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SCIENCE NEWS

Arctic ice shelf breakup reported

Largest ice shelf in region was solid for 3,000 years

By Maggie Fox

REUTERS

WASHINGTON, Sept. 22 — The largest ice shelf in the Arctic, a solid feature for 3,000 years, has broken up, scientists in the United States and Canada said Monday. They said the Ward Hunt Ice Shelf, on the north coast of Ellesmere Island in Canada's Nunavut territory, broke into two main parts, themselves cut through with fissures.

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Power Outrage

"We are sick and tired of them, and they had better change!"

Chicago Mayor Richard Daley on the August 1999 Blackout

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NYC 14 August 2003

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Brothers and sisters!
I want to tell you this.

The greatest thing on earth is to have the love of God in your heart…

and the next greatest thing is to have electricity in your house!

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The Energy SuperGrid

Paul M. Grant
Science Fellow

Chauncey Starr
Founder & President Emeritus

Electric Power Research Institute

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Prologue: Two Energy Lemmas

I. Any discussion of the application of energy technology must involve, from the very start, an explicit social and political scenario

II. The unique aspect of energy as a life-sustaining necessity separates it from the jurisdiction of many of the usual "laws" of economics

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The Challenge

Design a global energy economy to meet the needs of a densely populated industrialized world of 10^{10} souls in 2050.

Accomplish this within the highest levels of environmental, esthetic, safe, reliable, efficient and secure engineering practice possible.

…without requiring any major scientific discoveries or breakthroughs

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The Solution

A Symbiosis of

Nuclear/Hydrogen/Superconductivity

Technologies supplying Carbon-free, Non-Intrusive Energy for all Inhabitants of Planet Earth

Diablo Canyon

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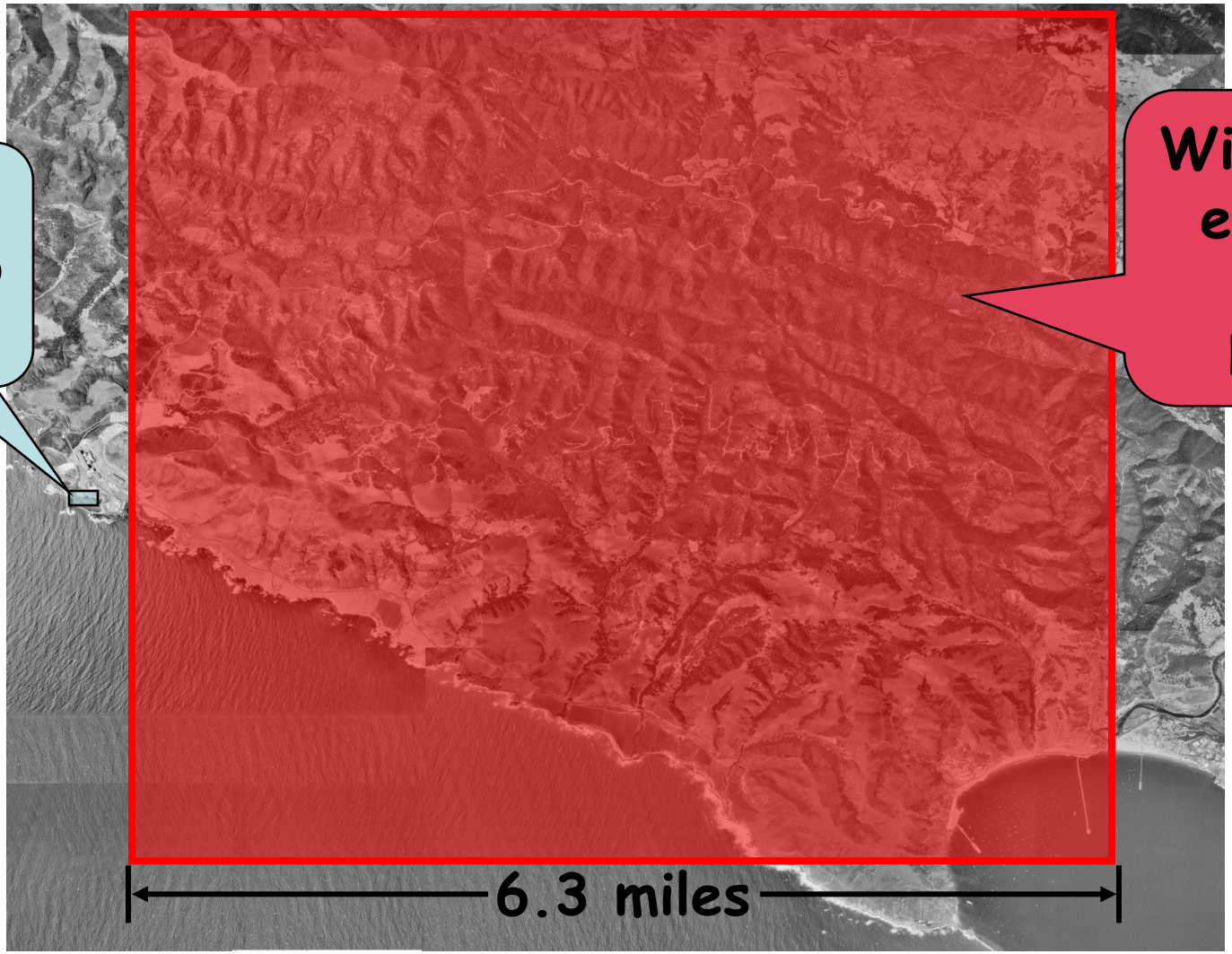
Diablo Canyon



Two Diablo Nukes

Wind Farm equal to ONE Diablo Unit

1100 1 MW Towers, 1000 ft apart

EPRI

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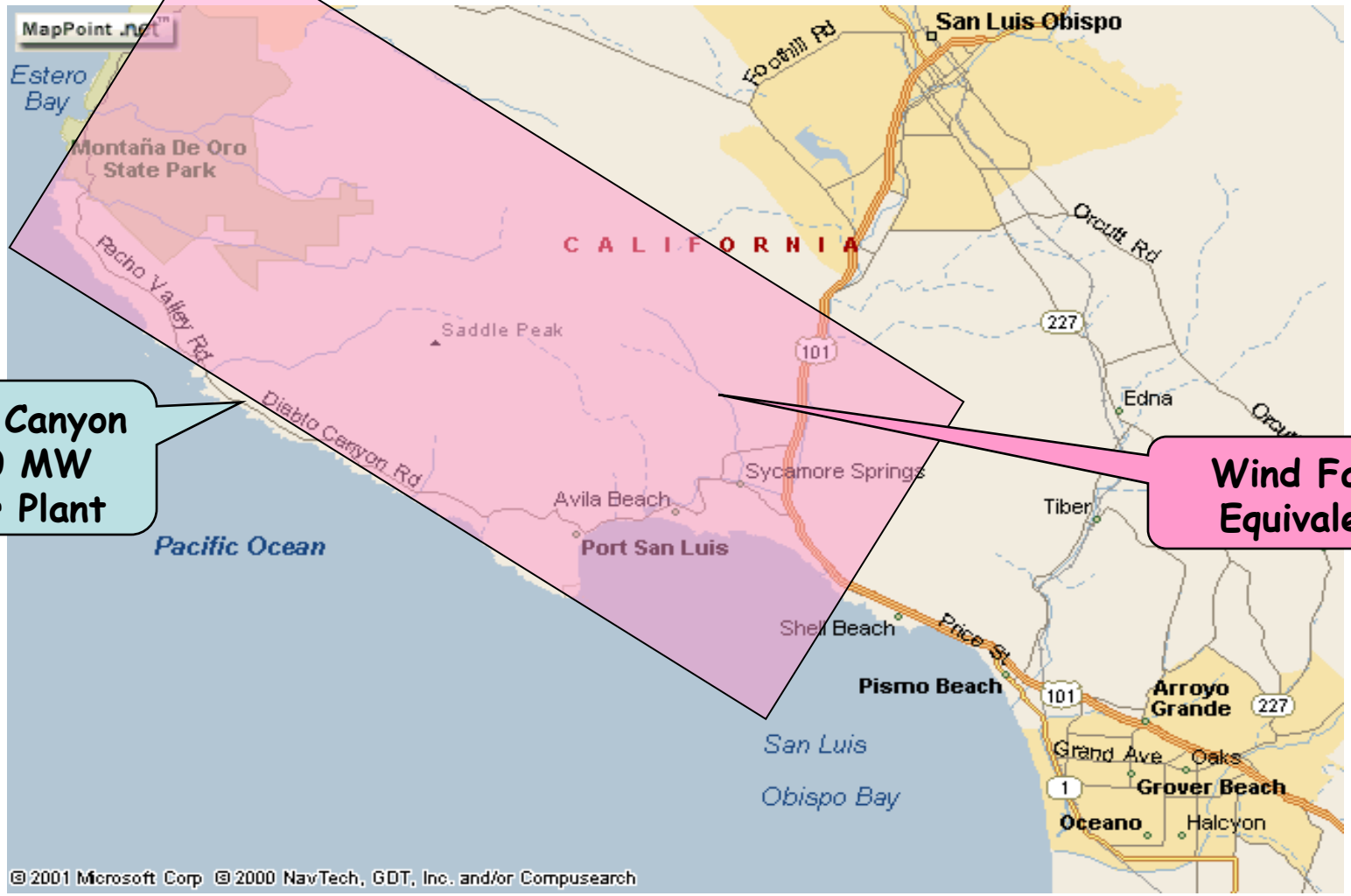
California Coast Power



Diablo Canyon 2200 MW Power Plant

Wind Farm Equivalent

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Hindenburg Hysteria

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Hydrogen

- You have to make it, just like electricity
- Electricity can make H_2, and H_2 can make electricity ($2H_2O \Leftrightarrow 2H_2 + O_2$)
- You have to make a lot of it
- You can make it cold, - 419 F (21 K)

P. M. Grant, "Hydrogen Lifts Off," Nature, 10 July 2003

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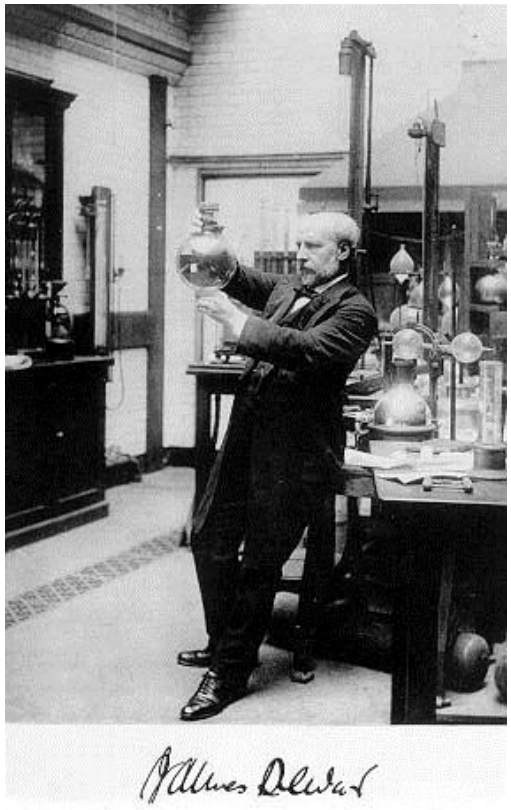
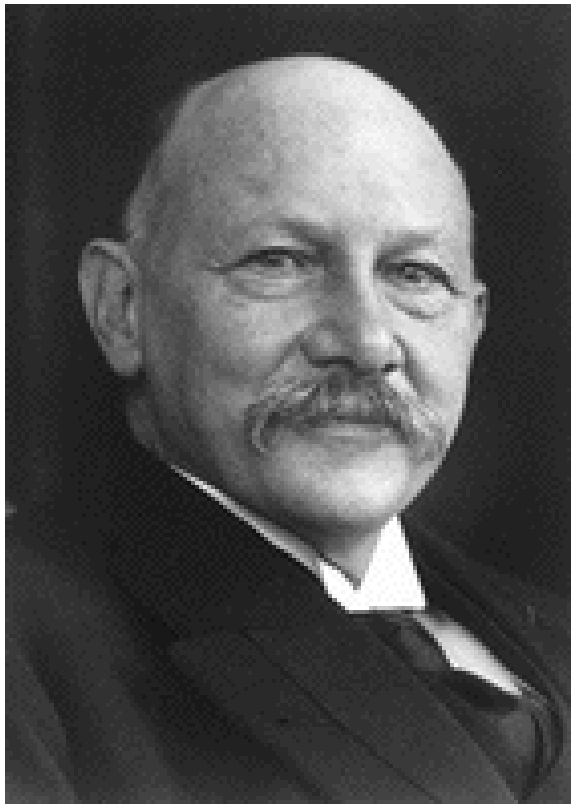
Fathers of Cryogenics



