The SuperGrid:

Symbiosis of Nuclear, Hydrogen and Superconductivity

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Session FB (Energy and Power)
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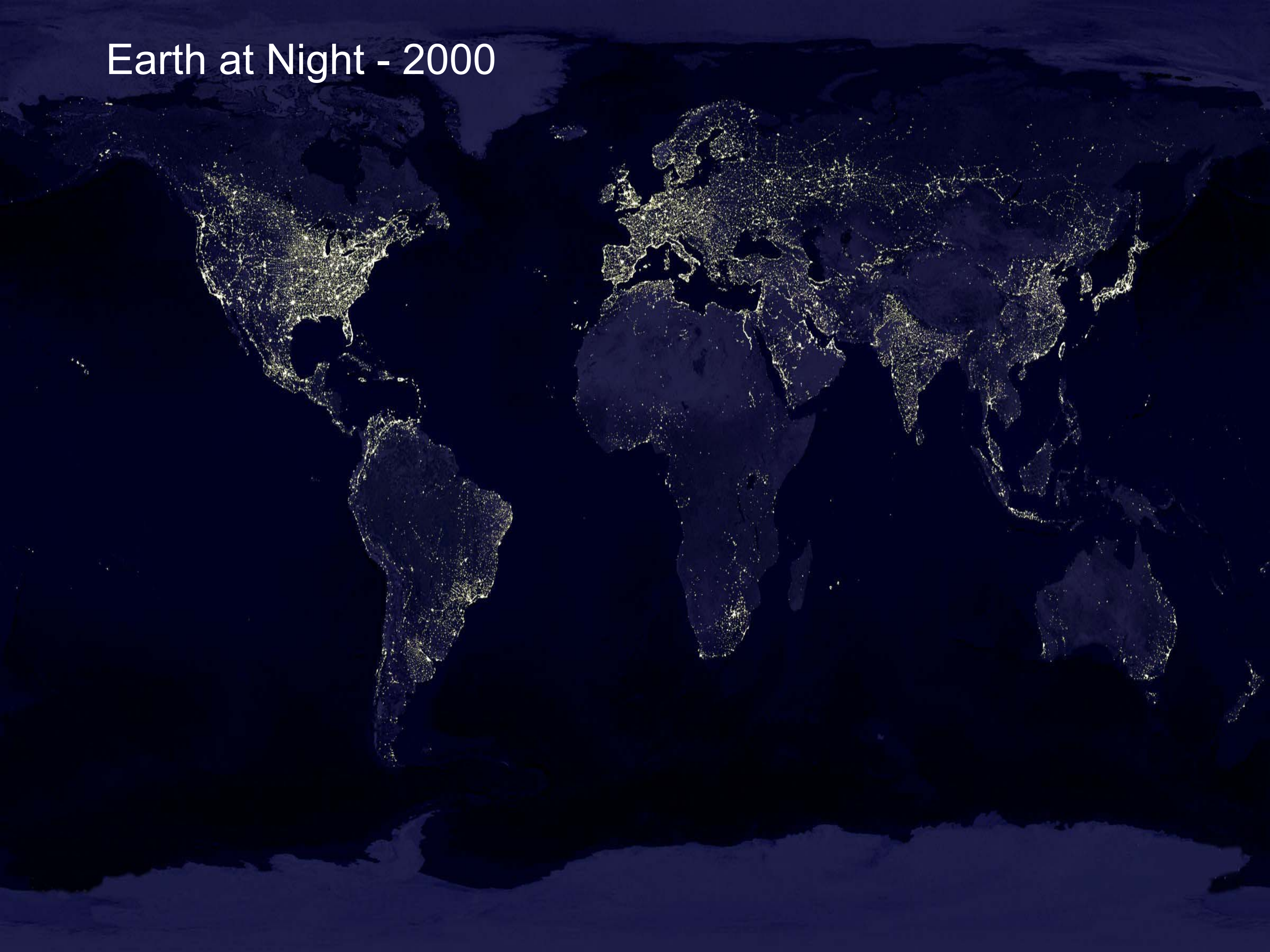
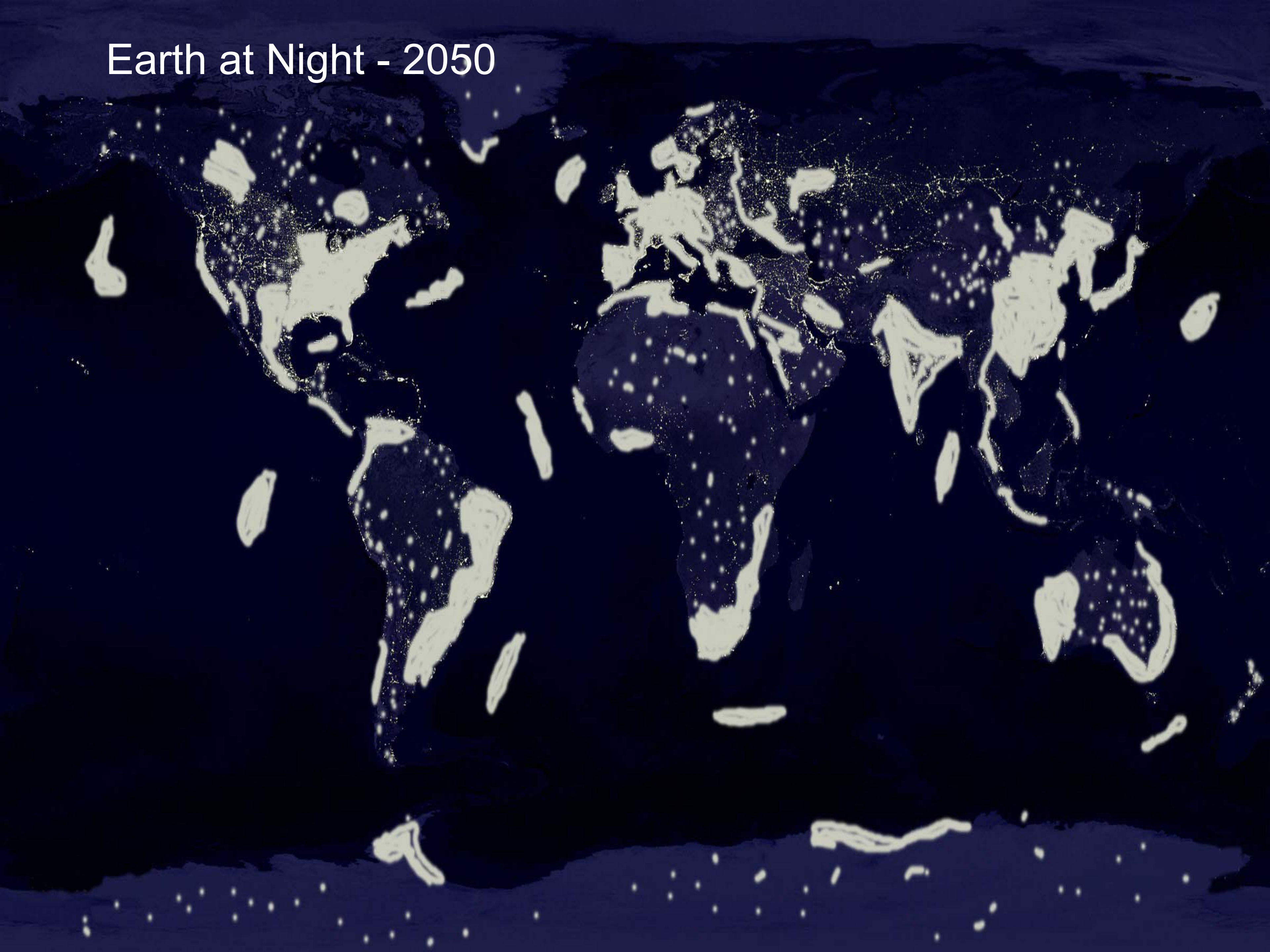

Earth at Night - 2000

Earth at Night - 2050



The 21st Century Energy Challenge

Design a communal energy economy to meet the needs of a densely populated industrialized world that reaches all corners of Planet Earth.

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

…without requiring any new scientific discoveries or breakthroughs!

Its Solution

A Symbiosis of

Nuclear/Hydrogen/Superconductivity

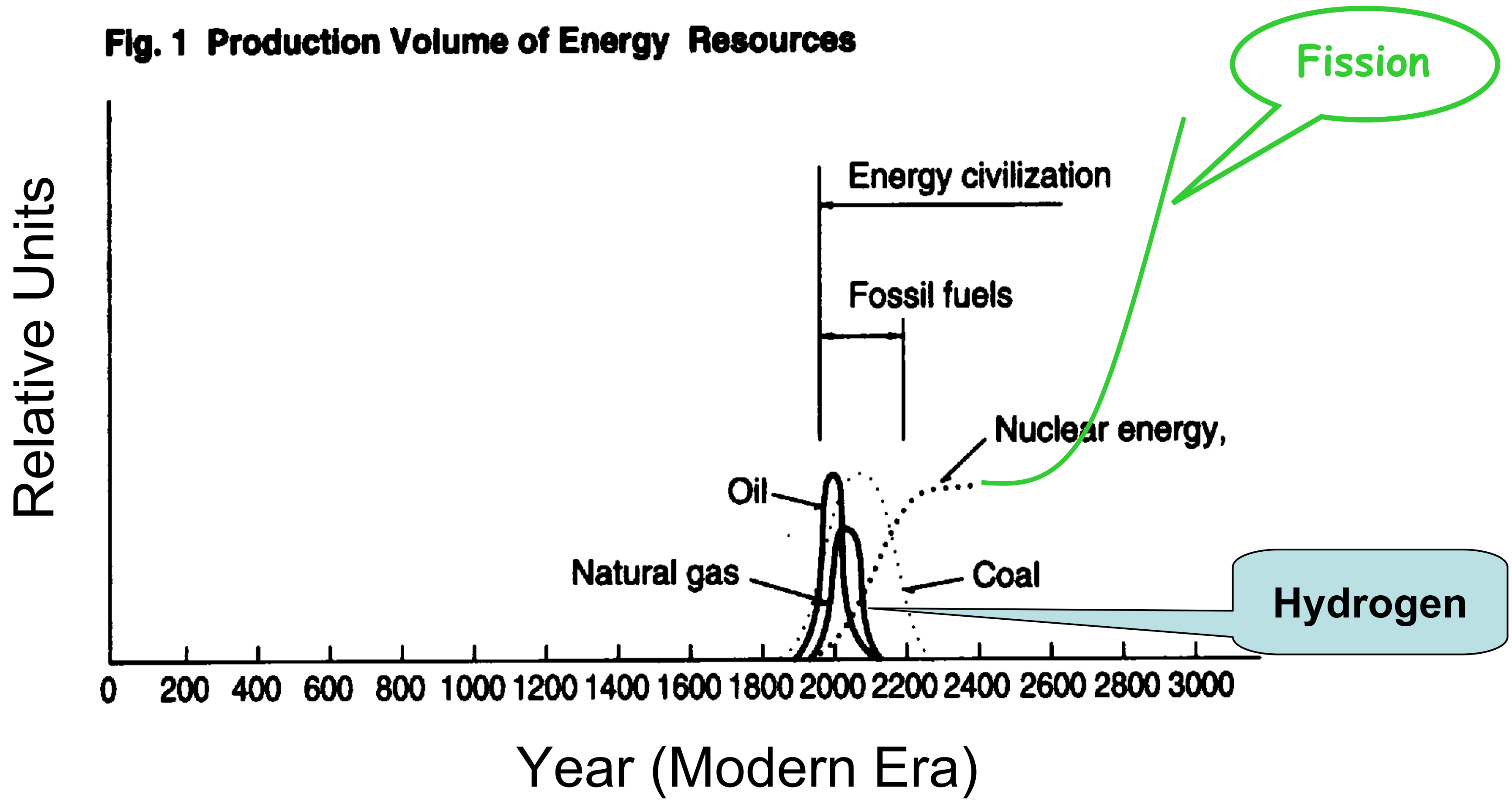
Technologies supplying Carbon-free, Non-Intrusive Energy for all Inhabitants of Planet Earth

