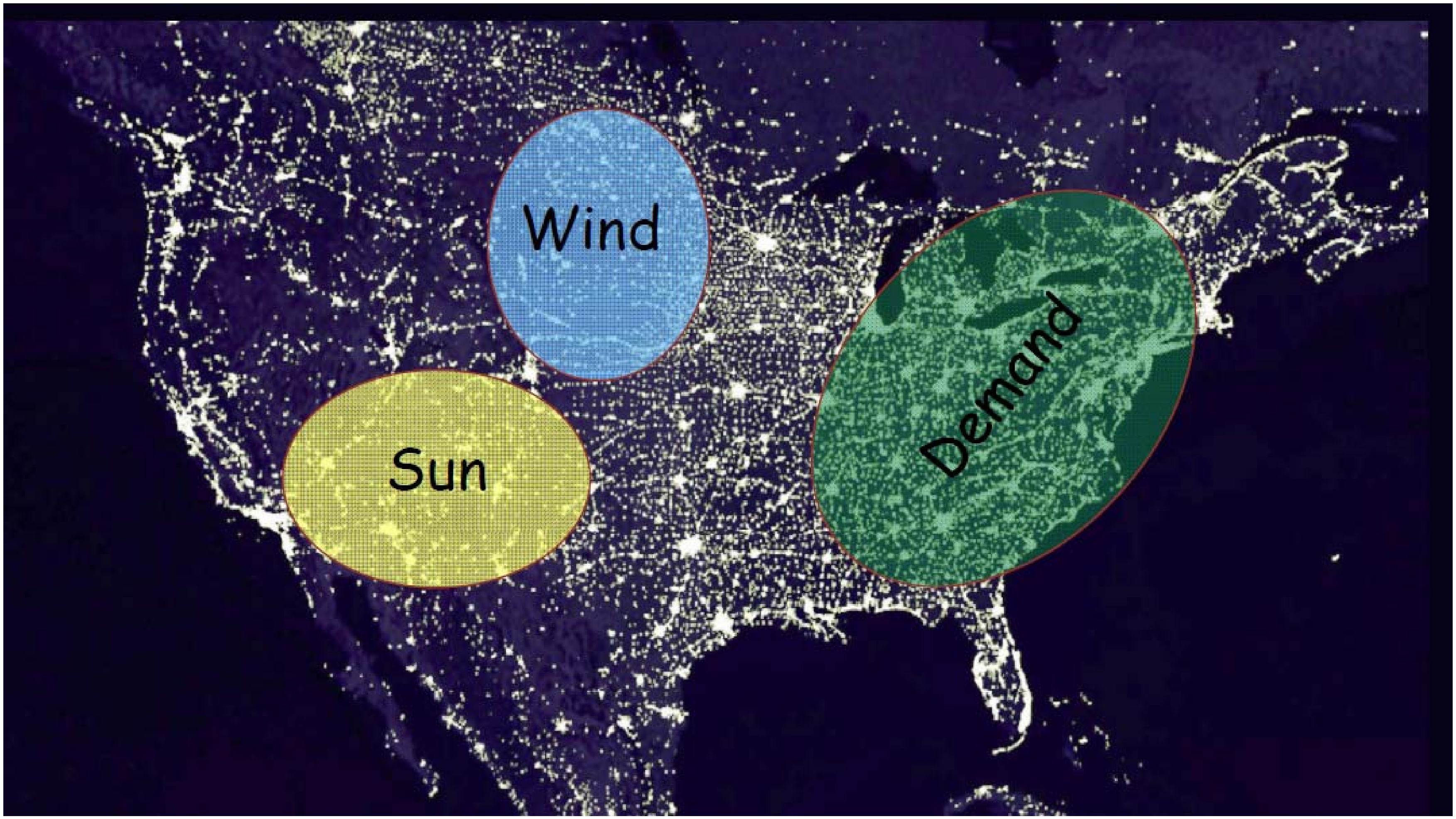
- HVDC, +/- 500 kV, 3.1 kA, 3.1 GW
- 1,362 km
- ~50% of LA Power Consumption
- Converter/Inverter Losses ~ 5%
- Ohmic Losses ~10%

Celilo I/C Station
"A Mountain of Silicon"