Dewar

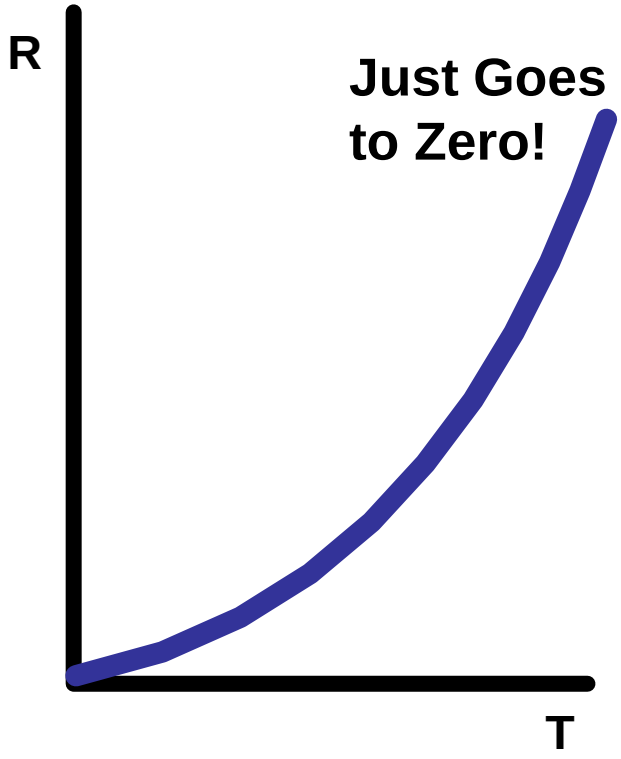
CH_4	112 K
O	90
N_2	77
Ne	27
H_2	20
He	4.2

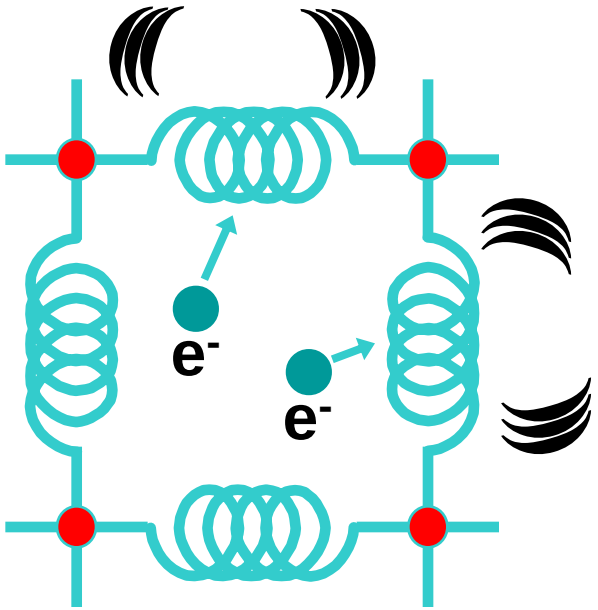


Kammerlingh-Onnes

Models of Electrical Conductivity

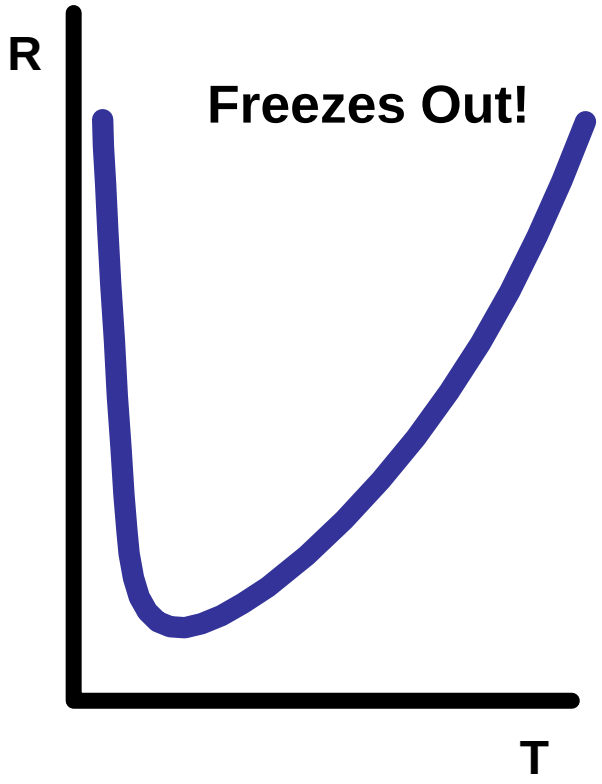
One Idea:

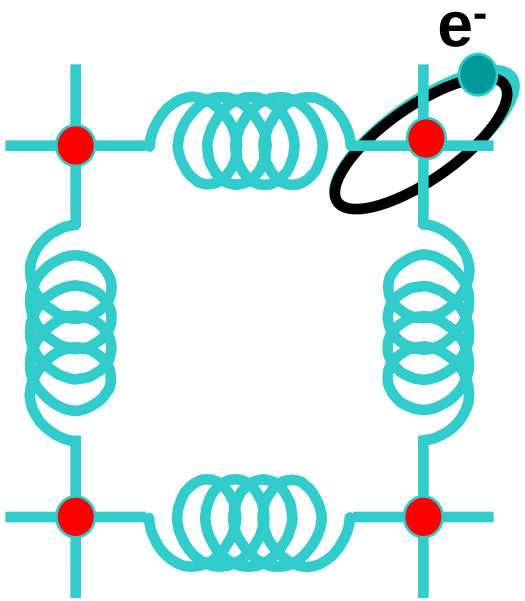




Models of Electrical Conductivity

The Most Popular:





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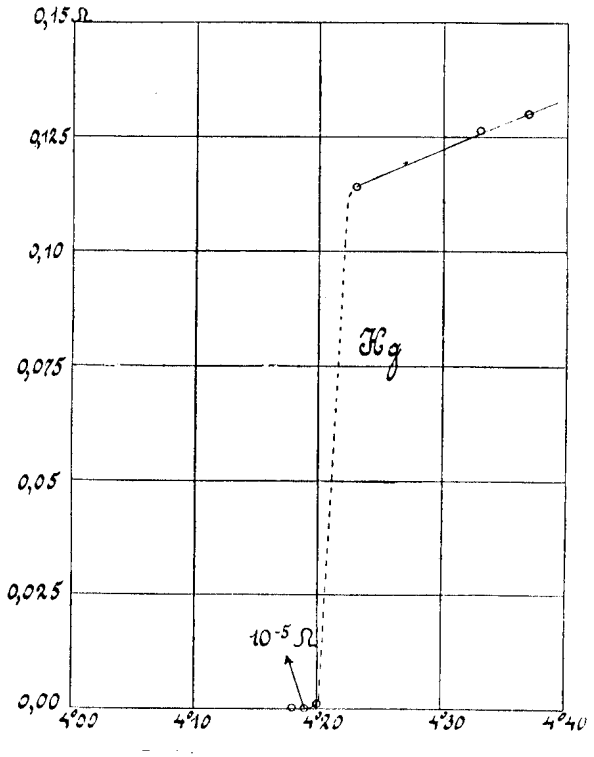
1911: A Big Surprise!



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)

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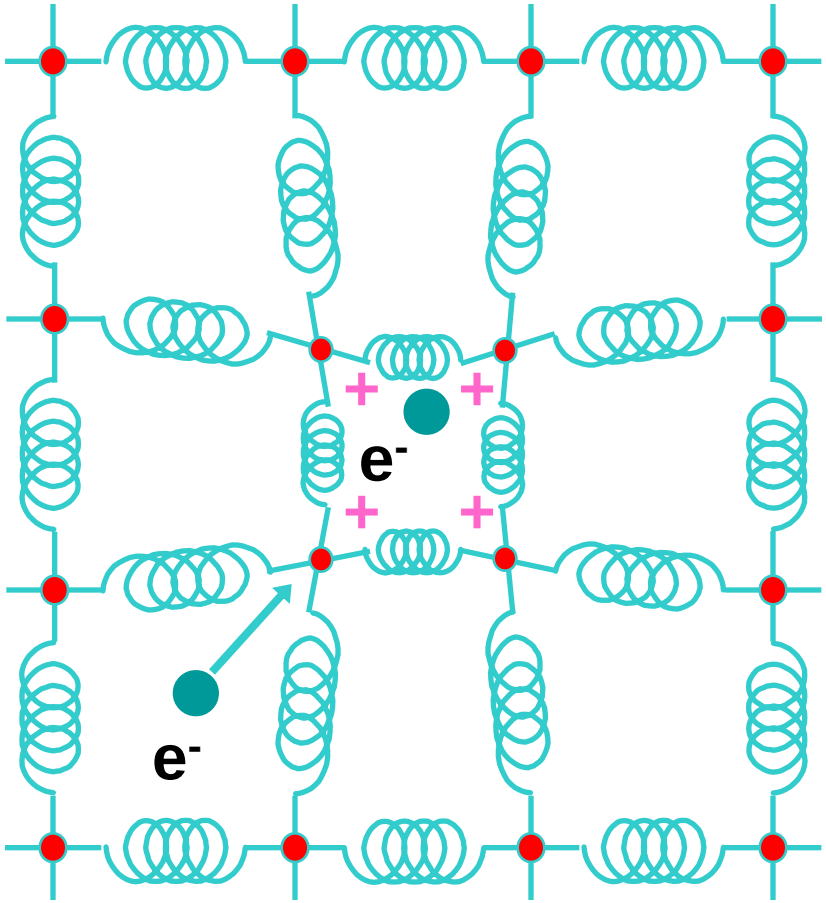
Physics of Superconductivity



Electrons Pair Off!

BCS Equation

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

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

$$\lambda = 0.28,$$

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

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1967: SC Cable Proposed!