Reading Assignment

1. **Garwin and Matisoo, 1967 (100 GW on Nb_3Sn)**
2. **Bartlit, Edeskuty and Hammel, 1972 (LH_2, LNG and 1 GW on LTSC)**
3. **Haney and Hammond, 1977 (Slush LH_2 and Nb_3Ge)**
4. **Schoenung, Hassenzahl and Grant, 1997 (5 GW on HTSC, 1000 km)**
5. **Grant, 2002 (SuperCity, Nukes+LH_2+HTSC)**
6. **Proceedings, SuperGrid Workshop, 2002**

These articles, and much more, can be found at www.w2agz.com, sub-pages SuperGrid/Bibliography

Past & Future Energy Supply



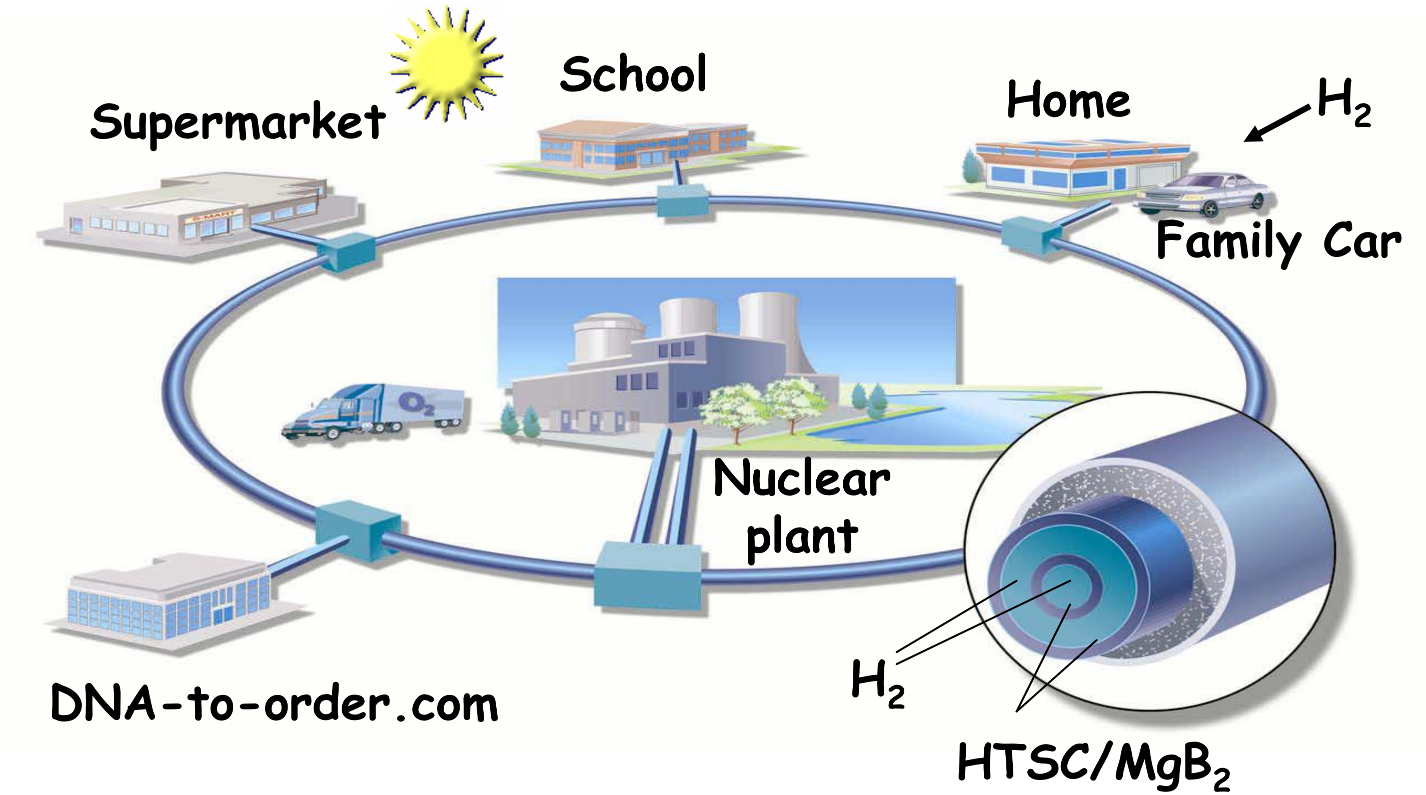



The Hydrogen Economy

- 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…with a heavy load," Nature 424, 129 (2003)

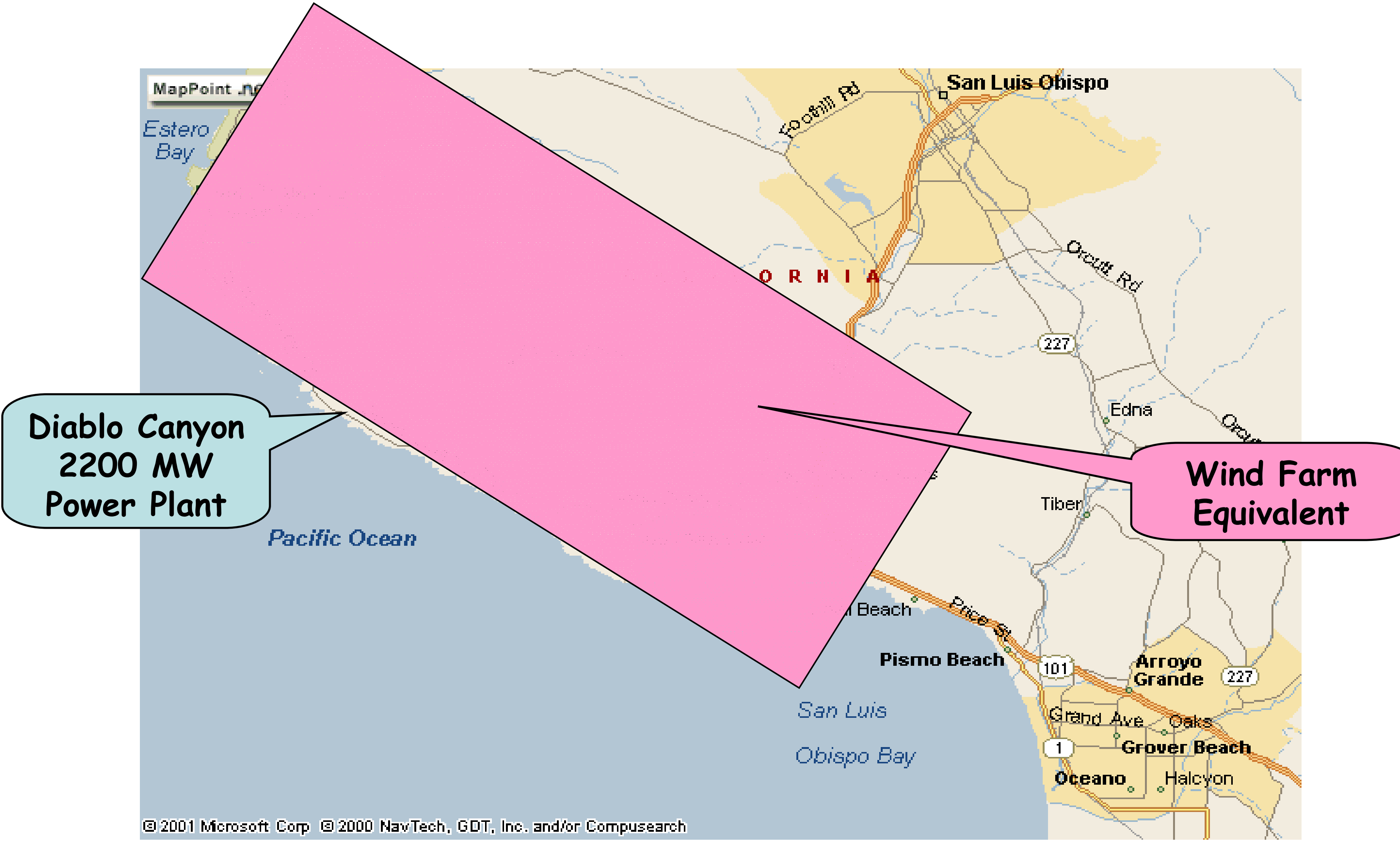
SuperCity



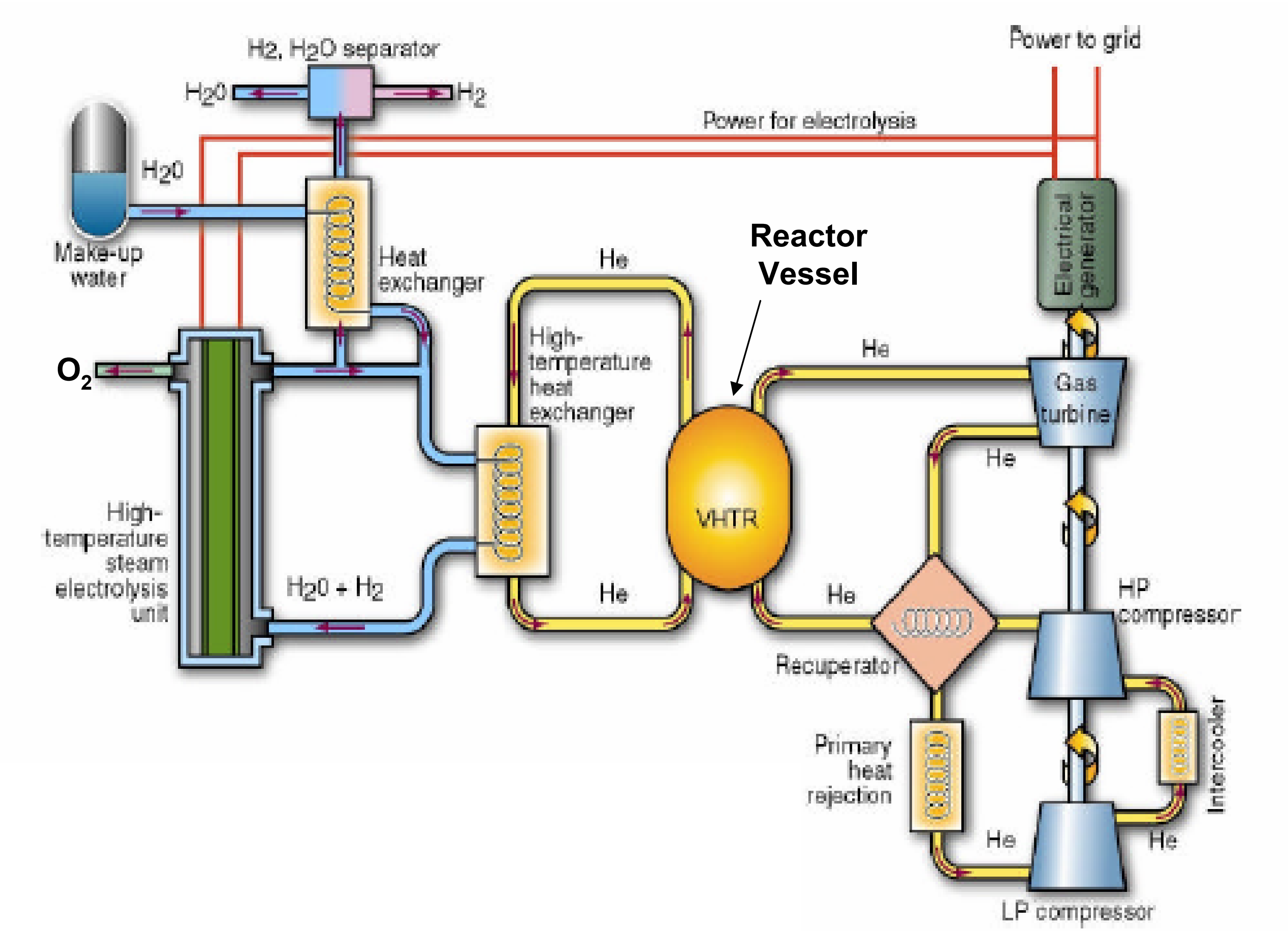
P.M. Grant, The Industrial Physicist, Feb/March Issue, 2002