North American HVDC

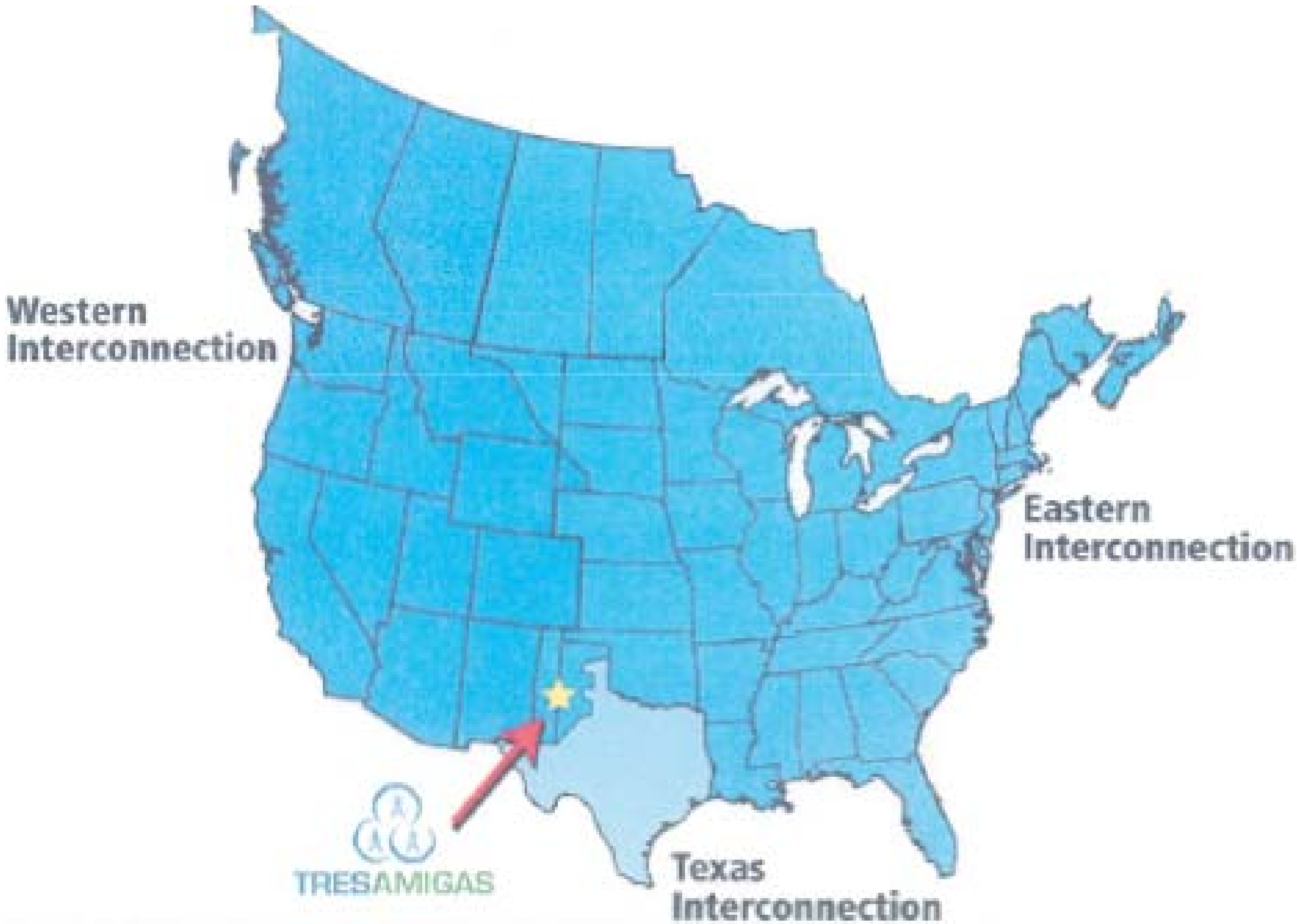


The "Green" Energy Economy



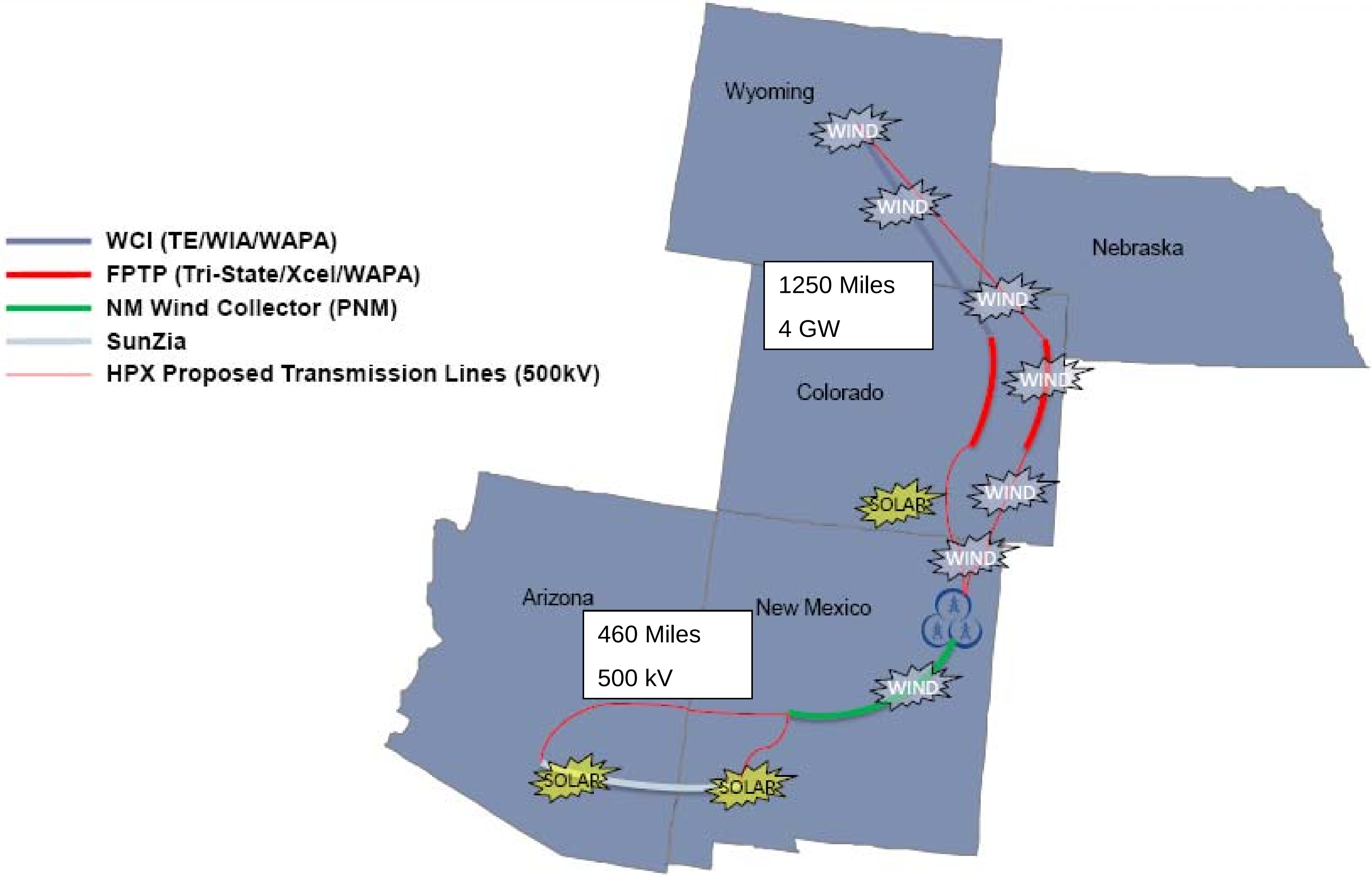
www.sunzia.net

“Three Girl Friends”