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

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

R. L. GARWIN AND J. MATISOO

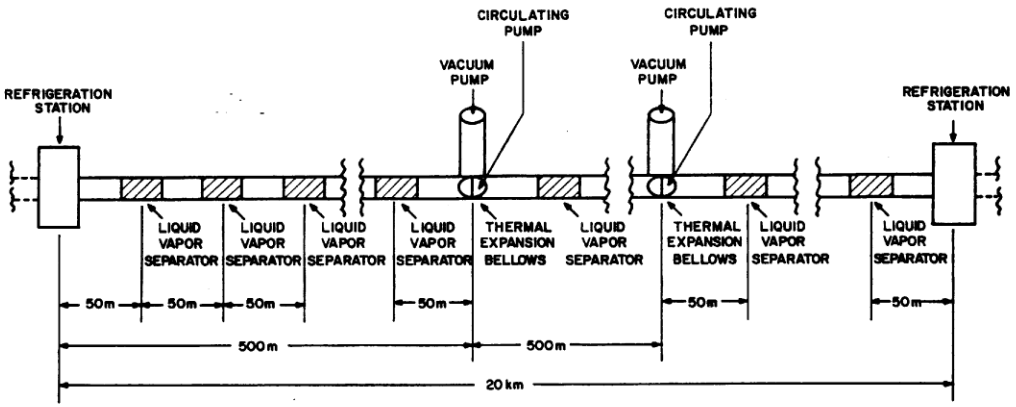


Fig. 2. A 20-km module of the 1000-km, 100-GW line.

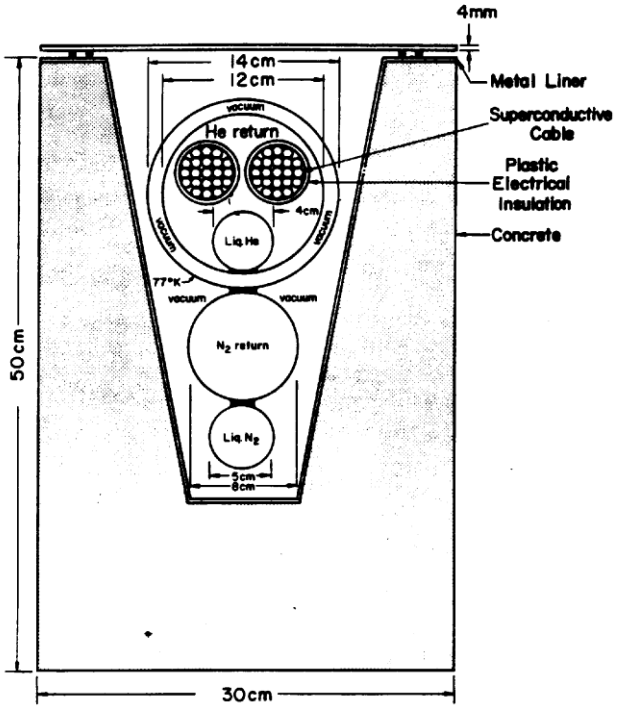


Fig. 1. Cross section of the 100-GW line.

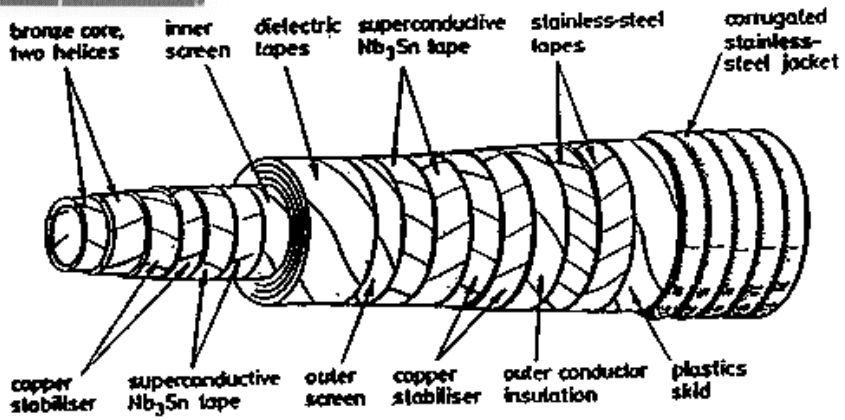
100 GW dc, 1000 km !

Brookhaven 1975-86 LTS ac Cable

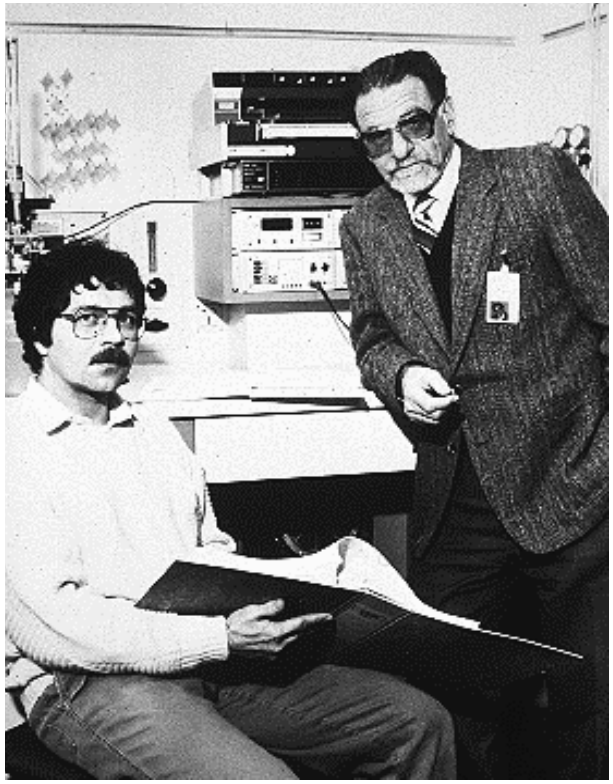
- Technical Success
- Economics Unclear

135 kV, 1000 MVA, 3ϕ, 115 m

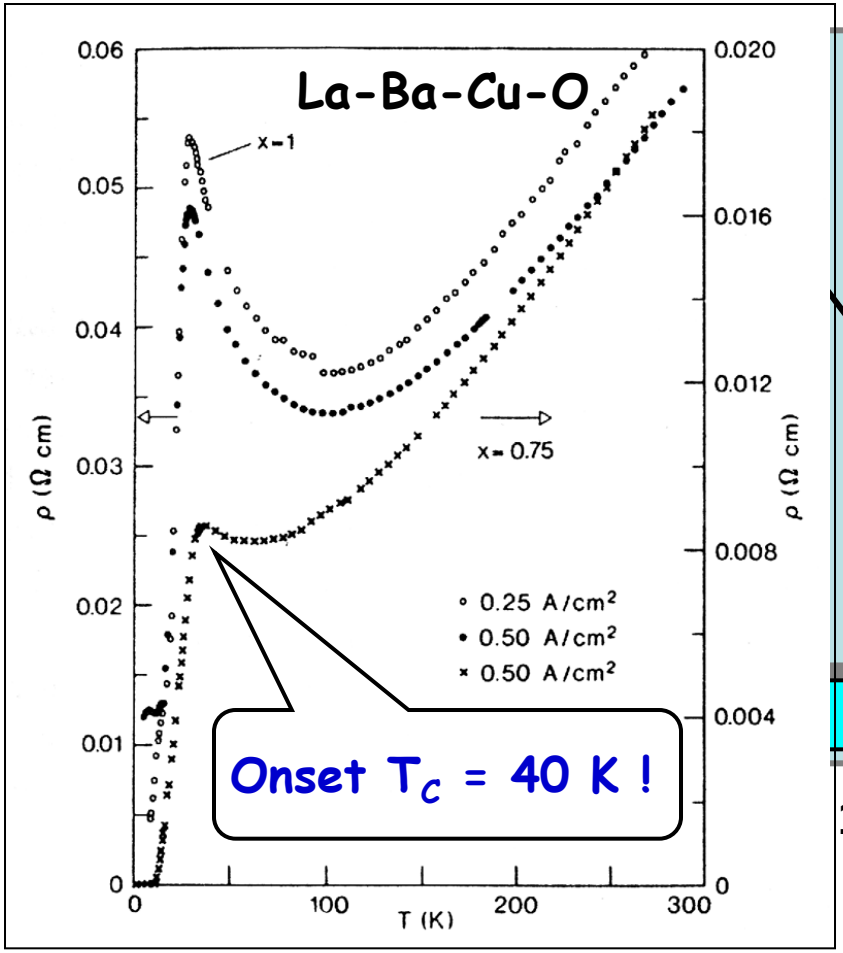
Nb_3Sn, 7-9 K

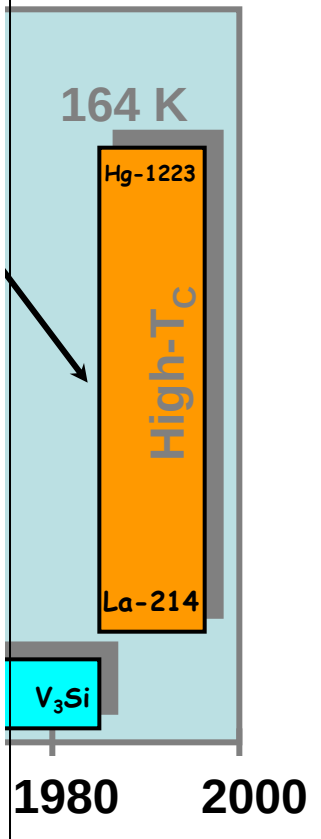


1986: Another Big Surprise!



Bednorz and Mueller
IBM Zuerich, 1986





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1987: "The Prize!"

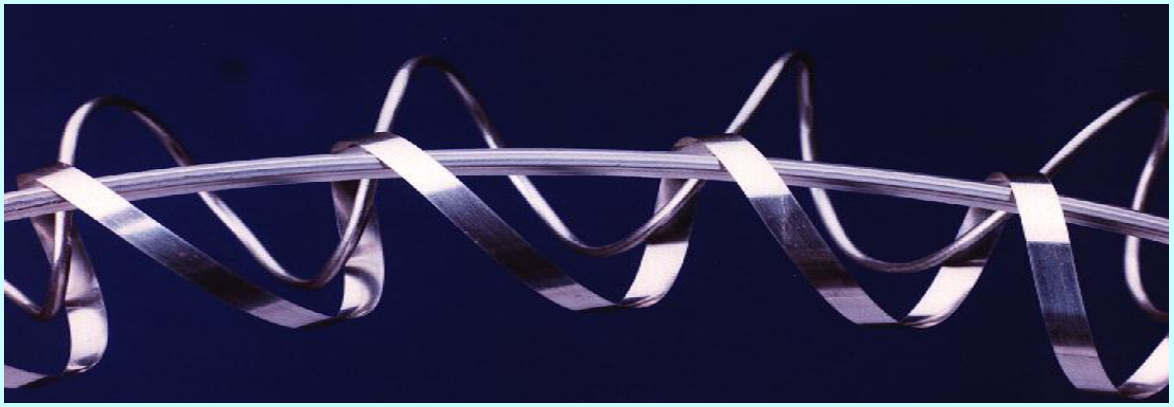
Associated Press

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

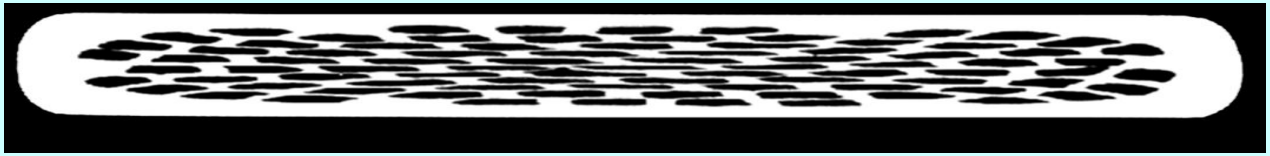
2 Get Nobel for Unlocking Superconductor Secret

HTSC Wire Can Be Made!