Diablo Canyon

California Coast Power

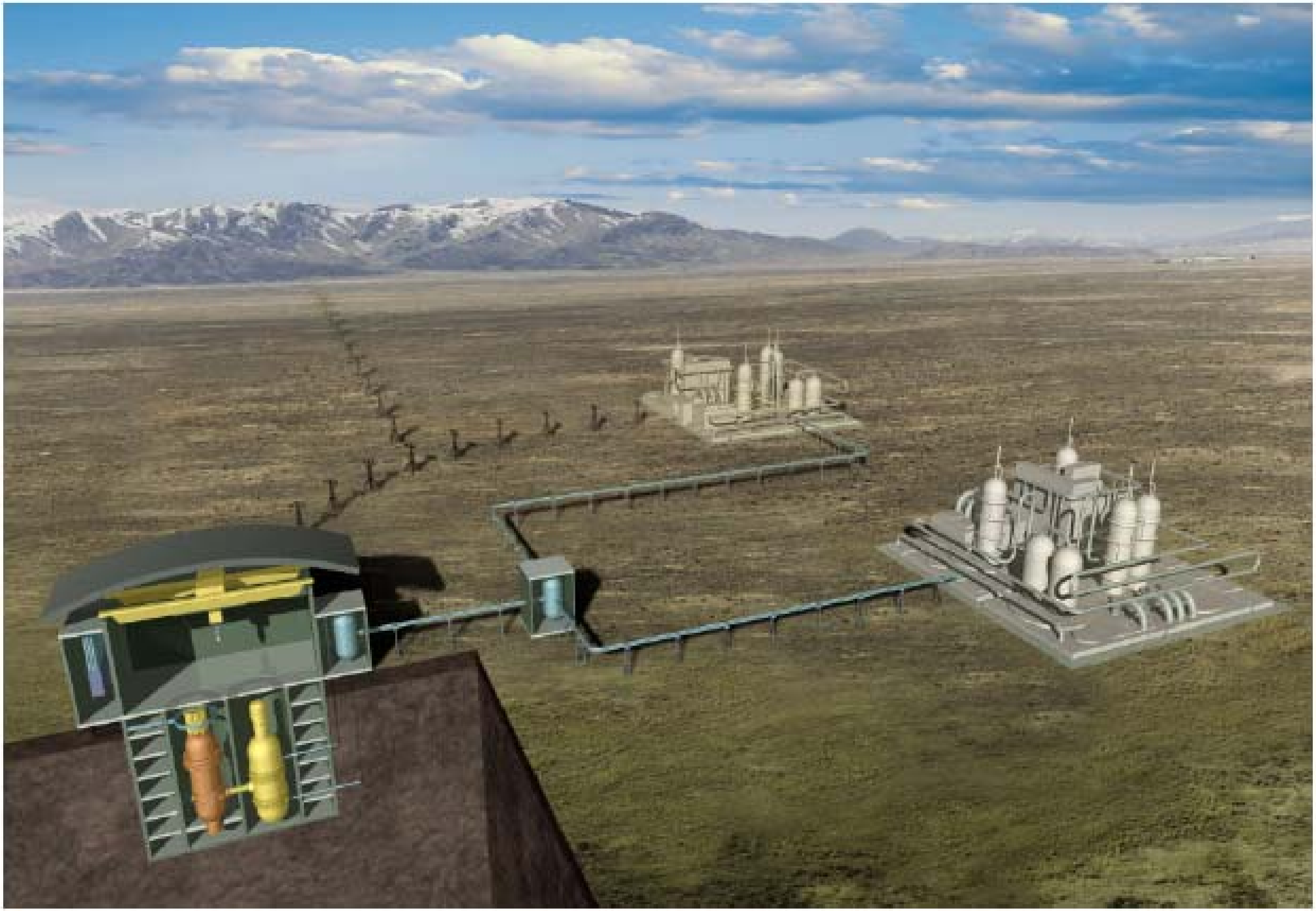


Co-Production of Hydrogen and Electricity



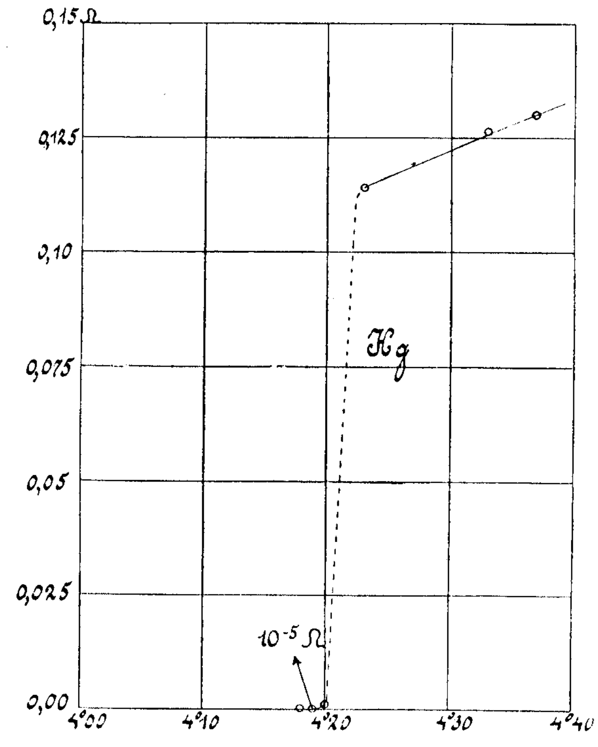
Source: INEL & General Atomics

Nuclear "Hydricity" Production Farm

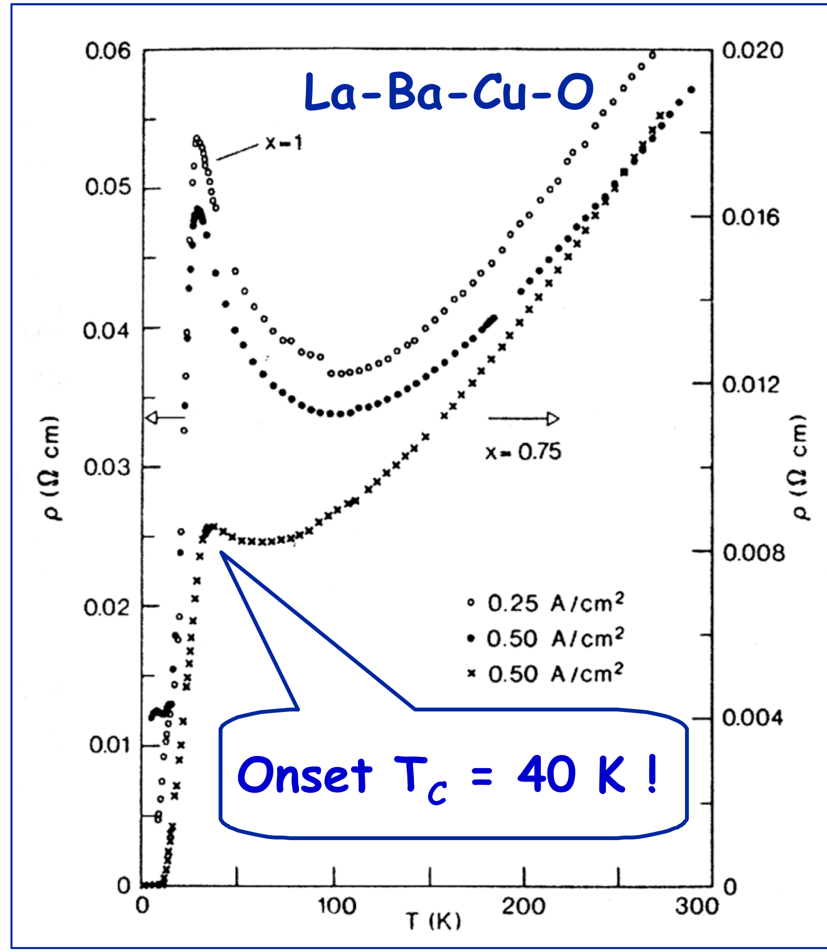


Source: General Atomics

The Discoveries

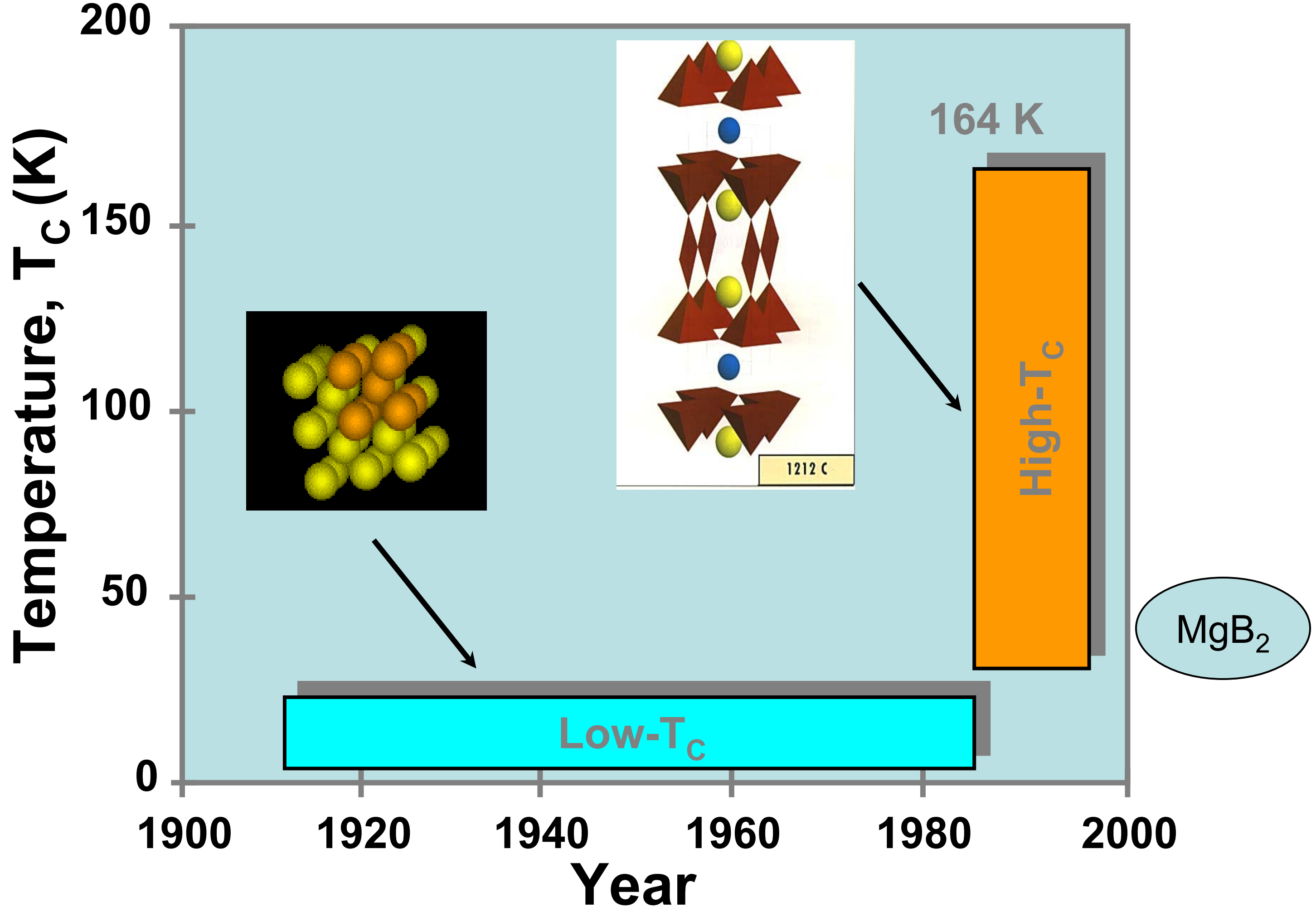


Leiden, 1914

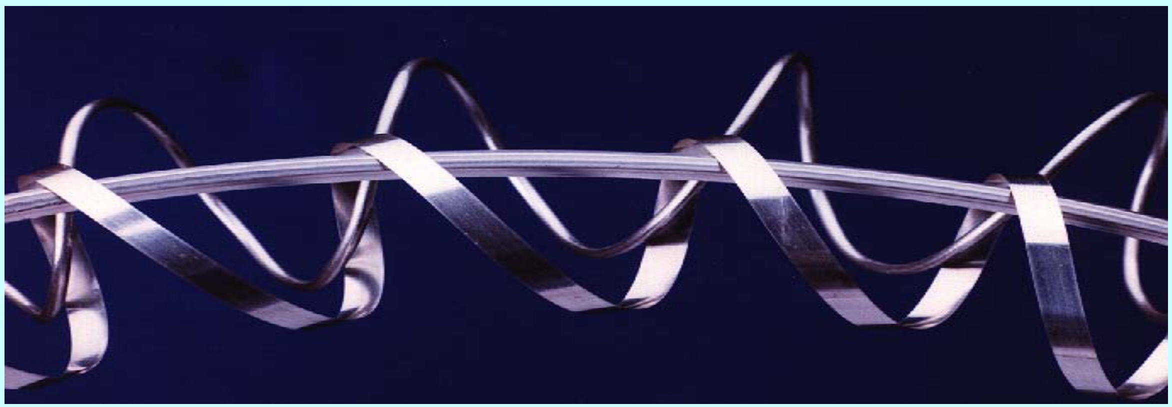


Zürich, 1986

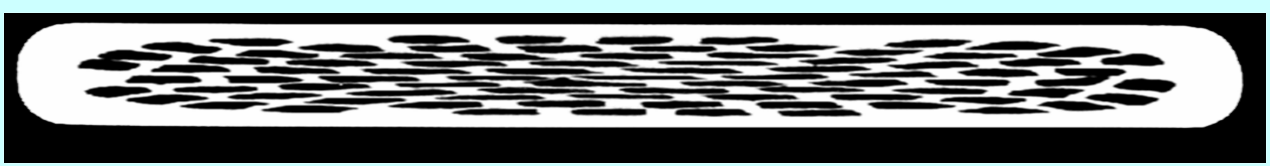
T_C vs Year: 1991 - 2001



HTSC Wire Can Be Made!



↑ ***But it's 70% silver!***



Finished Cable