Clovis, NM

Potential Beneficiaries in WECC

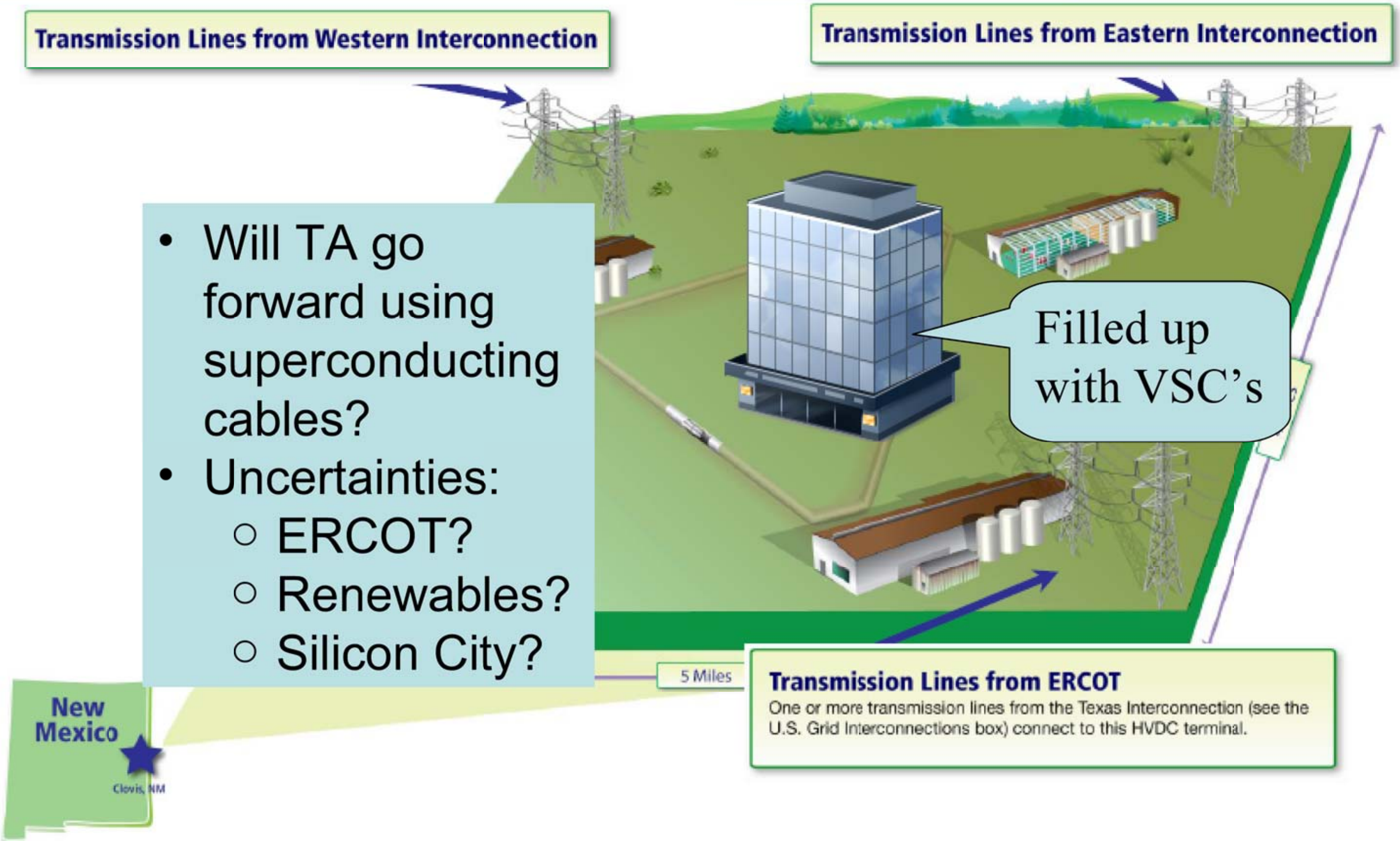


HTSC Cables

- Deployment Realities -

The Tres Amigas SuperStation

- Will TA go forward using superconducting cables?
- Uncertainties:
  - ERCOT?
  - Renewables?
  - Silicon City?



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 - > "beyond" 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 (don’t ever underestimate the ingenuity of a utility engineer to improvise, adopt and adapt)

"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?