"The Miracle of 1989"



But it's 70% silver!



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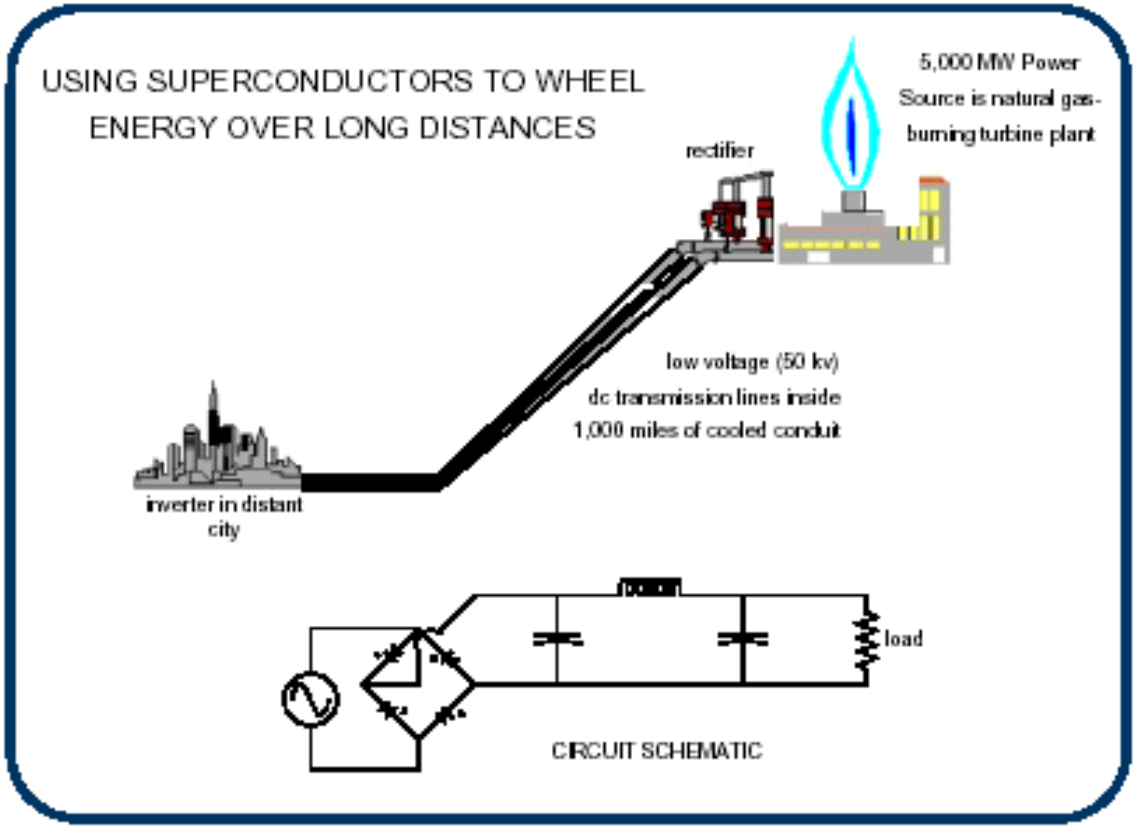
HTSC Cable

Electricity Pipe



Initial EPRI study on long distance (1000 km) HTSC dc cable cooled by liquid nitrogen

-- 1997 --

P.M. Grant, S. Schoenung, W. Hassenzahl, EPRI Report 8065-12, 1997

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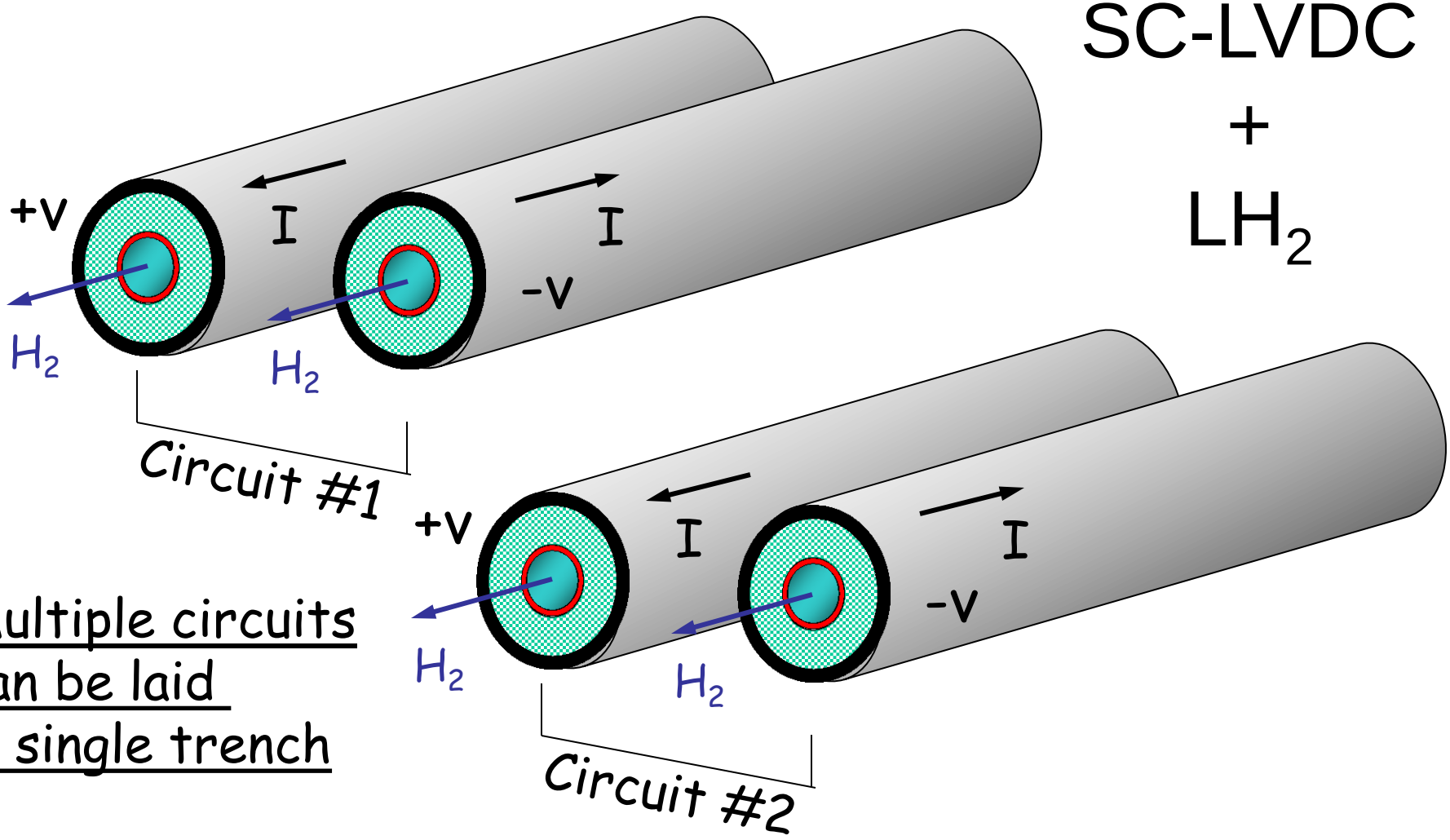
SuperCables

SC-LVDC
+
LH_2



Multiple circuits can be laid in single trench

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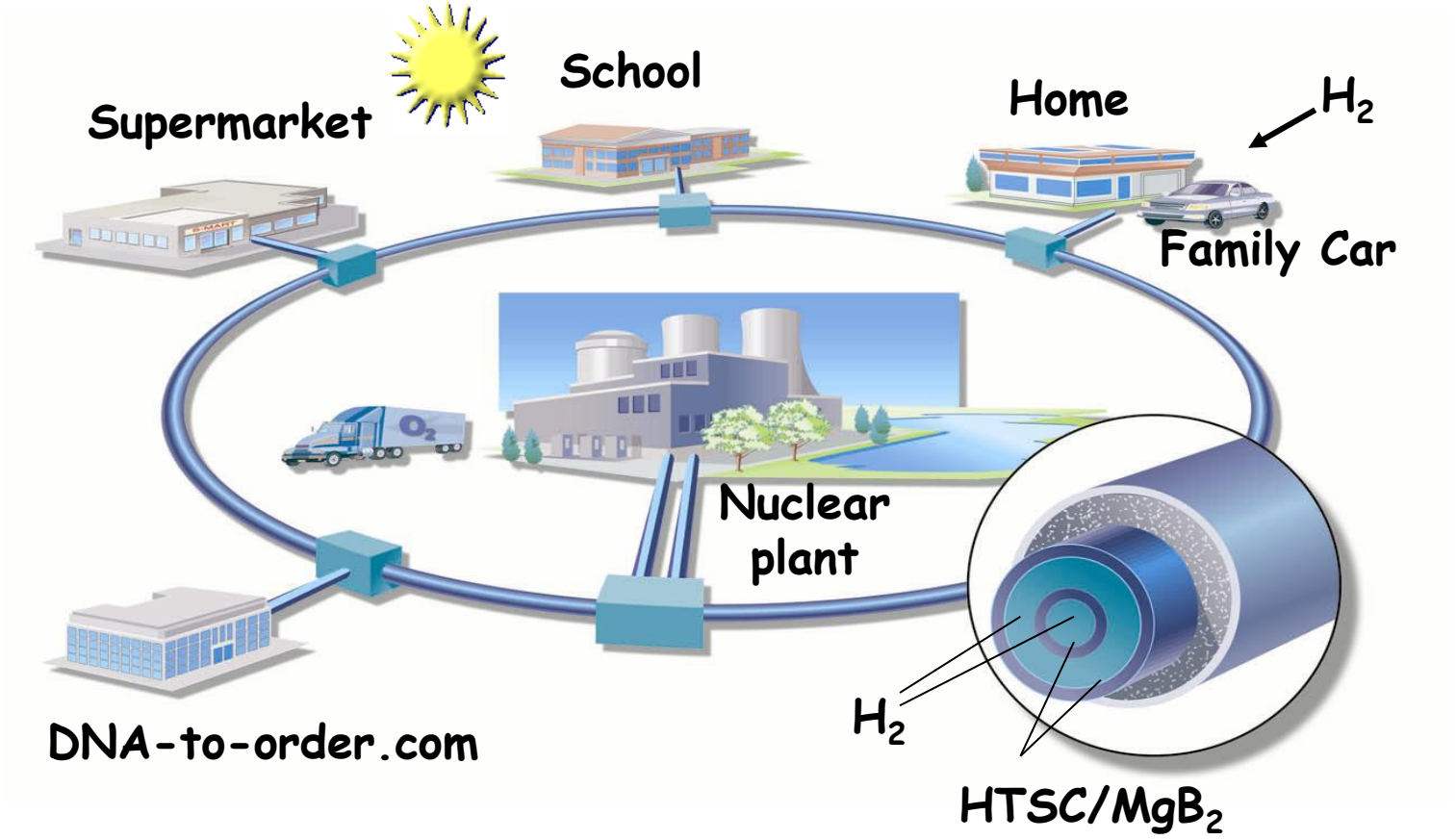
SuperCity