Reading Assignment

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6. Proceedings, SuperGrid Workshop, 2002

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1967: SC Cable Proposed!

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

R. L. GARWIN AND J. MATISOO

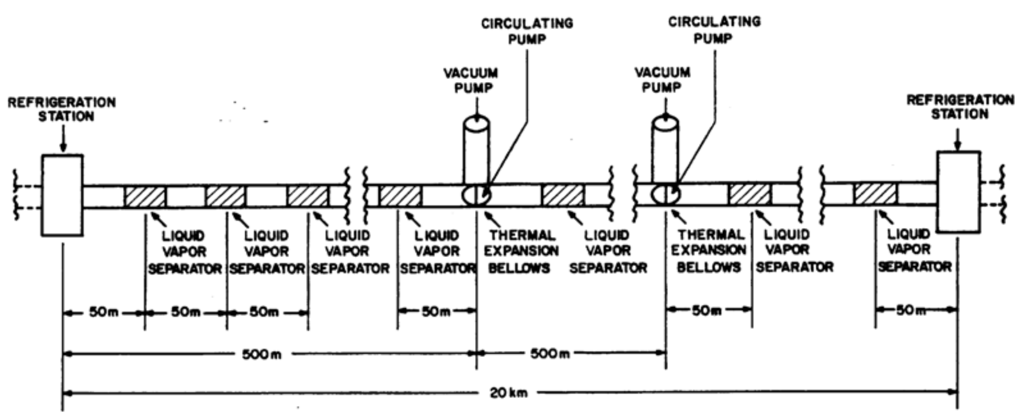


Fig. 2. A 20-km module of the 1000-km, 100-GW line.

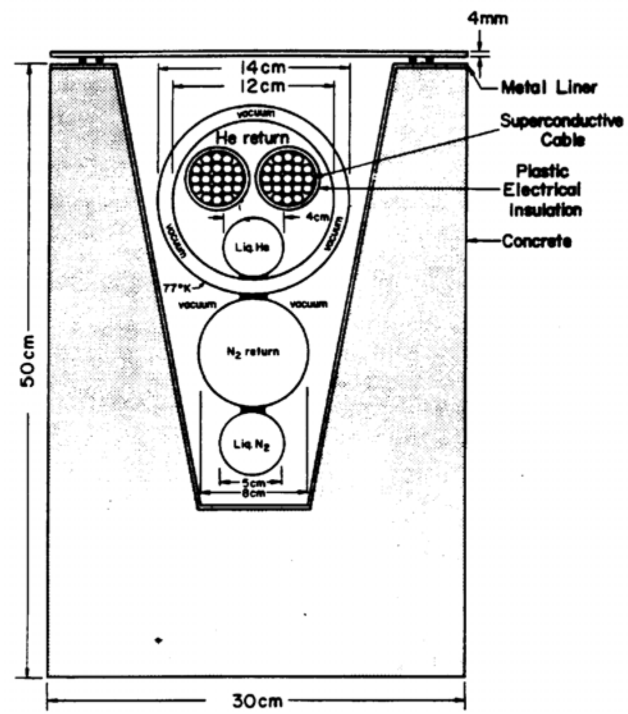
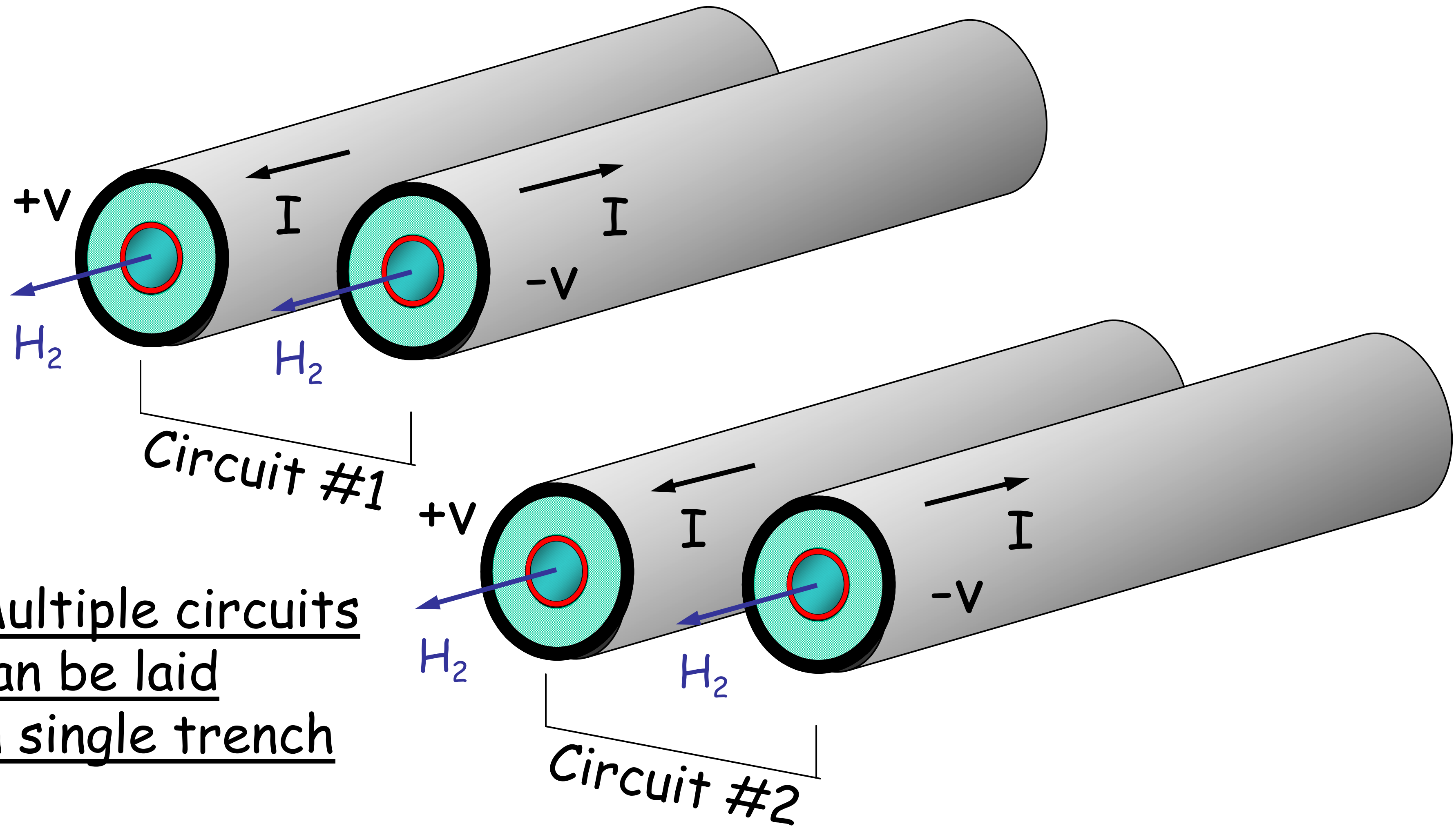


Fig. 1. Cross section of the 100-GW line.

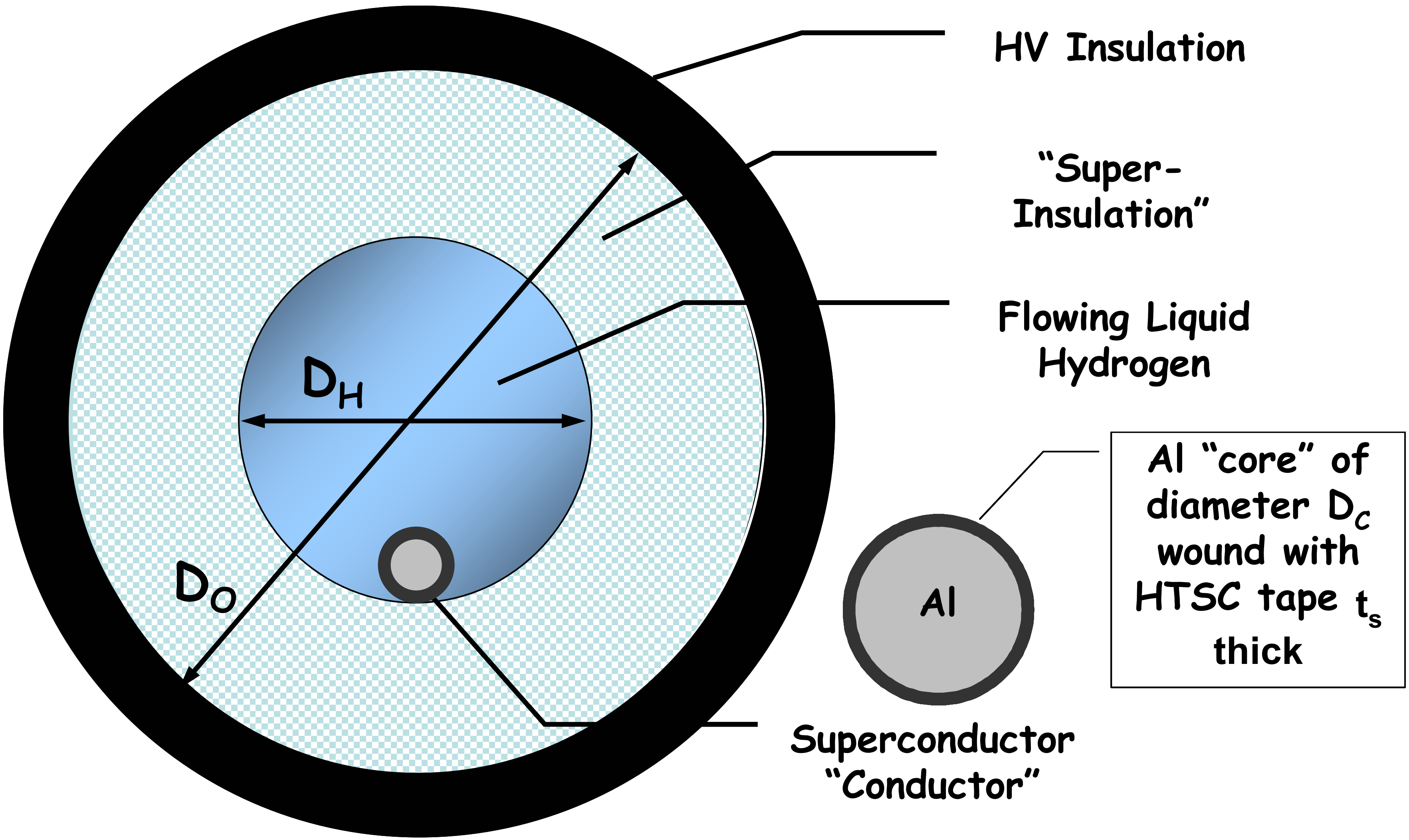
100 GW dc, 1000 km !