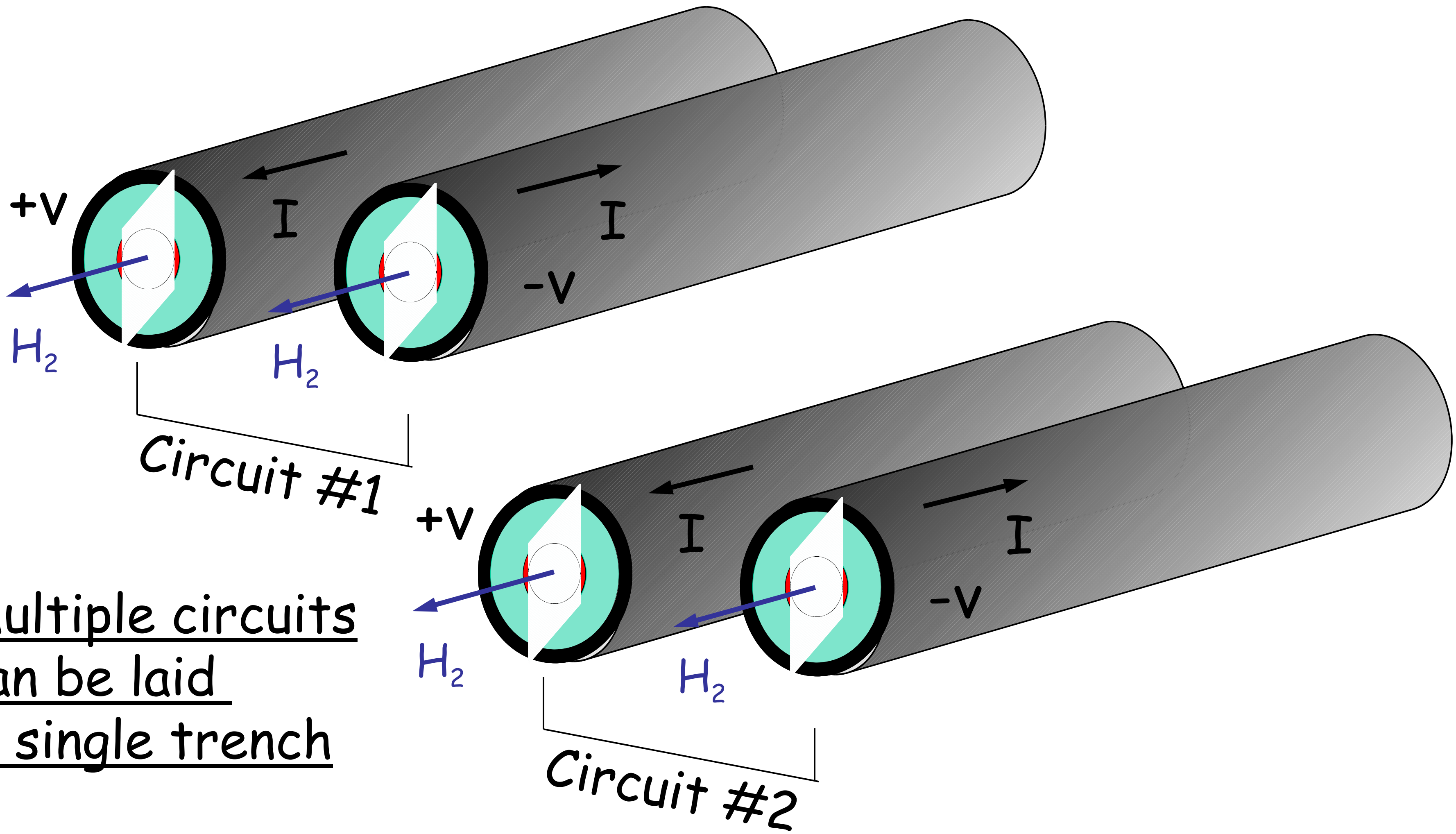
Questions for US HTSC Wire Manufacturers

- AMSC
  - Estimated gross revenue from wire sales (and actual delivery) for FY2011?
  - Note: 3Q10 gross revenue from wire sales was 1.8% of total quarter
- SuperPower
  - Same as AMSC #1 above
  - Estimated employee/manpower growth in CY2011
- Ultera/Southwire
  - Is Carrolton plant cable (Gen 1) still in operation?
  - Plans to replace/extend?
- Nexans/AMSC/LIPA
  - Status of Gen II wire/cable upgrade
- AMSC/ConEd/DHS
  - Status/funding of Project Hydra