P.M. Grant, The Industrial Physicist, Feb/March Issue, 2002

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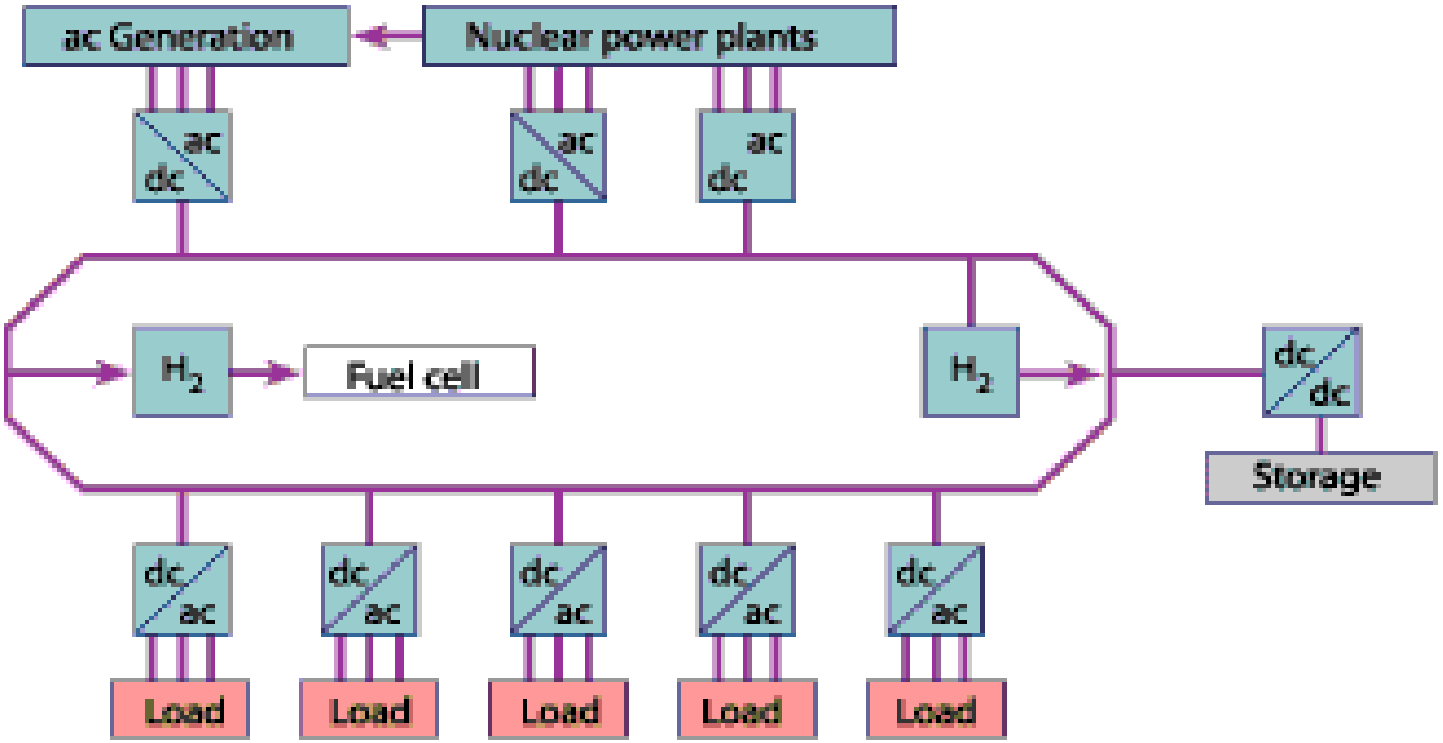
SuperGrid



Continental SuperGrid

C. S. Starr, "Continential SuperGrid," Nuclear News, Spring Issue, 2002

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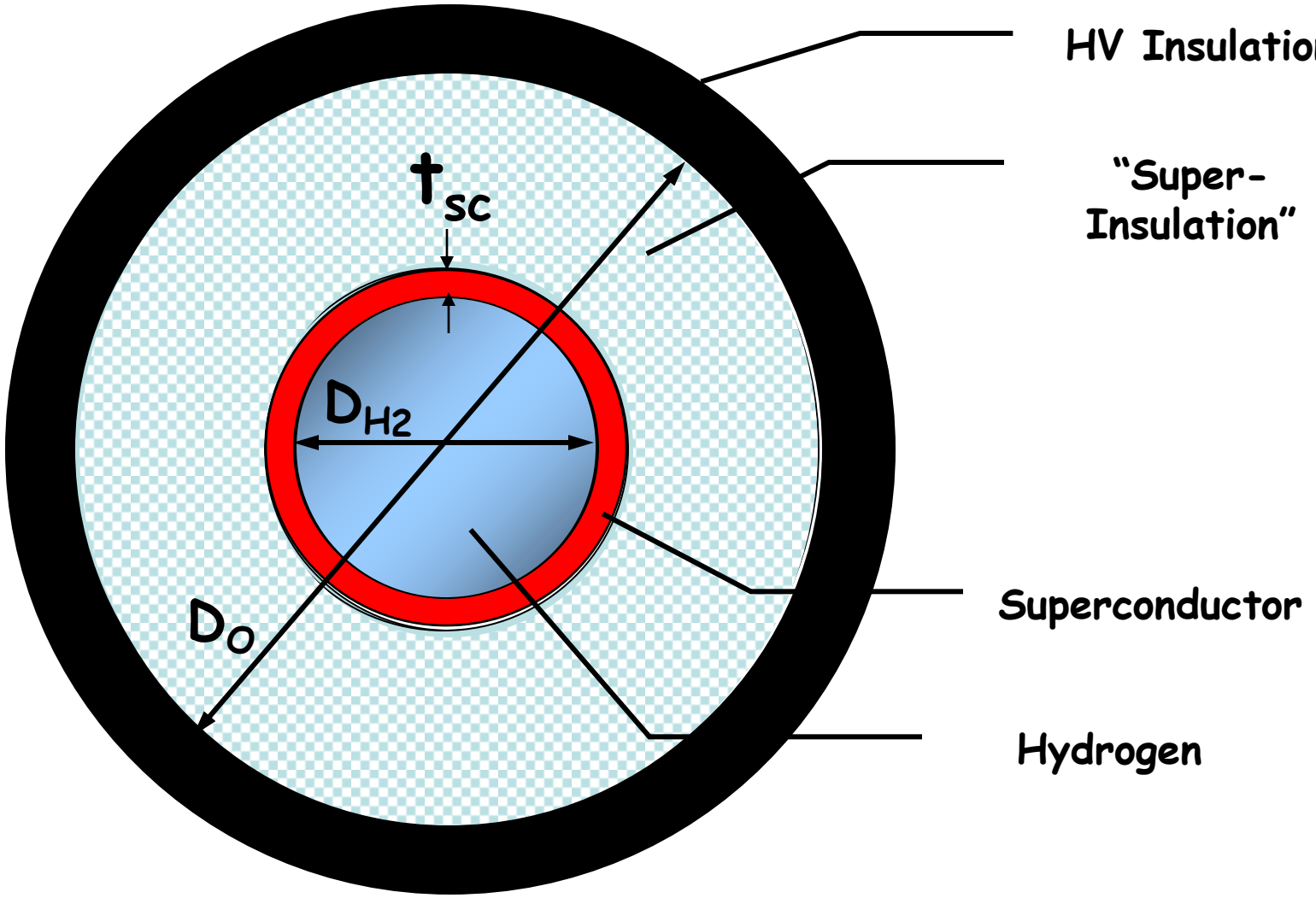
LH_2 SuperCable



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Electric & H_2 Power

Electricity

Power (MW)	Voltage (V)	Current (A)	Critical Current Density (A/cm^2)	Annular Wall Thickness (cm)
1000	+/- 5000	100,000	25,000	0.125

Hydrogen (LH_2, 20 K)

Power (MW)	Inner Pipe Diameter, D_{H2} (cm)	H_2 Flow Rate (m/sec)	"Equivalent" Current Density (A/cm^2)
500	10	3.81	318

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Thermal Losses

Radiation Losses

$W_R = 0.5\varepsilon\sigma\,(T^4_{amb} - T^4_{SC})$, where

W_R = Power radiated in as watts/unit area
$\sigma = 5.67\times10^{-12}$ W/cm^{2}K^4
T_{amb} = 300 K
T_{SC} = 20 K
ε = 0.05 per inner and outer tube surface
D_{SC} = 10 cm

W_R = 3.6 W/m

Superinsulation: $W_R^f = W_R/(n-1)$, where

n = number of layers

Target: W_R^f = 0.5 W/m requires ~10 layers

Other addenda (convection, conduction): W_A = 0.5 W/m

$W_T = W_R^f + W_A$ = 1.0 W/m

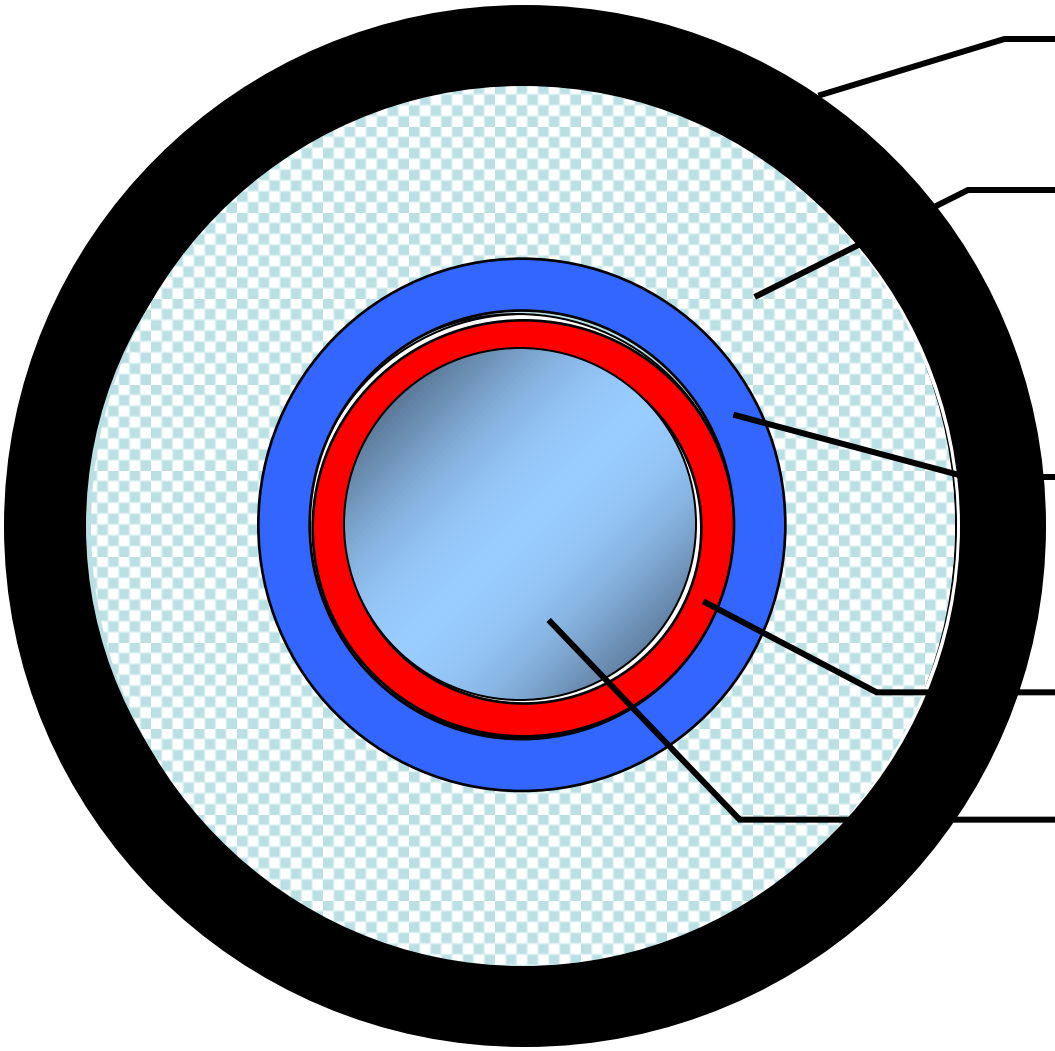
Heat Removal

$dT/dx = W_T/(\rho v C_P A)_{H2}$, where

dT/dx = Temp rise along cable, K/m
W_T = Thermal in-leak per unit Length
ρ = H_2 Density
v = H_2 Flow Rate
C_P = H_2 Heat Capacity
A = Cross-sectional area of H_2 cryotube