"Hydricity" SuperCables



Multiple circuits
can be laid
in single trench

SuperCable


HV Insulation
"Super-
Insulation"
Flowing Liquid
Hydrogen
D_H
D_O
Al
Al "core" of
diameter D_C
wound with
HTSC tape t_s
thick
Superconductor
"Conductor"

Power Flows

Electricity

$P_{SC} = 2|V|IA_{SC}$, where

P_{SC} = Electric power flow
V = Voltage to neutral (ground)
I = Supercurrent
A_{SC} = Cross-sectional area of superconducting annulus

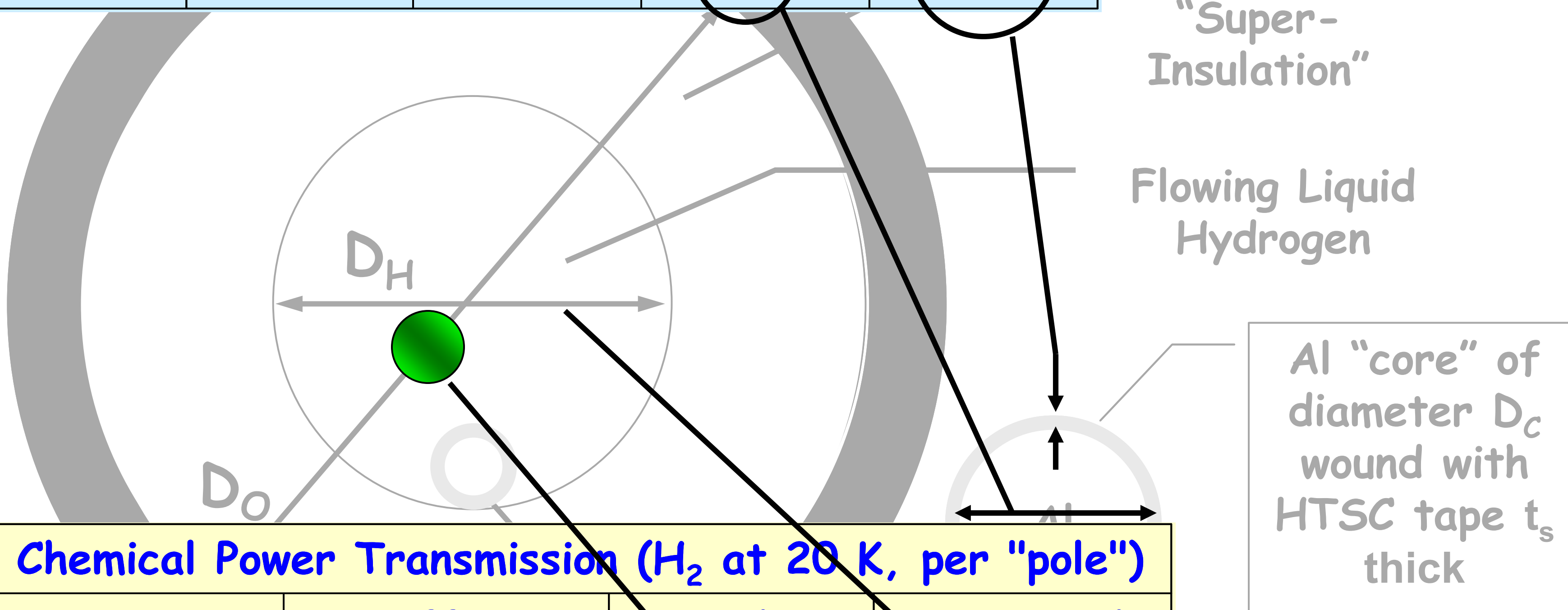
Hydrogen

$P_{H2} = 2(Q\rho vA)_{H2}$, where

P_{H2} = Chemical power flow
Q = Gibbs H_2 oxidation energy (2.46 eV per mol H_2)
ρ = H_2 Density
v = H_2 Flow Rate
A = Cross-sectional area of H_2 cryotube

Power Flows: 5 GW_e/10 GW_{th}

Electrical Power Transmission (+/- 25 kV)				
Power (MW_e)	Current (A)	HTS J_C (A/cm^2)	D_C (cm)	t_S (cm)
5,000	100,000	25,000	3.0	0.38



Chemical Power Transmission (H_2 at 20 K, per "pole")			
Power (MW_{th})	D_H-effective (cm)	H_2 Flow (m/s)	D_H-actual (cm)
5,000	40	4.76	45.3

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_H = 45.3 cm

W_R = 16.3 W/m

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

n = number of layers = 10

Net Heat In-Leak Due to Radiation = 1.8 W/m

Fluid Friction Losses

$$p_{loss} = \lambda\ (l / d_h)\ (\rho\ v^2 / 2)$$

where

p_{loss} = pressure loss (Pa, N/m^2)

λ = friction coefficient

l = length of duct or pipe (m)

d_h = hydraulic diameter (m)

$$W_{loss} = M\ P_{loss} / \rho\ ,$$

Where M **= mass flow per unit length**
P_{loss} **= pressure loss per unit length**
ρ **= fluid density**

$$1 / \lambda^{1/2} = -2{,}0 \log_{10} [\ (2{,}51 / (Re\ \lambda^{1/2})) + (\varepsilon / d_h\ ) / 3{,}72\ ]$$

Fluid	Re	ε(mm)	D_H (cm)	v (m/s)	ΔP (atm/10 km)	Power Loss (W/m)
H (20K)	2.08×10^6	0.015	45.3	4.76	2.0	3.2

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

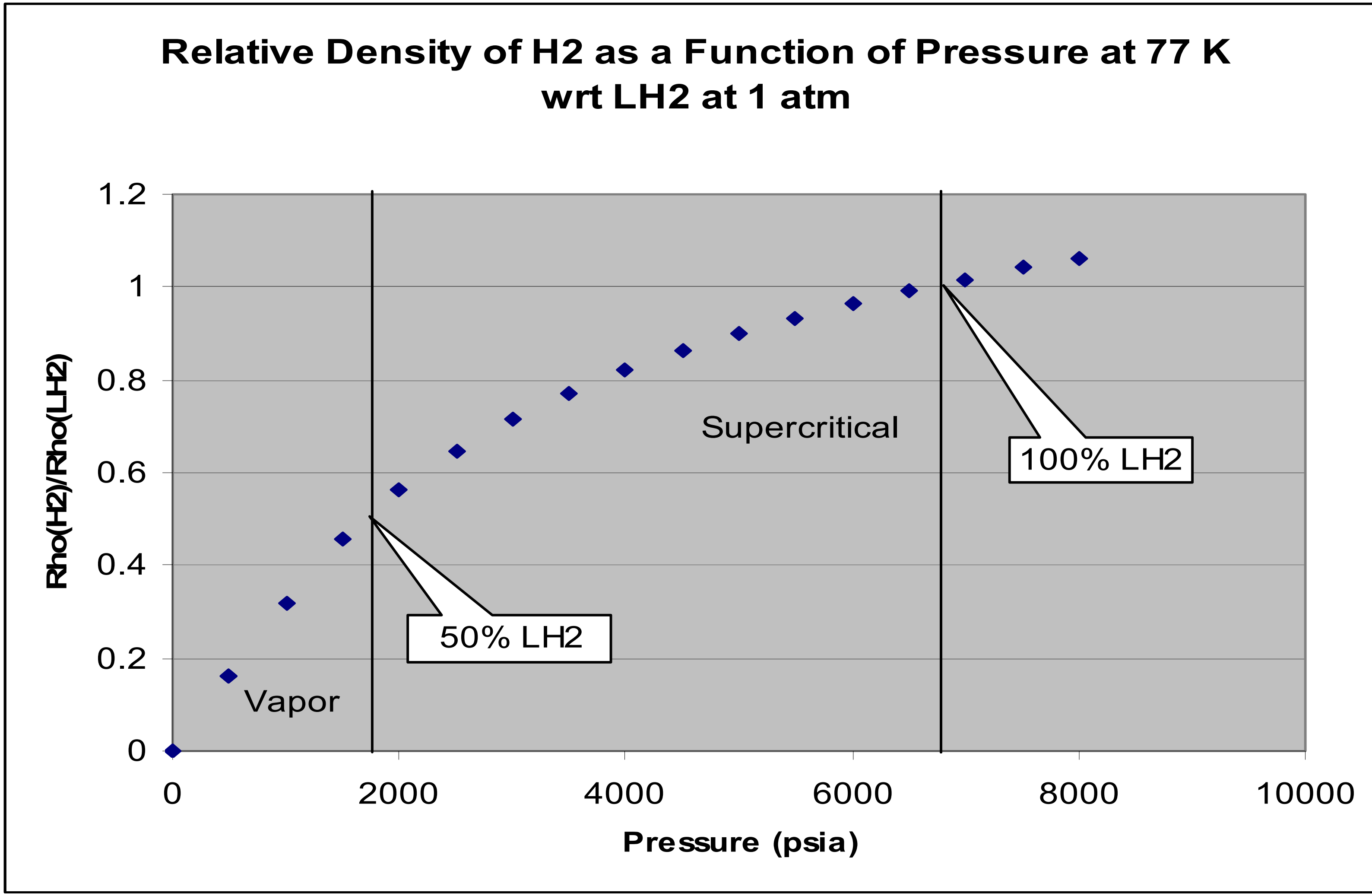
SuperCable Losses (W/M)					K/10km
Radiative	**Friction**	**ac Losses**	**Conductive**	**Total**	**dT/dx**
1.8	**3.2**	**1**	**1**	**7**	**10^{-2}**