HTSC Cables

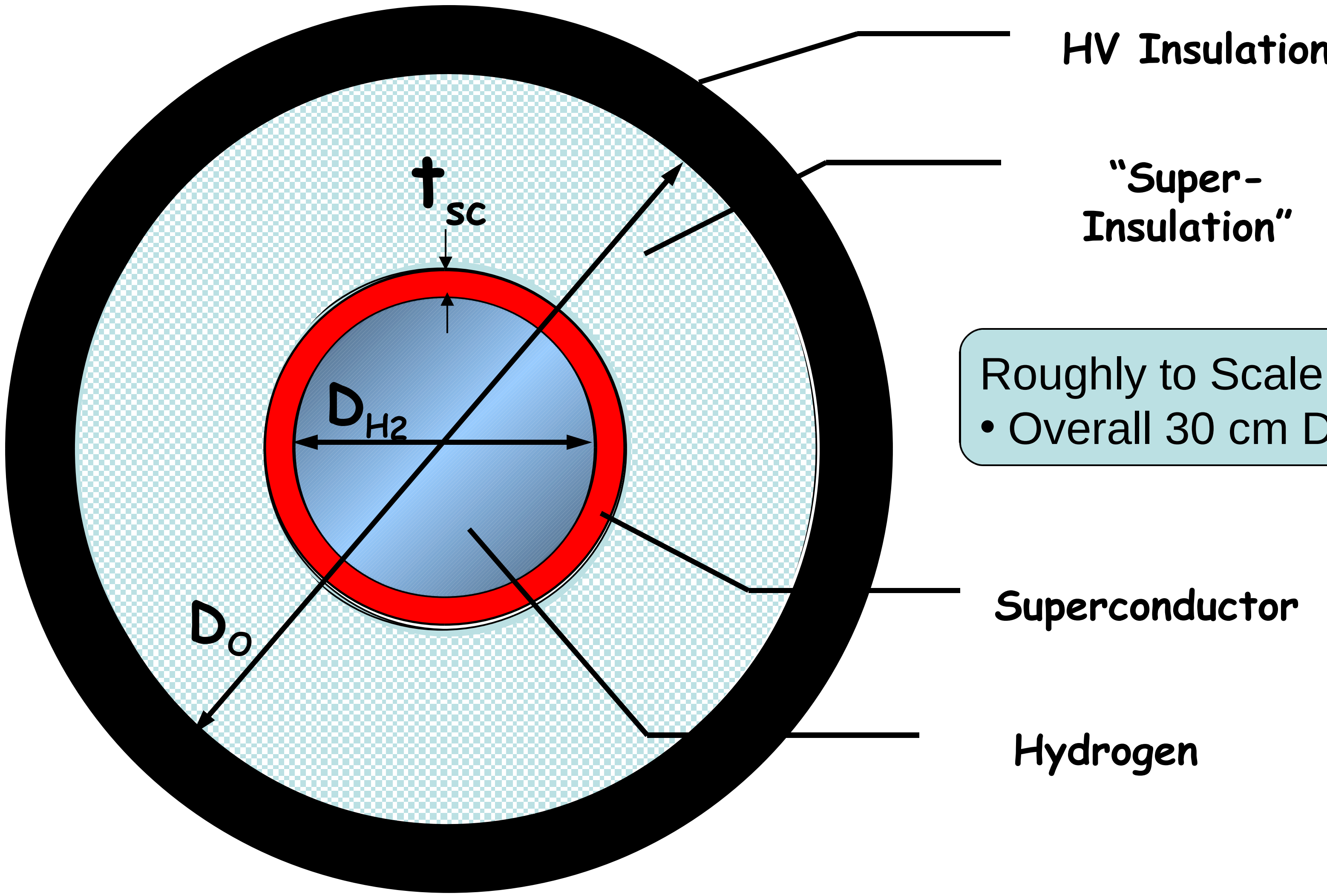
- SuperCables -

"Hydricity" SuperCables:
"Proton/Electron Power (PEP) to the People"



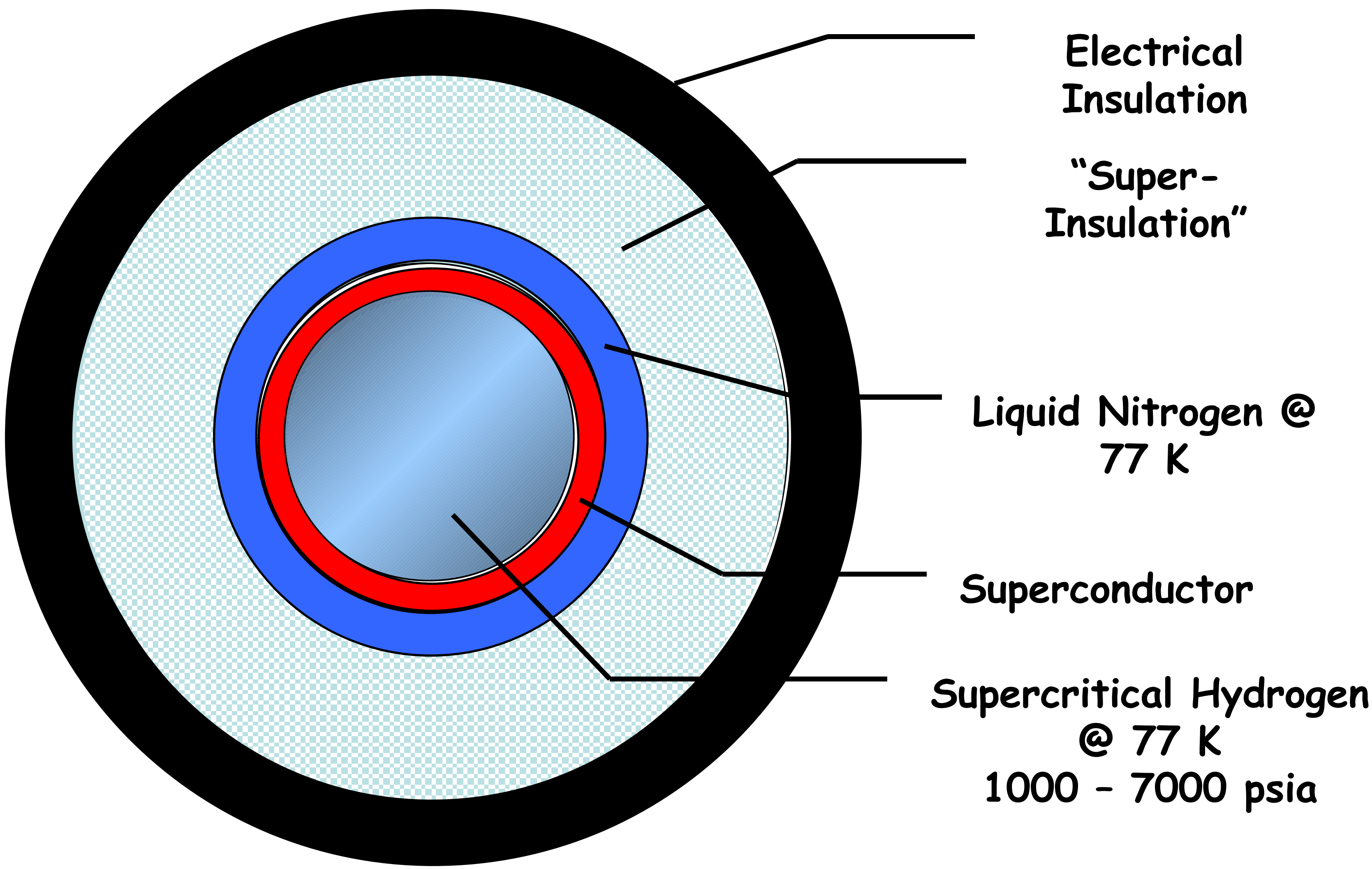
<u>Multiple circuits</u>
<u>can be laid</u>
<u>in single trench</u>