Take W_T = 1.0 W/m, then $dT/dx = 1.89 \times 10^{-5}$ K/m,
Or, 0.2 K over a 10 km distance

H_2 - Gas SuperCable



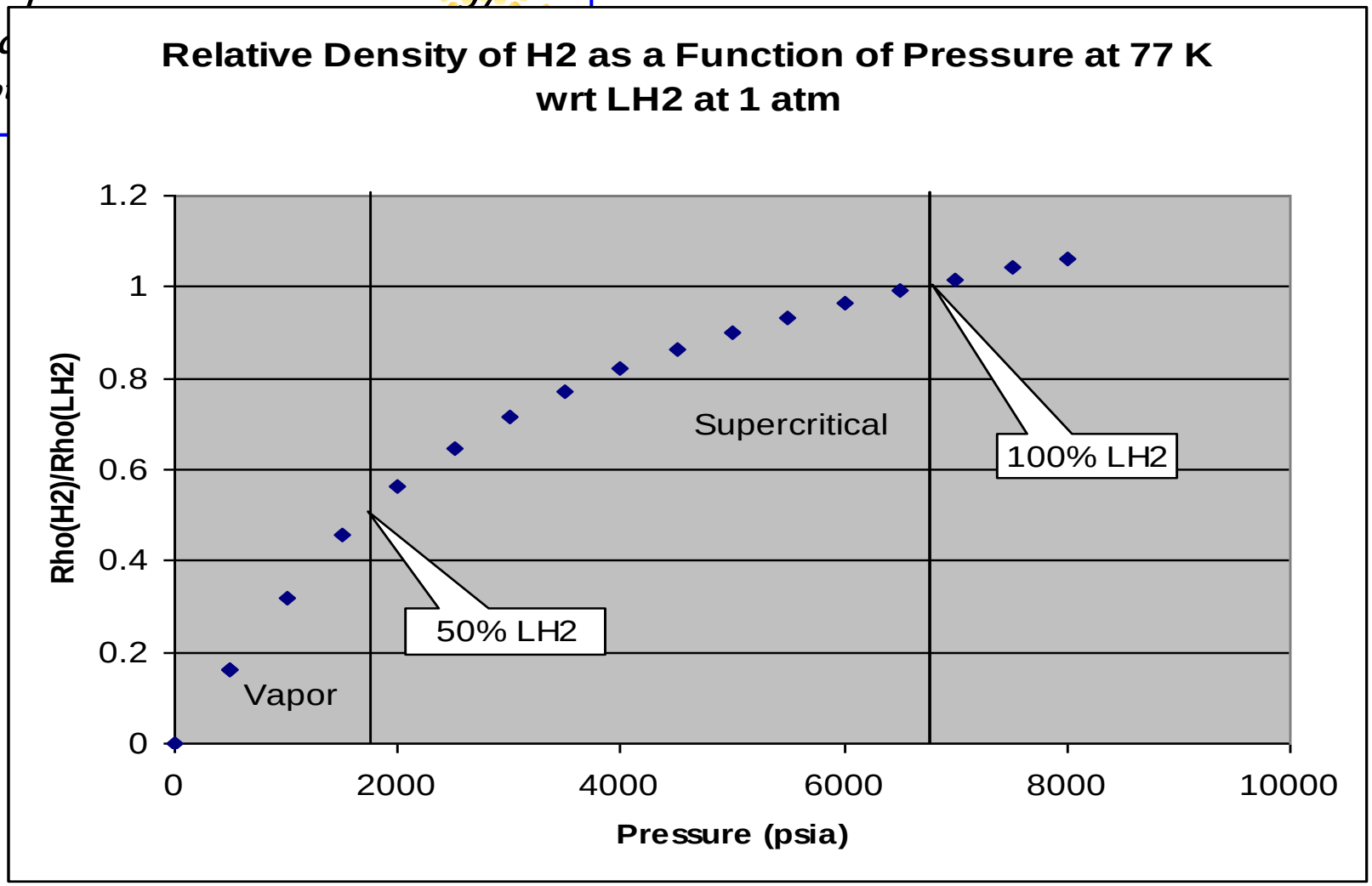
Electrical Insulation

"Super-Insulation"

Liquid Nitrogen @ 77 K

Superconductor

Supercritical Hydrogen @ 77 K 2000 – 7000 psia



H_2 Gas at 77 K and 1850 psia has 50% of the energy content of liquid H_2 and 100% at 6800 psia

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SuperCable H_2 Storage

Some Storage Factoids	Power (GW)	Storage (hrs)	Energy (GWh)
TVA Raccoon Mountain	1.6	20	32
Alabama CAES	1	20	20
Scaled ETM SMES	1	8	8

One Raccoon Mountain = 13,800 cubic meters of LH2

LH_2 in 10 cm diameter, 250 mile bipolar SuperCable
= Raccoon Mountain

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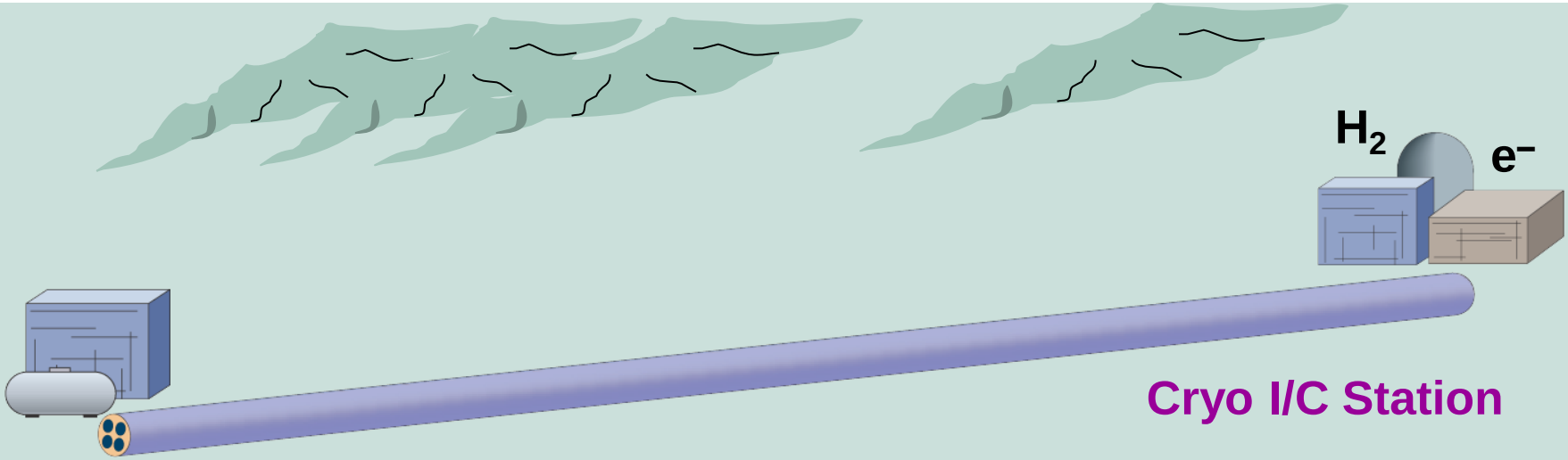
SuperCable Prototype Project



500 m Prototype

"Appropriate National Laboratory"
2005-09

Remaining Issues

Current stabilization via voltage control

- AC interface (phases)
- Ripple suppression
- Charge/Discharge cycles

Remaining Issues

Power Electronic Discretes

- GTOs vs IGBTs
- 12" wafer platforms
- Cryo-Bipolars
  - Minority carrier concentration
  - Doping profiles

Remaining Issues

Hydrogen Issues

- Safety
- Generation (electrolysis)
- Cryocoolers
- Liquid vs Pressurized Gas
- Flow Rate
- Storage

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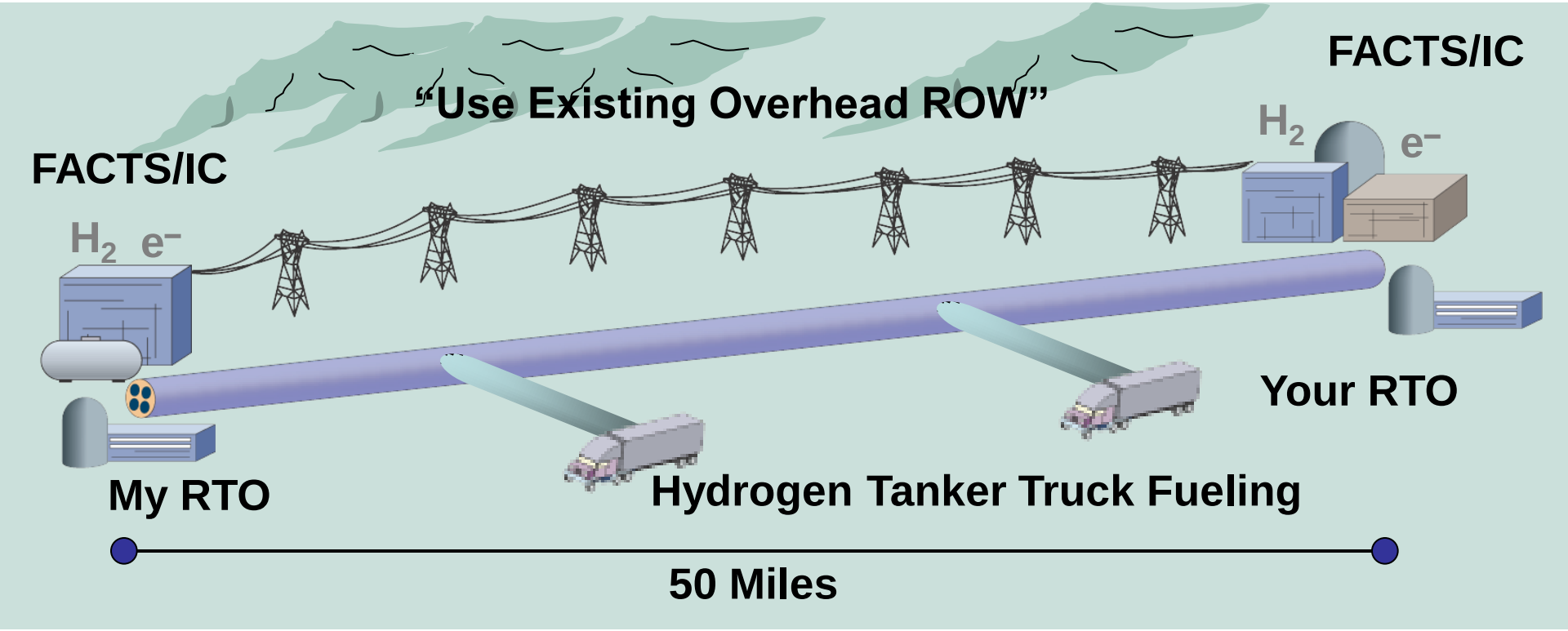
RegionGrid Interconnection



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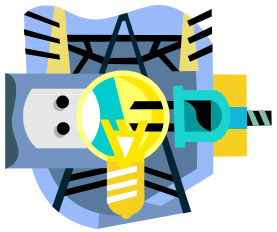
Grid Architecture

Thanks, Jimmy!