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

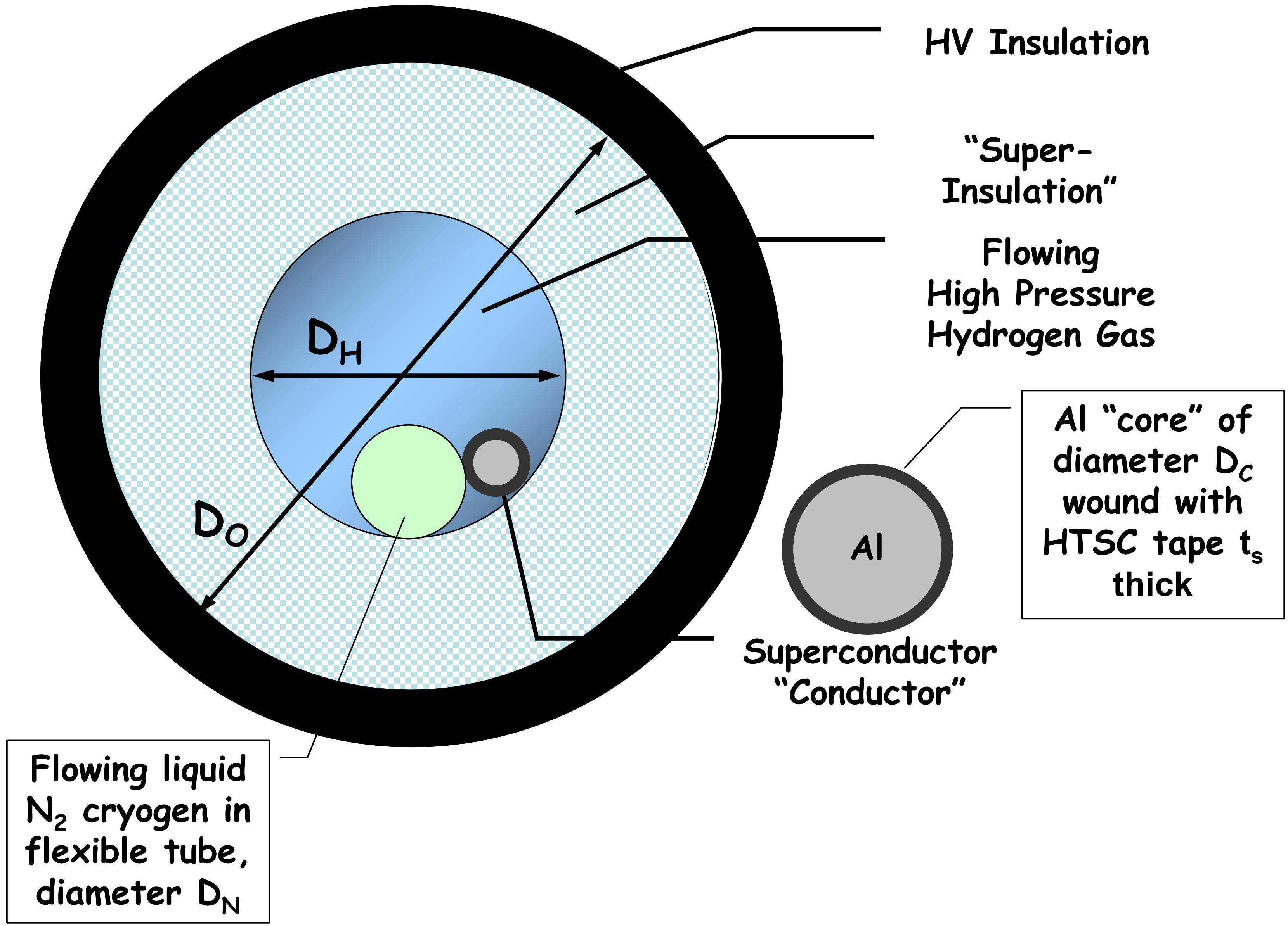
One Raccoon Mountain = 13,800 cubic meters of LH2

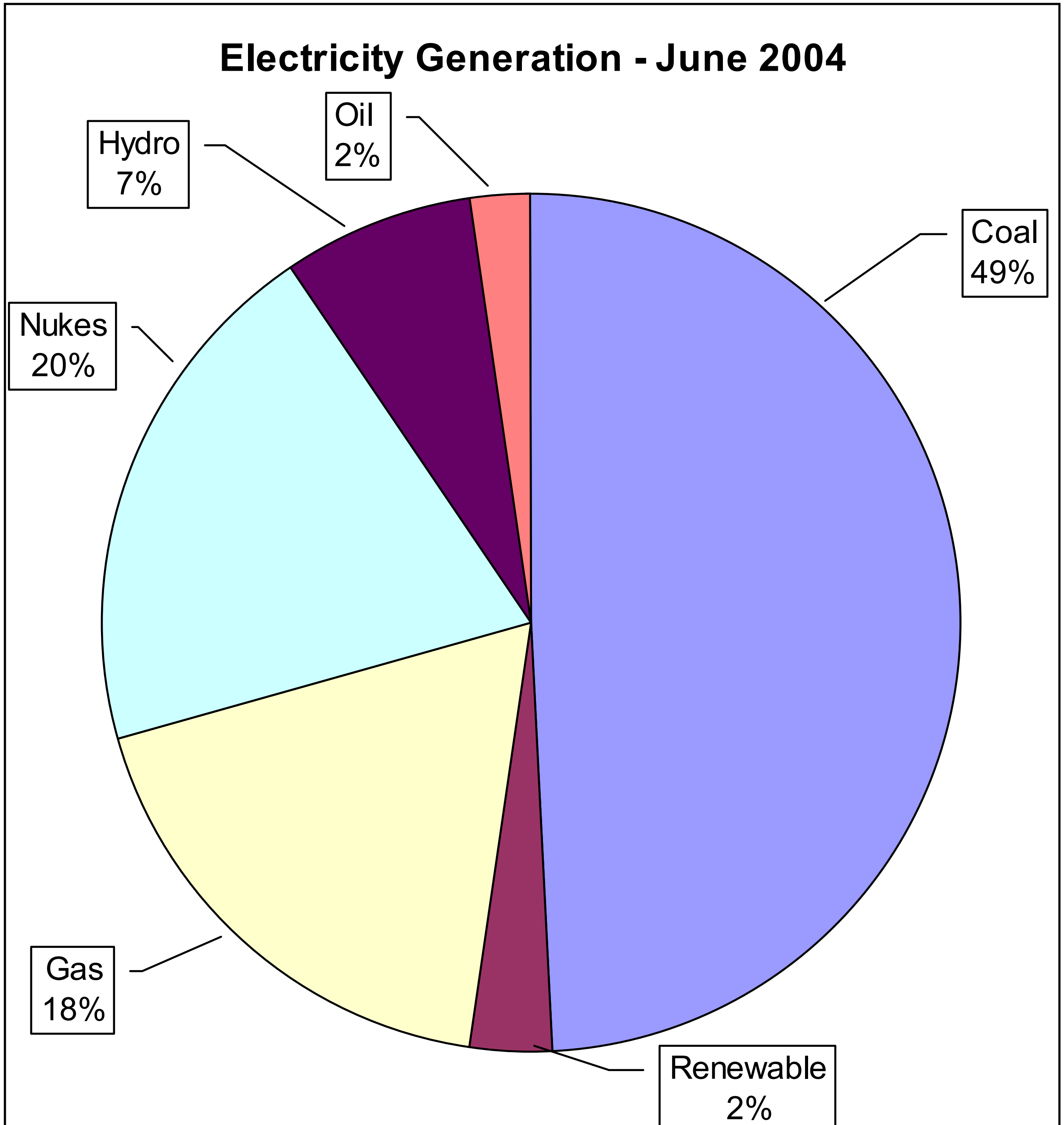
LH_2 in 45 cm diameter, 12 mile bipolar SuperCable
= Raccoon Mountain



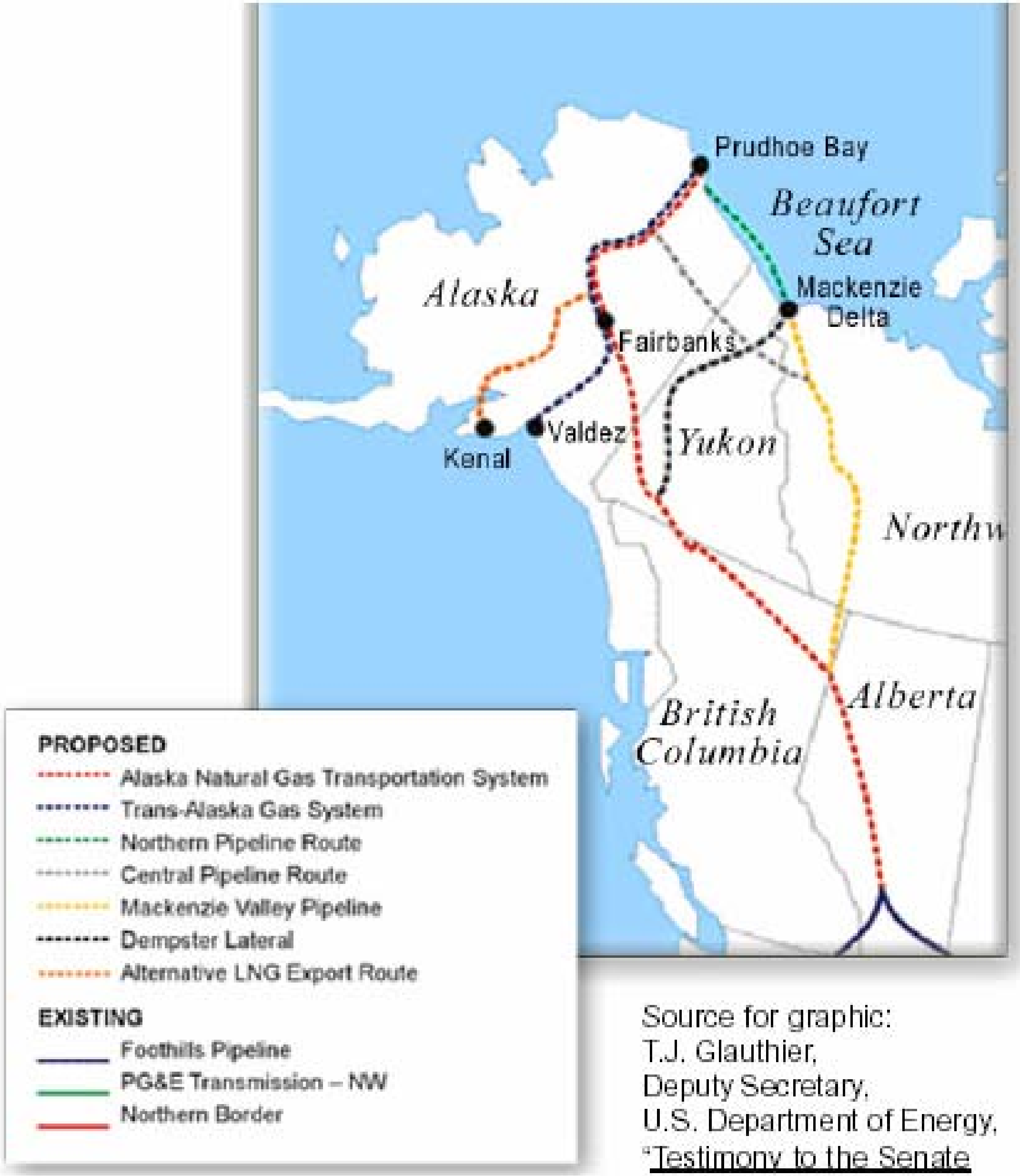
H_2 Gas at 77 K and 1850 psia has 50% of the energy content of liquid H_2 and 100% at 6800 psia