LH_2 SuperCable



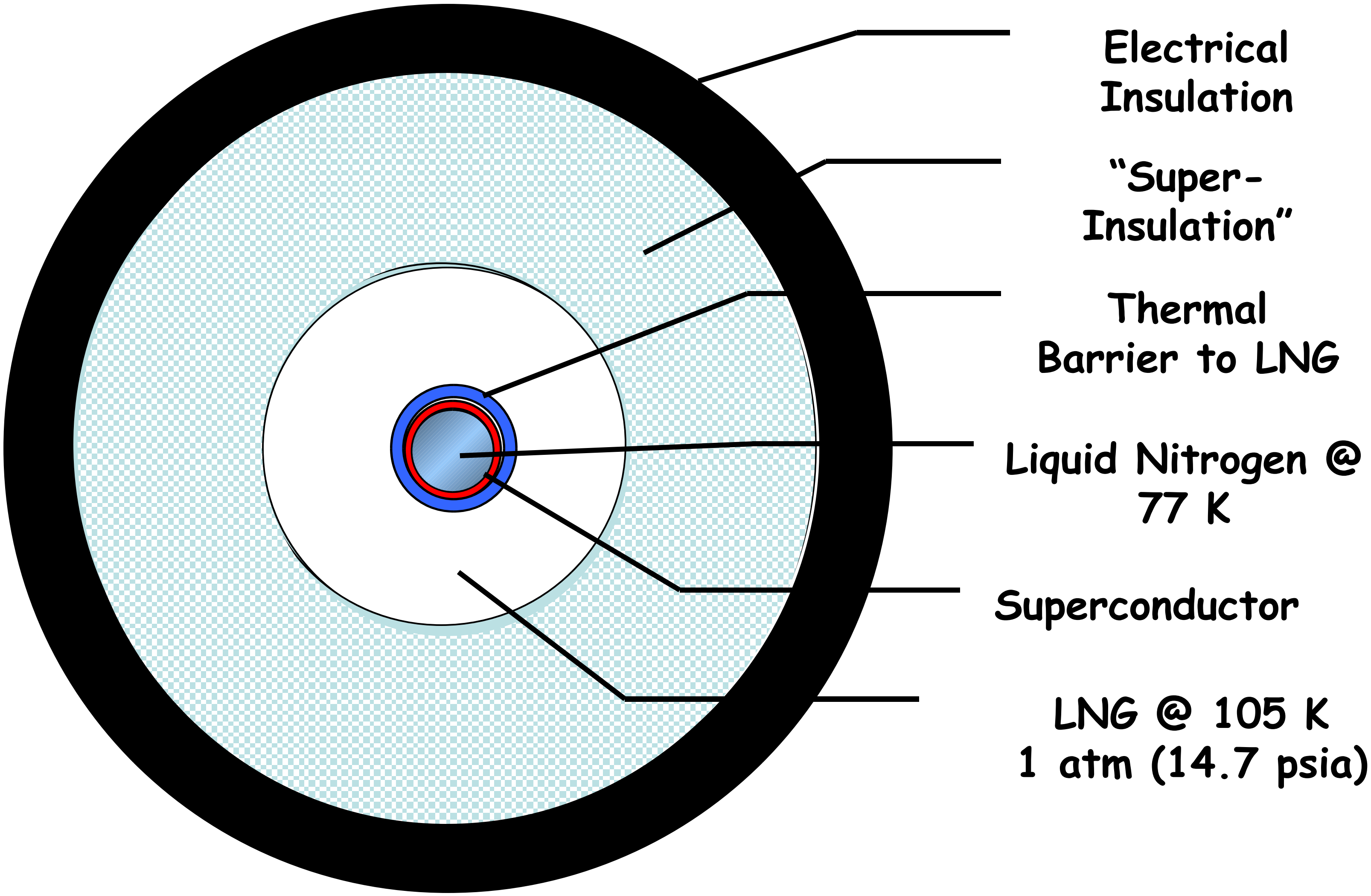
Roughly to Scale:
- Overall 30 cm Diameter

Supercritical H_2 SuperCable



Design for eventual conversion to high pressure cold or liquid H_2

LNG SuperCable



Hg-1223 !

(12) **United States Patent**
Chu et al.

(10) **Patent No.:** **US 6,329,325 B1**
(45) **Date of Patent:** **Dec. 11, 2001**

(54) **HIGH TEMPERATURE SUPERCONDUCTING TAPE AND METHOD OF MANUFACTURE**

(75) Inventors: **Ching-Wu Chu**; **Ruling L. Meng**; **Yu-Yi Xue**, all of Houston, TX (US)

(57) **ABSTRACT**

Highly oriented $HgBa_2Ca_2Cu_3O_{8+\delta}$ on Ni-tapes with a buffer layer of Cr/Ag or Cr/(Ag—Pd) have been described with a high transition temperature are described along with, one and two step methods of manufacture.