Three Dimensions

- ***SuperGrid*** – A superconducting, H_2-cooled interstate "backbone" connecting regions coast to coast.

- ***RegionGrid*** – Two grid operators (East and West) with upgraded high capacity lines to transmit power regionally.



- ***CityGrid*** – Local mini- and micro-grids with distributed intelligence, energy resources, and demand response

Integrated systems architecture enables *NationalGrid* operations across all dimensions.

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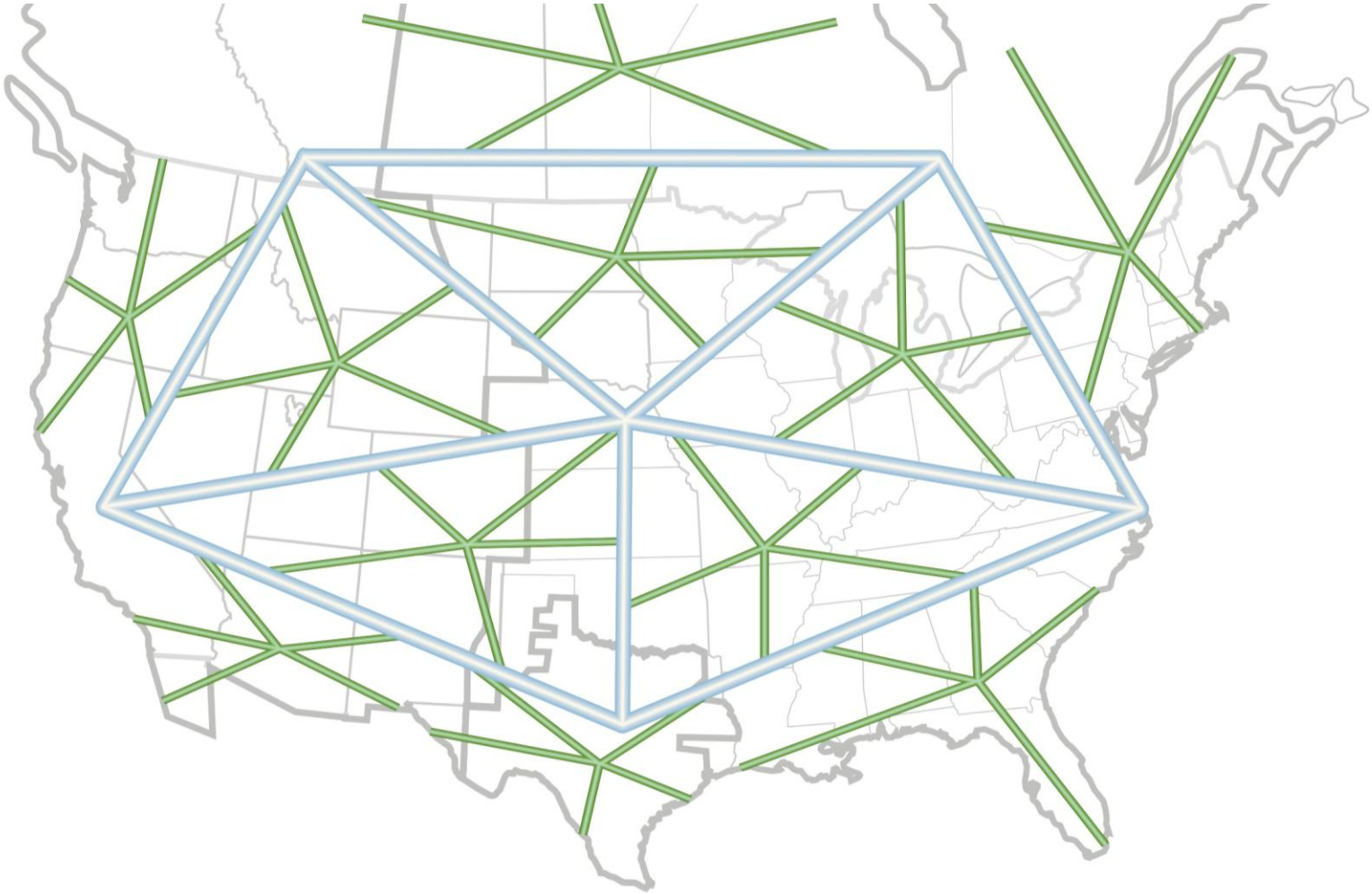
SuperGrid RegionGrid



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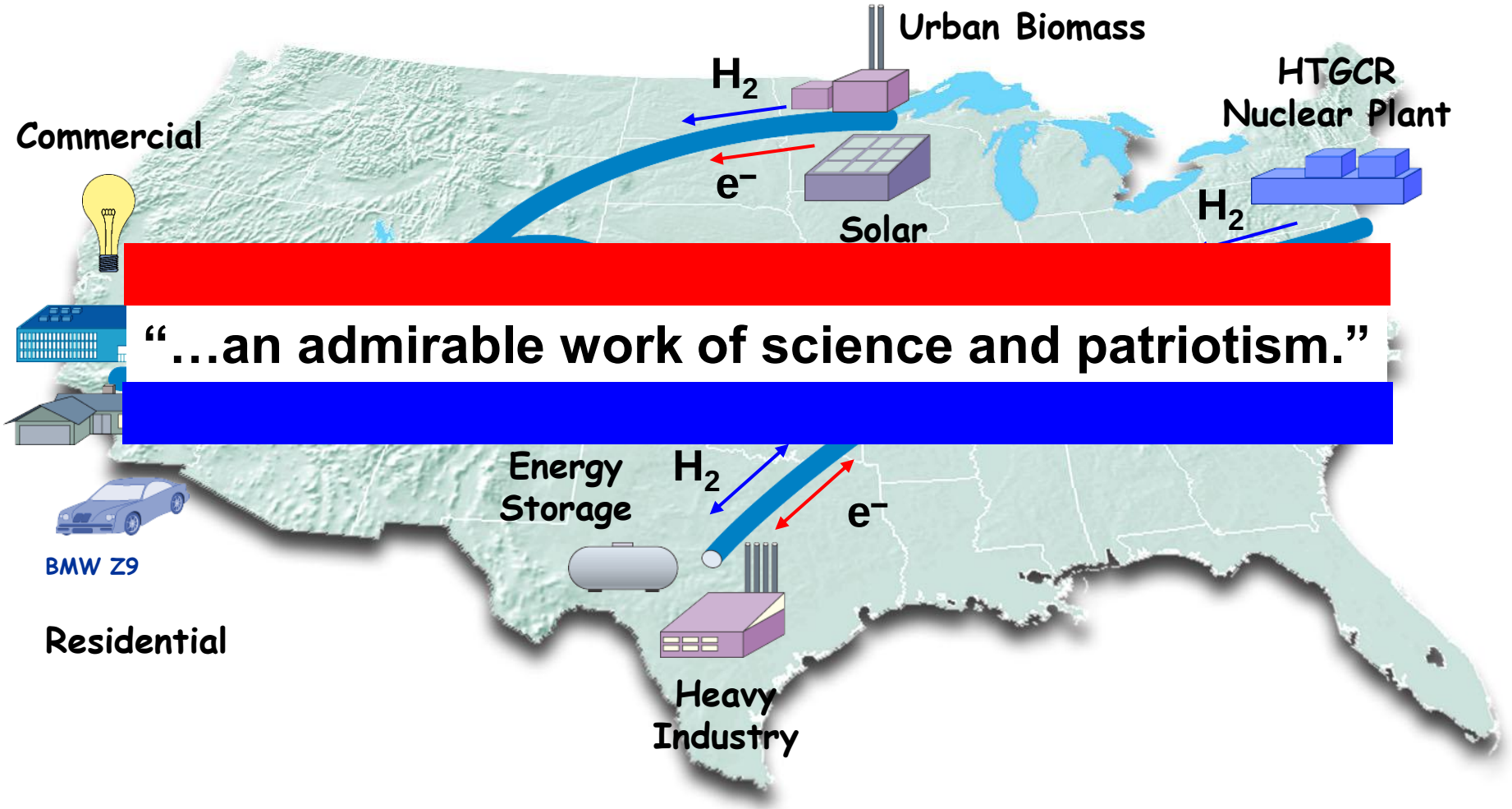
2050: An Energy SuperGrid



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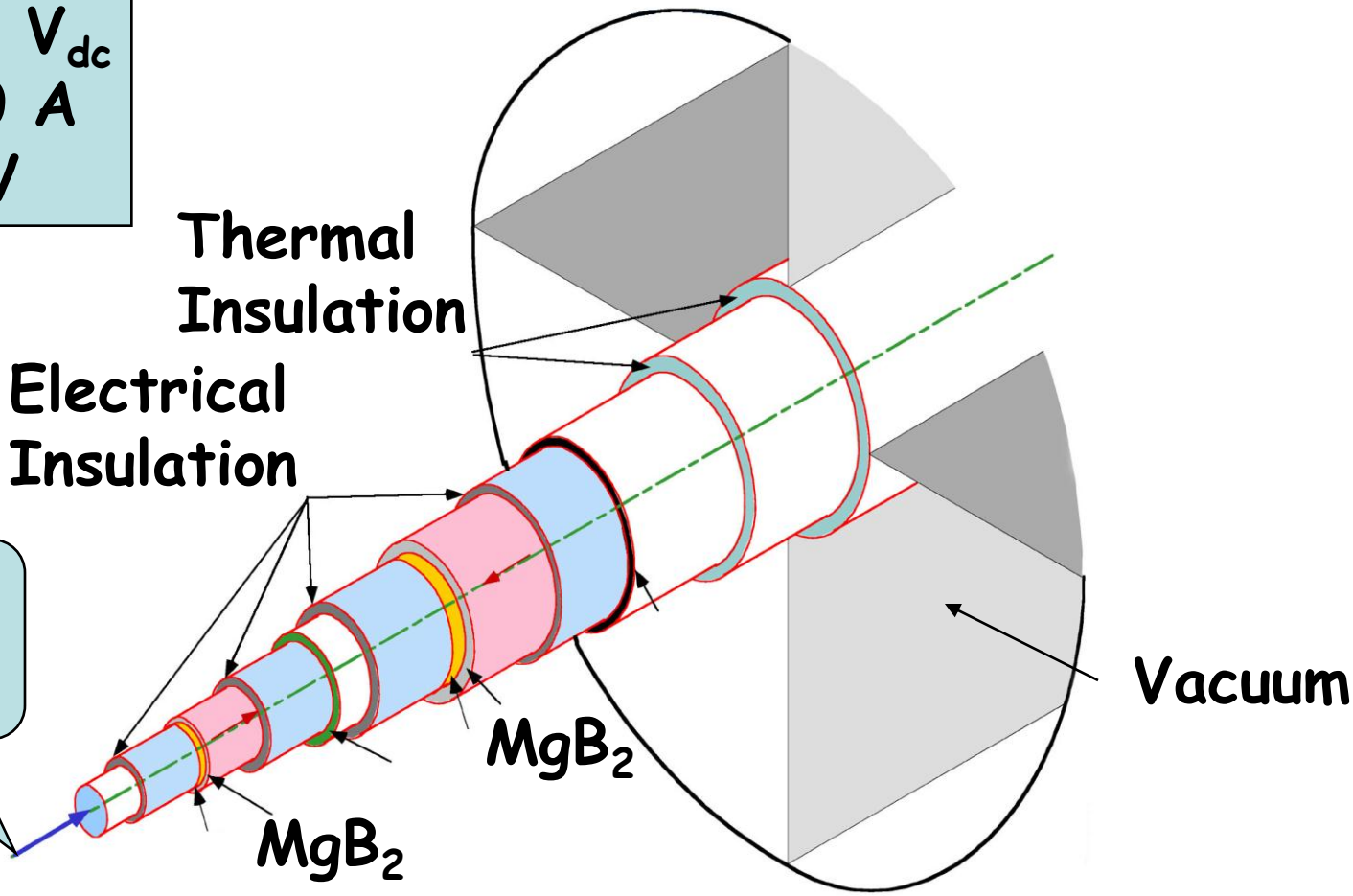
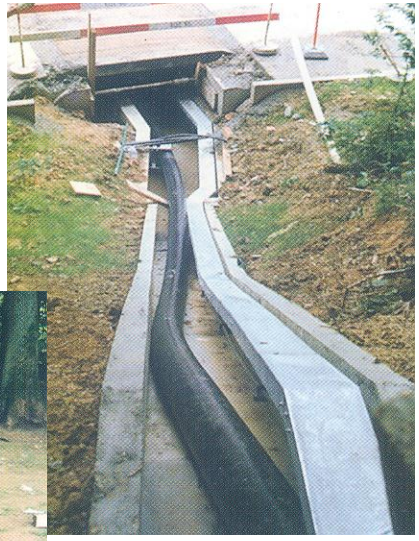
"The Energy Pipeline"