“Hybrid” SuperCable

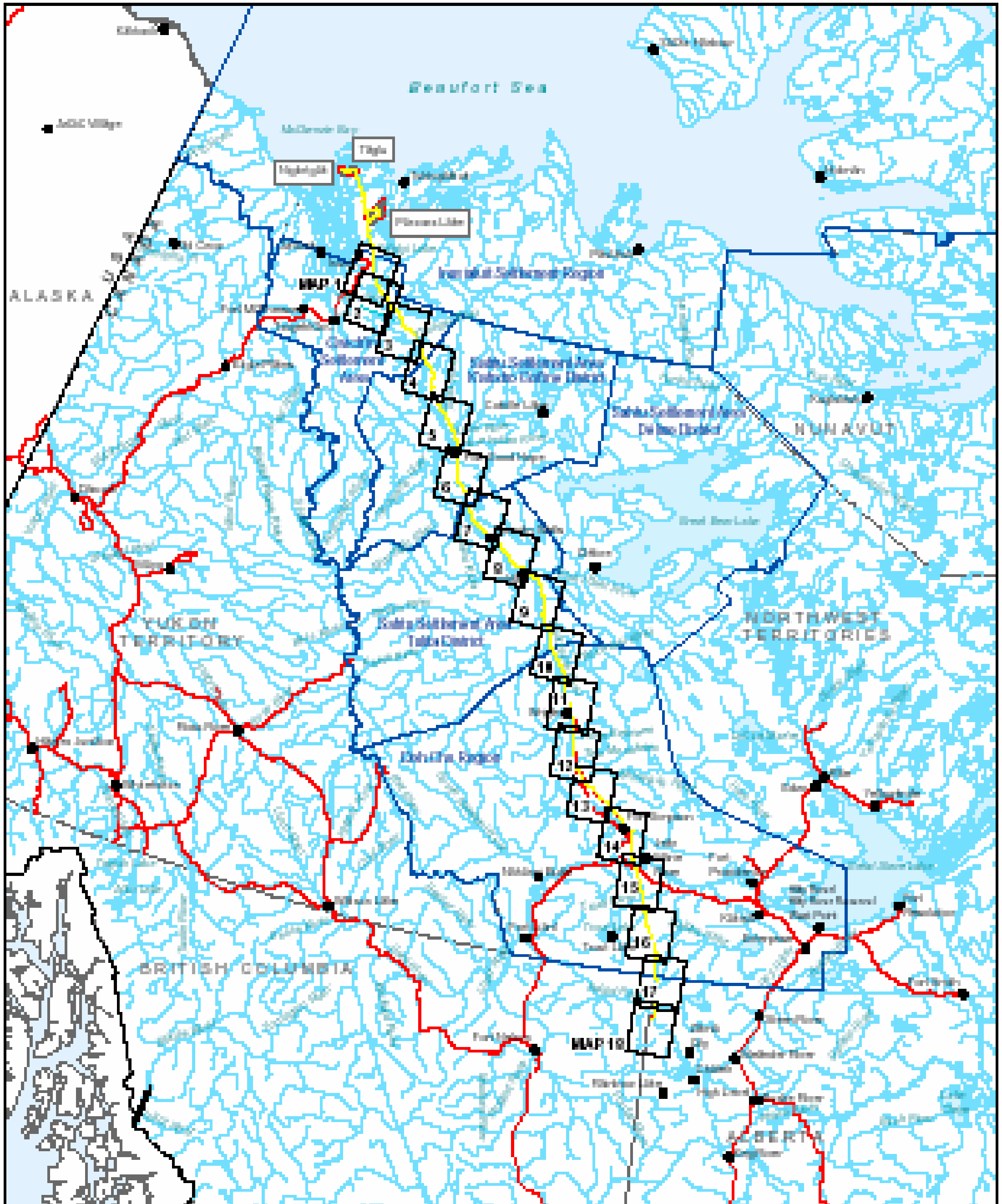



Electricity Generation - June 2004
Oil 2%
Hydro 7%
Coal 49%
Nukes 20%
Gas 18%
Renewable 2%

Al-Can Gas Pipeline Proposals



Source for graphic:
T.J. Glauthier,
Deputy Secretary,
U.S. Department of Energy,
"Testimony to the Senate Committee on Energy and Natural Resources"
(September 14, 2000).

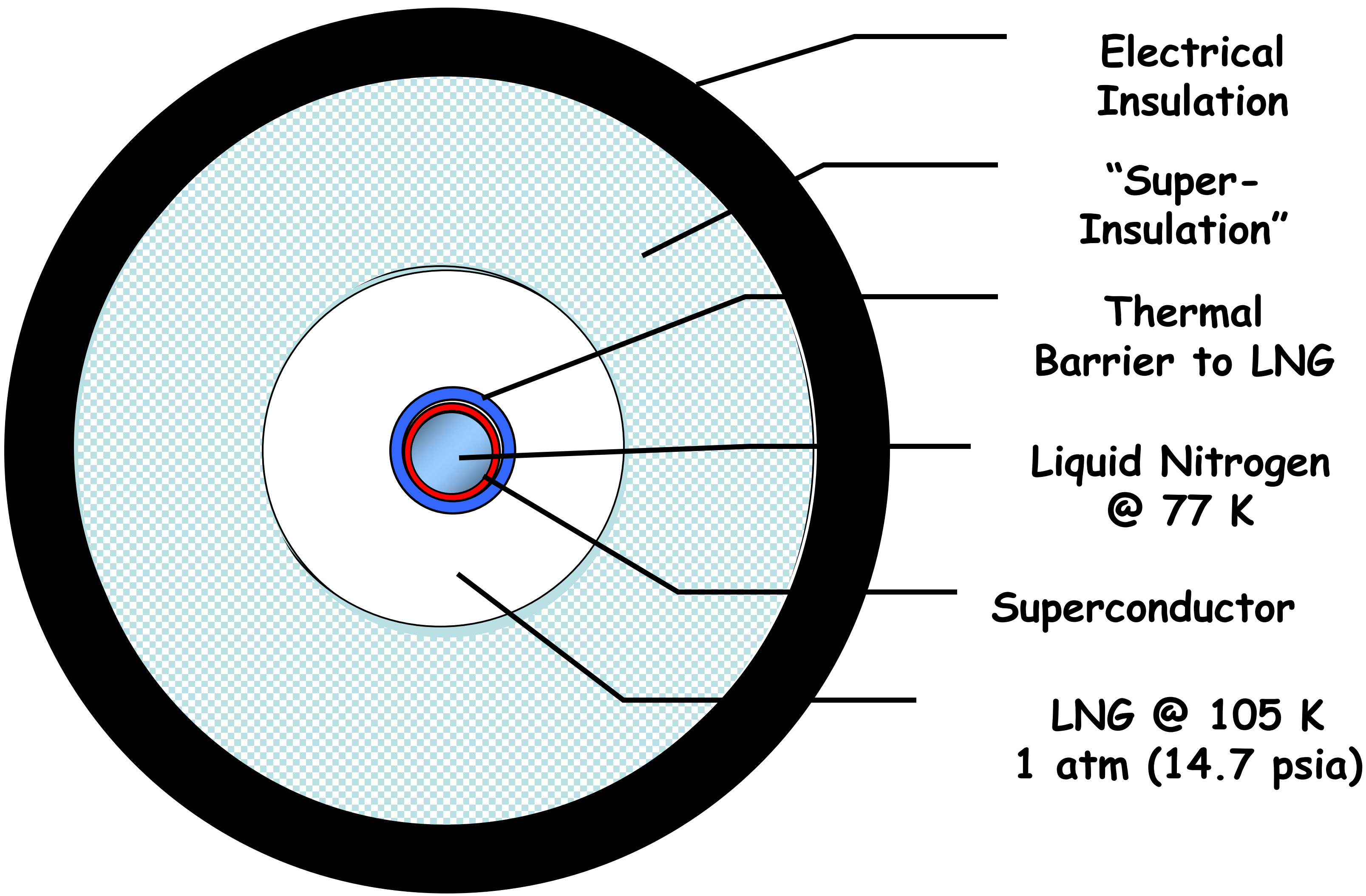


Mackenzie Valley Pipeline

1300 km

18 GW-thermal

LNG SuperCable



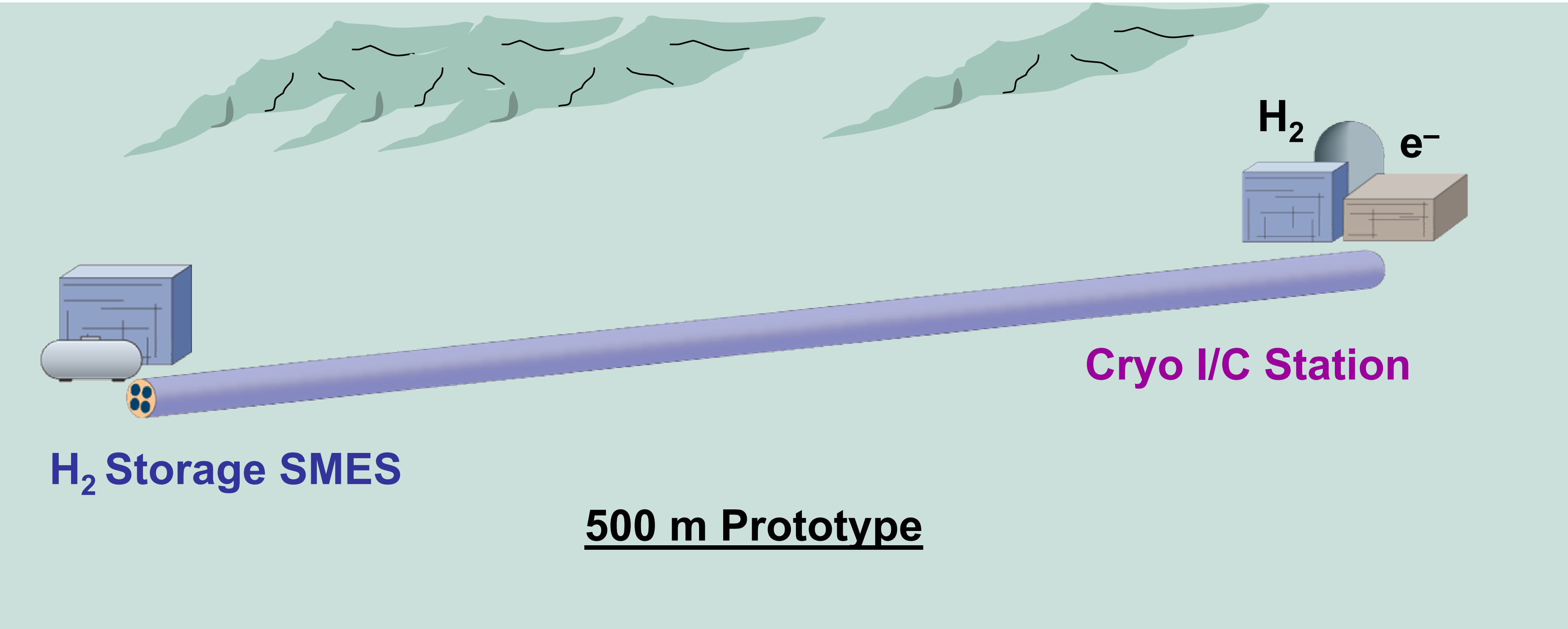
Electrical Issues

- Voltage – current tradeoffs
  - "Cold" vs "Warm" Dielectric
- AC interface (phases)
  - Generate dc? Multipole, low rpm units (aka hydro)
- Ripple suppression
  - Filters
- Cryogenics
  - Pulse Tubes
  - "Cryobreaks"
- Mag Field Forces
- Splices (R = 0?)
- Charge/Discharge cycles (Faults!)
- Power Electronics
  - GTOs vs IGBTs
  - 12" wafer platforms
  - Cryo-Bipolars

Construction Issues

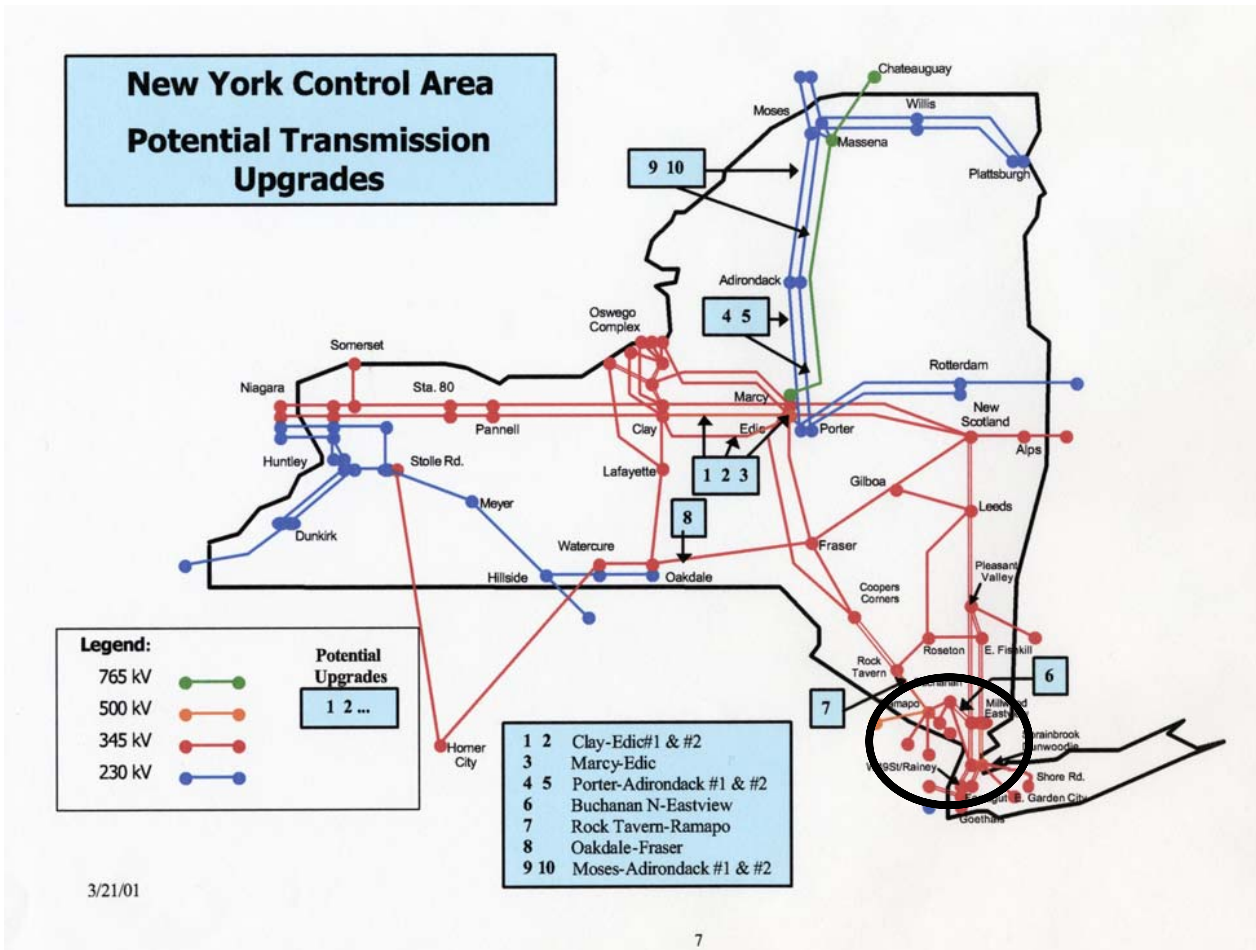
- Pipe Lengths & Diameters (Transportation)
- Coax vs RTD
- Rigid vs Flexible?
- On-Site Manufacturing
  - Conductor winding (3-4 pipe lengths)
  - Vacuum: permanently sealed or actively pumped?
- Joints
  - Superconducting
  - Welds
  - Thermal Expansion (bellows)