HTSC Cables

- MegaProjects -

A Canadian's View of the World

The Mackenzie Valley Pipeline

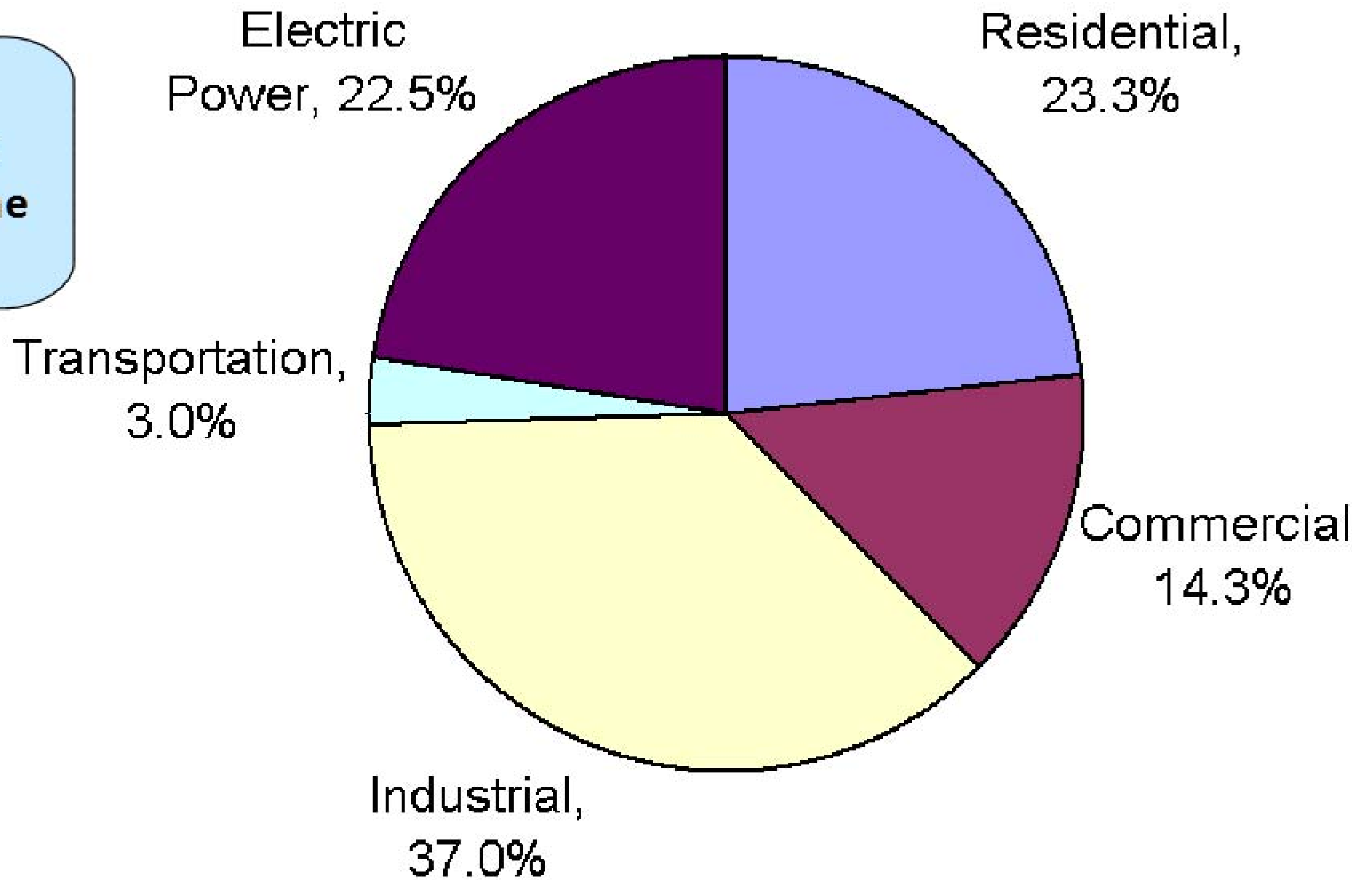
http://www.mackenziegasproject.com

1220 km
18 GW-thermal
2006 - 2010

2004 Natural Gas End Use

Schoenung, Hassenzahl and Grant, 1997
(5 GW on HTSC @ LN2, 1000 km)

Why not generate this electricity at the wellhead?



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)