± 50,000 V_{dc}
100,000 *A*
10 GW



Small Scale Demonstration



Nexans LH_2 Transfer Line

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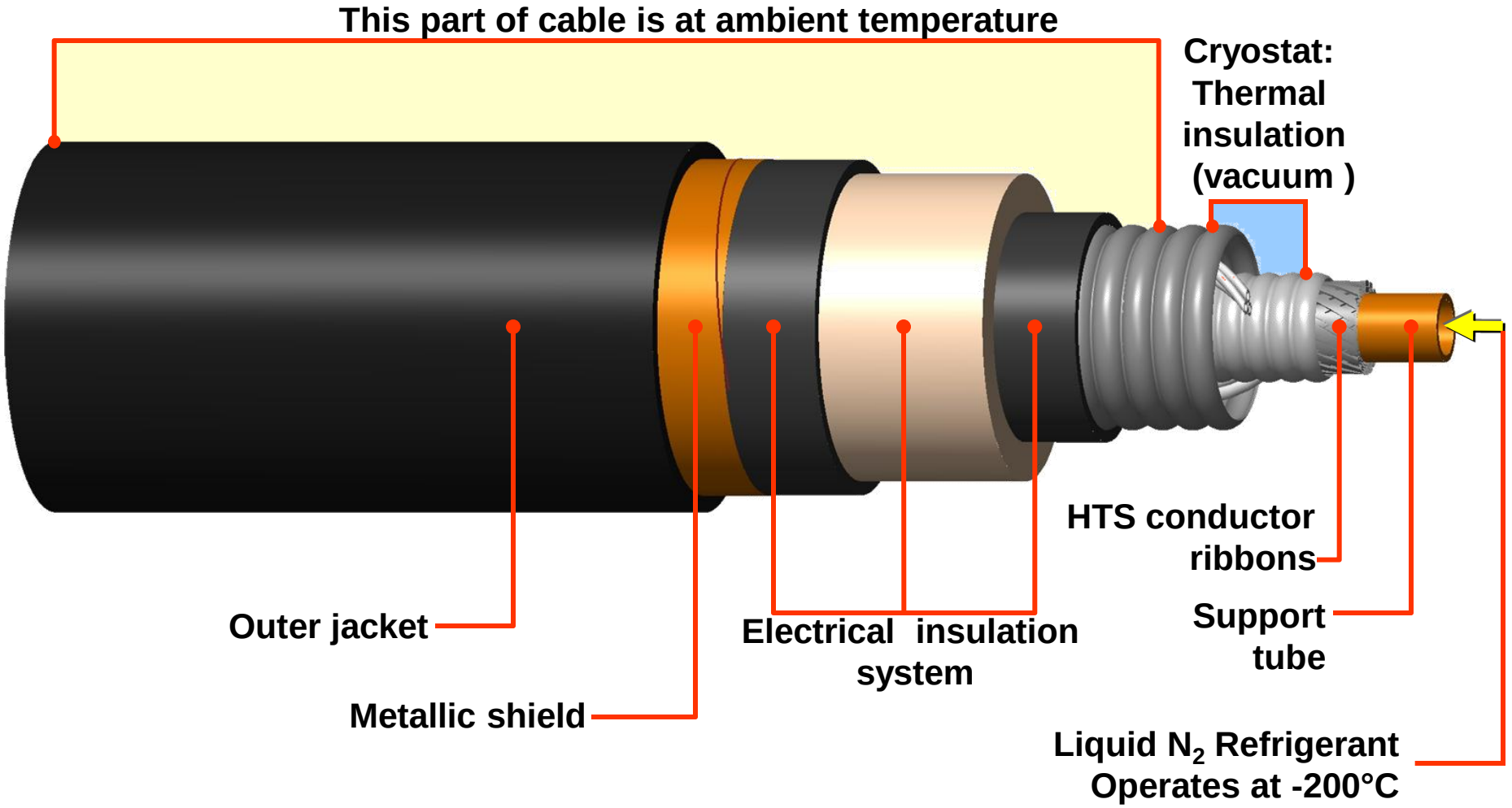
Hydrogen Factoids

- 0.025 $/kWh Electricity -> 0.22 $/kWh Hydrogen
- Hydrogen flowing @ 1 m/s -> 0.6 MW/cm^2
- Delivering 2000 MW Hydrogen -> 67 cm dia pipe

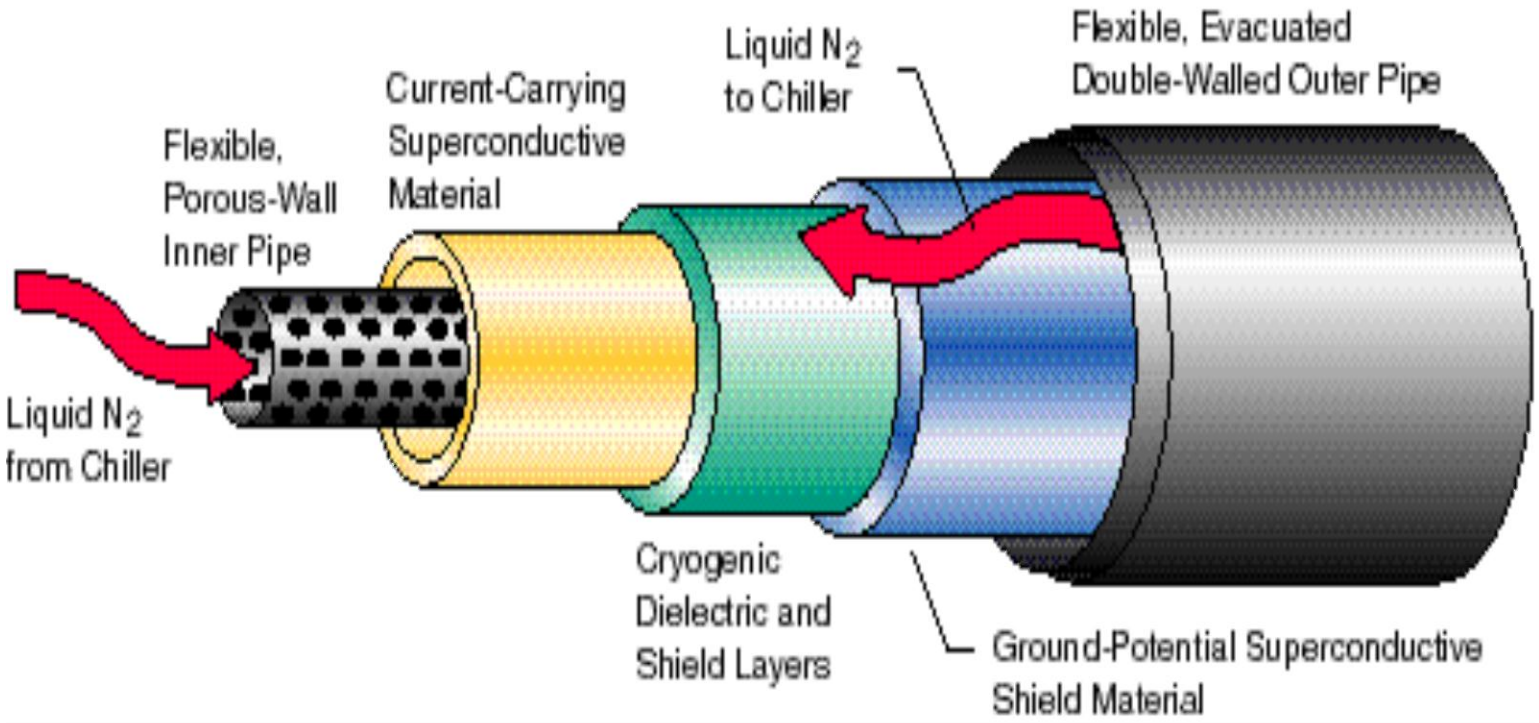
Electricity via superconductivity is essentially free!

- To power all cars in the US with hydrogen would require expropriating all present electric power generated in the US
- German studies show water emissions from powering all cars with hydrogen could

WTD Cable Breakaway



Cold Dielectric Cable



Issues (Superconductivity)

- Wire Cost & Performance
  - Gen I (BSCCO/Ag) 50 $/kA×m
  - Gen II (Y123 CC) 10
  - MgB_2 2
  - NBTi 0.90
- Length
  - Gen I (BSCCO/Ag) > 1000 m
  - Gen II (Y123 CC) 10
  - MgB_2 > 100
  - NBTi > 1000
- Joints & Splices
  - HTSC TBD

Issues (Cryogenic & Vacuum)

- Cryoplants: Cost & Performance
  - Liquid or Gas?
  - ECE = 0.20 T_{cold} /(T_{sink} - T_{cold})
  - Cryo-unit Cost ~ $5/W Rating
- Vacuum
  - Continuously pumped, periodic or sealed?
  - Distance between ports
  - Gettering materials

Issues (Cable Design/Power Control)

- Cable
  - Parallel vs. Coaxial
  - Flexible vs. Rigid
- Power
  - Balance between Voltage & Current
  - dc vs. ac
  - ac Losses (ripple factor)

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HTSC Cable Projects Worldwide

	1998 1999	2000 2005	
Pirelli DOE	50m/115kV/2kA "EPRI"	130m/24kV/2.5kA 3ph "Frisbie"	900m/66kV/0.7kA 3ph "LIPA"
EdF		50m/225kV/2.6kA/3ph	
Southwire	30m/12.5kV/2.6kA/3ph	300m/15kV/3ph "AEP"	
IGC		400m/35kV/3ph "Albany"	
NKT	30m/60kV/3kA/3ph "COP"		
SEI/TEPCO	30m/66kV/1kA "proto"	100m/66kV/1kA/3ph	Japanese National Program?