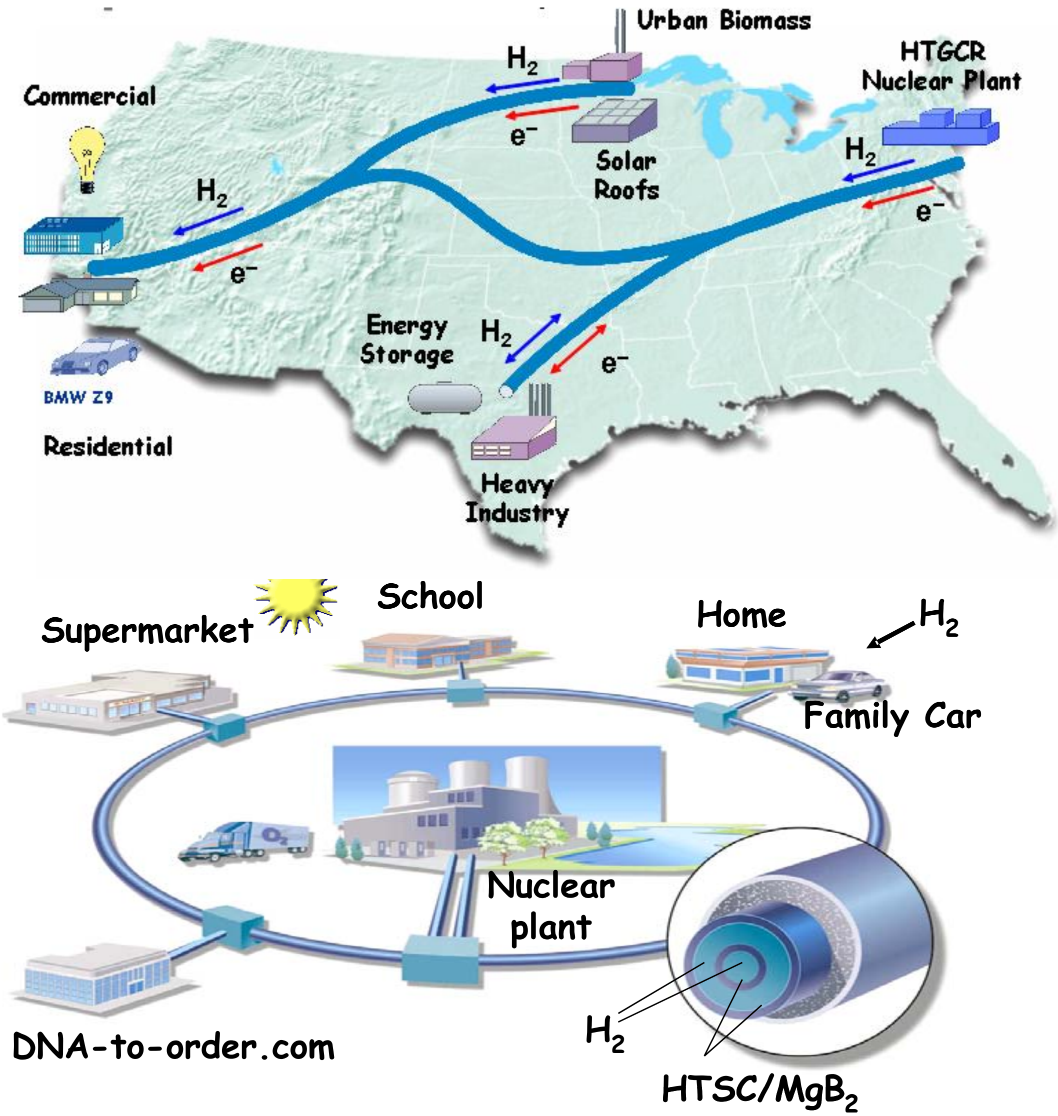
SuperCable Parameters for LNG Transport

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

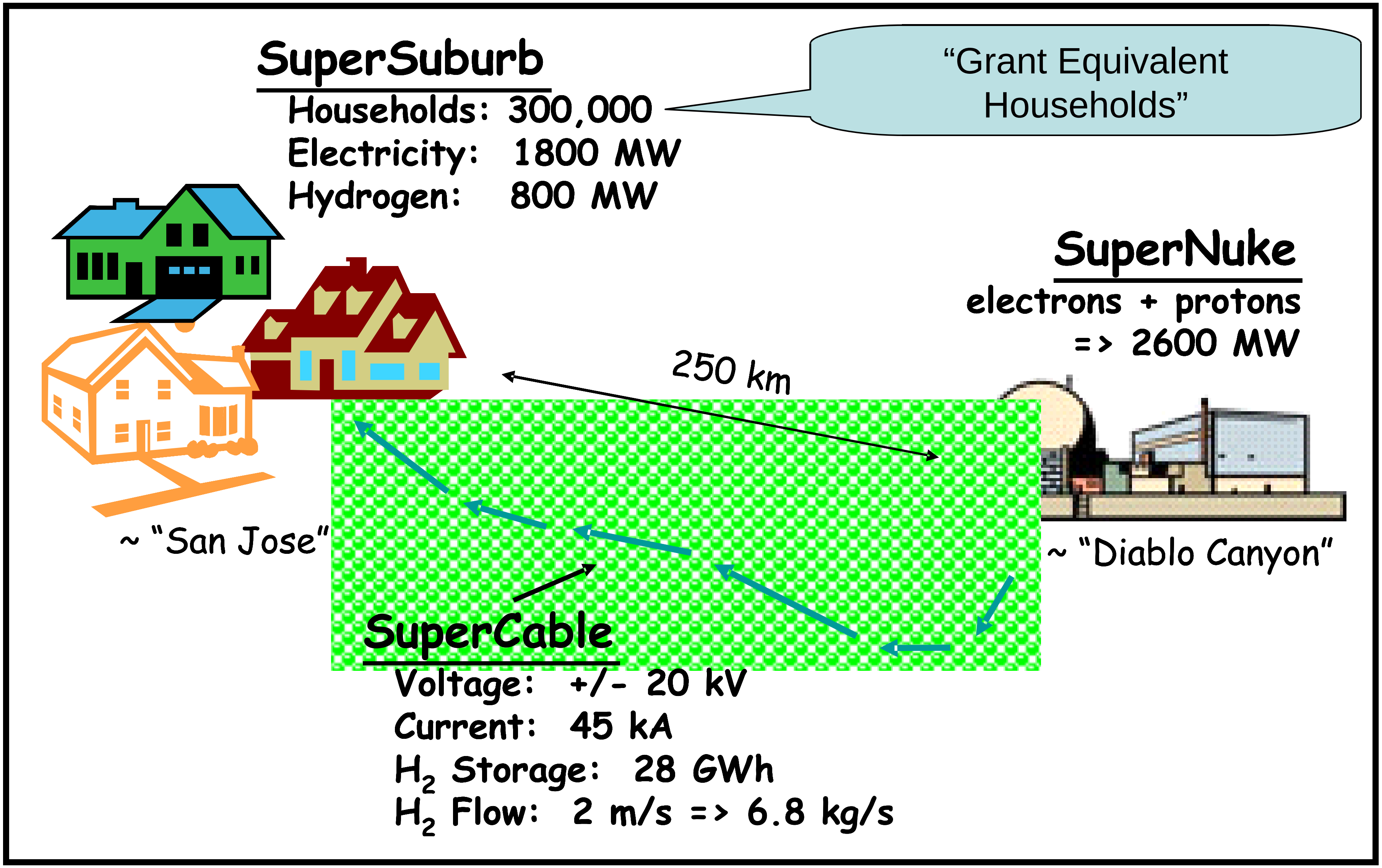
- *The Gas runs out!*
- We have built the LNG SuperCable years before
- Put HTCGR Nukes on the now empty gas fields to make hydrogen and electricity (some of the electricity infrastructure, e.g., I/C stations, already in place)
- Enable the pre-engineered hydrogen capabilities of the LNG SuperCable to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

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**

SuperSuburb



Powering the Middle East
- "*The e-Pipe*" – The Ultimate Vision!

<u>Concept:</u>

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

<u>Specifications:</u>

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

Caveat Emptor
(wisdom from Garwin-Matisoo, 1967)

- "…for low power levels and sufficiently short distances…it will be more economical to use conventional ac EHV transmission."
- "…the use of superconducting power lines appears feasible. Whether it is necessary or desirable is another matter entirely."