SuperCable Prototype Project

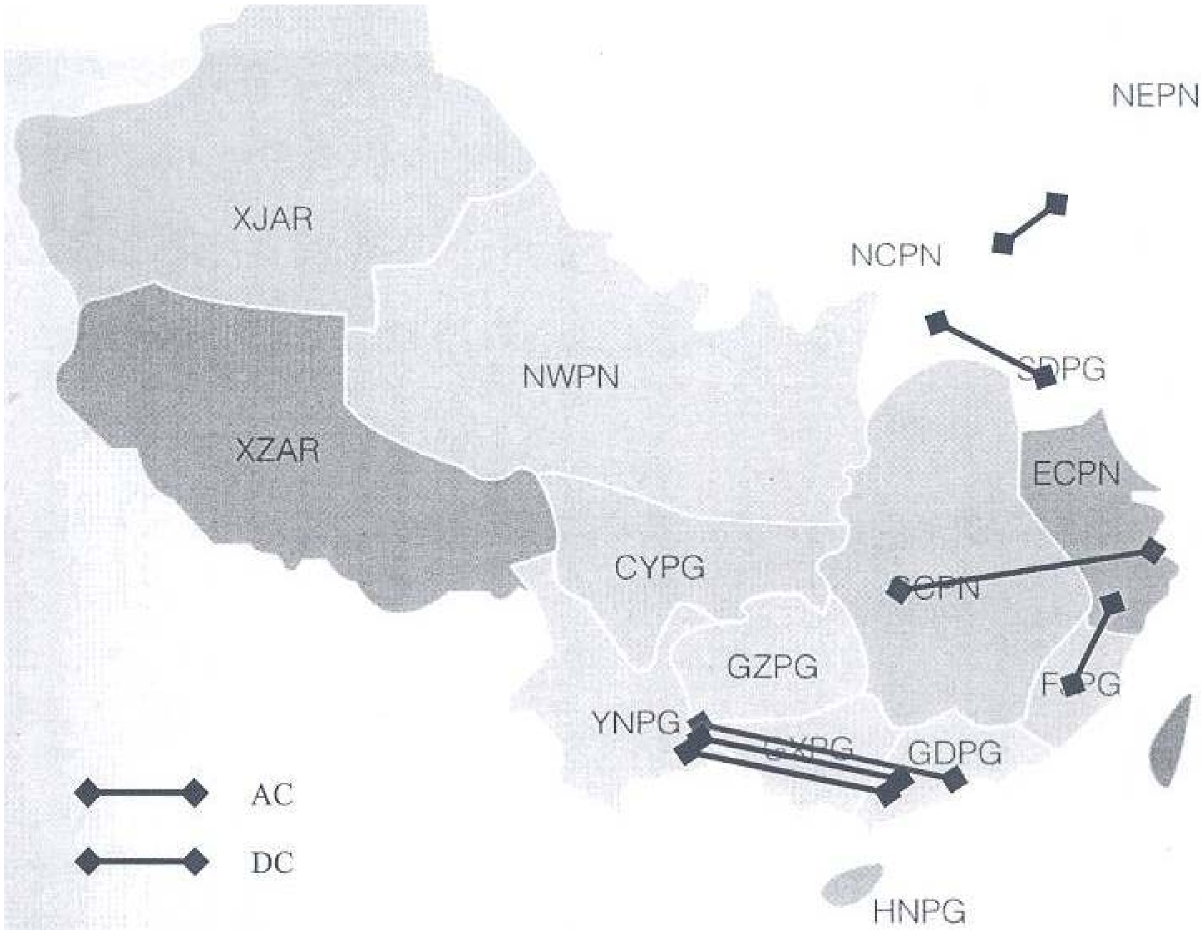


"Appropriate National Laboratory"
2005-09

Regional System Interconnections

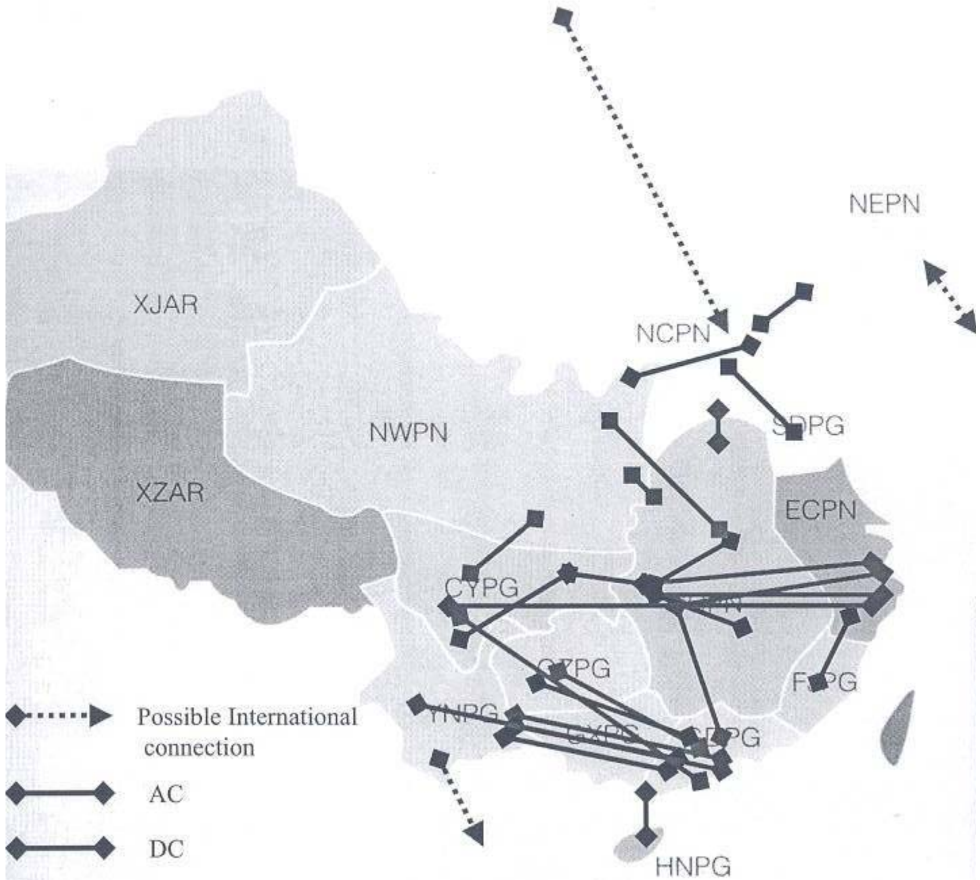


China: Present

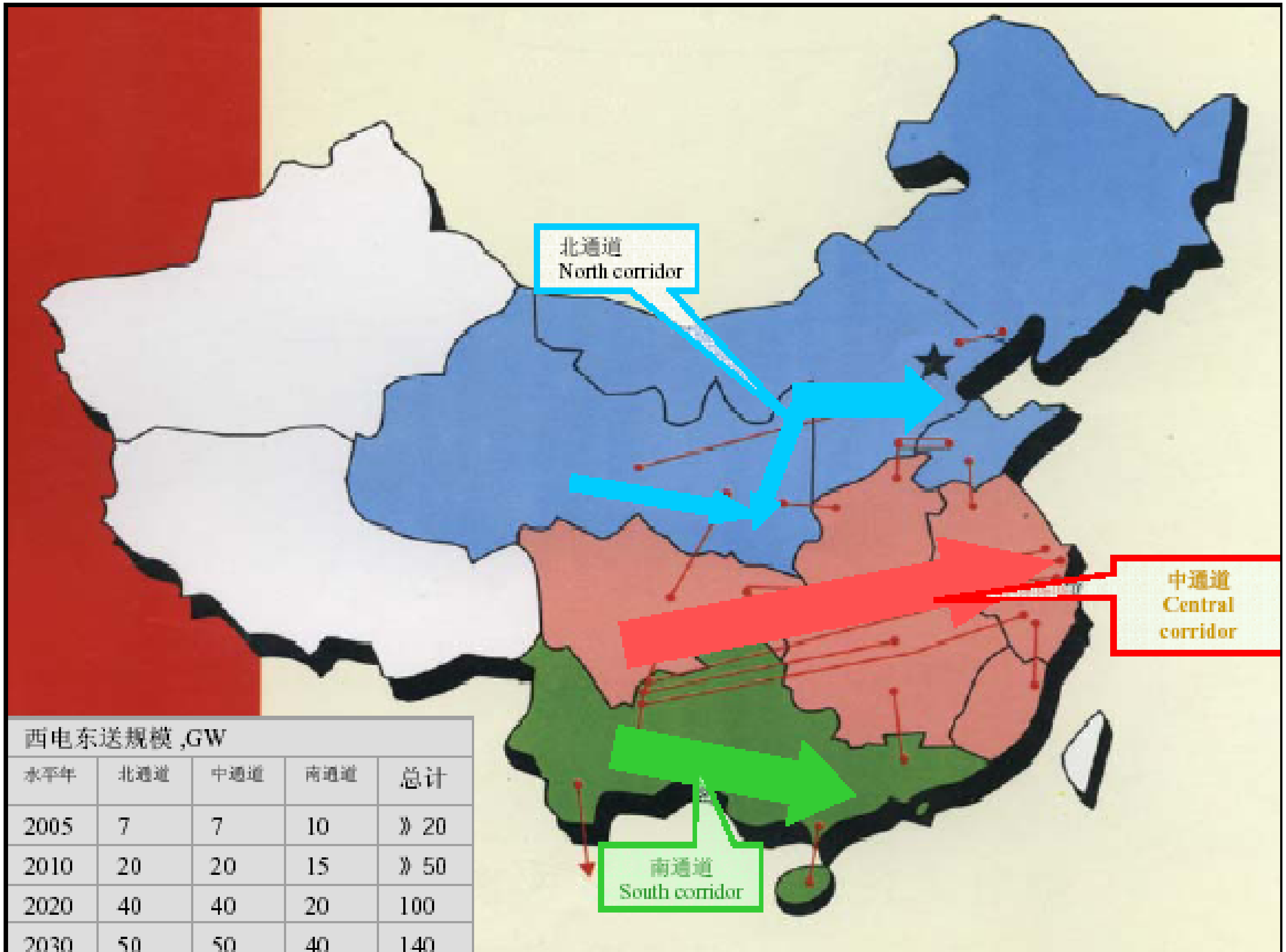


Regional Grids Interconnection in 2001-2002

China: 2015 - 2020



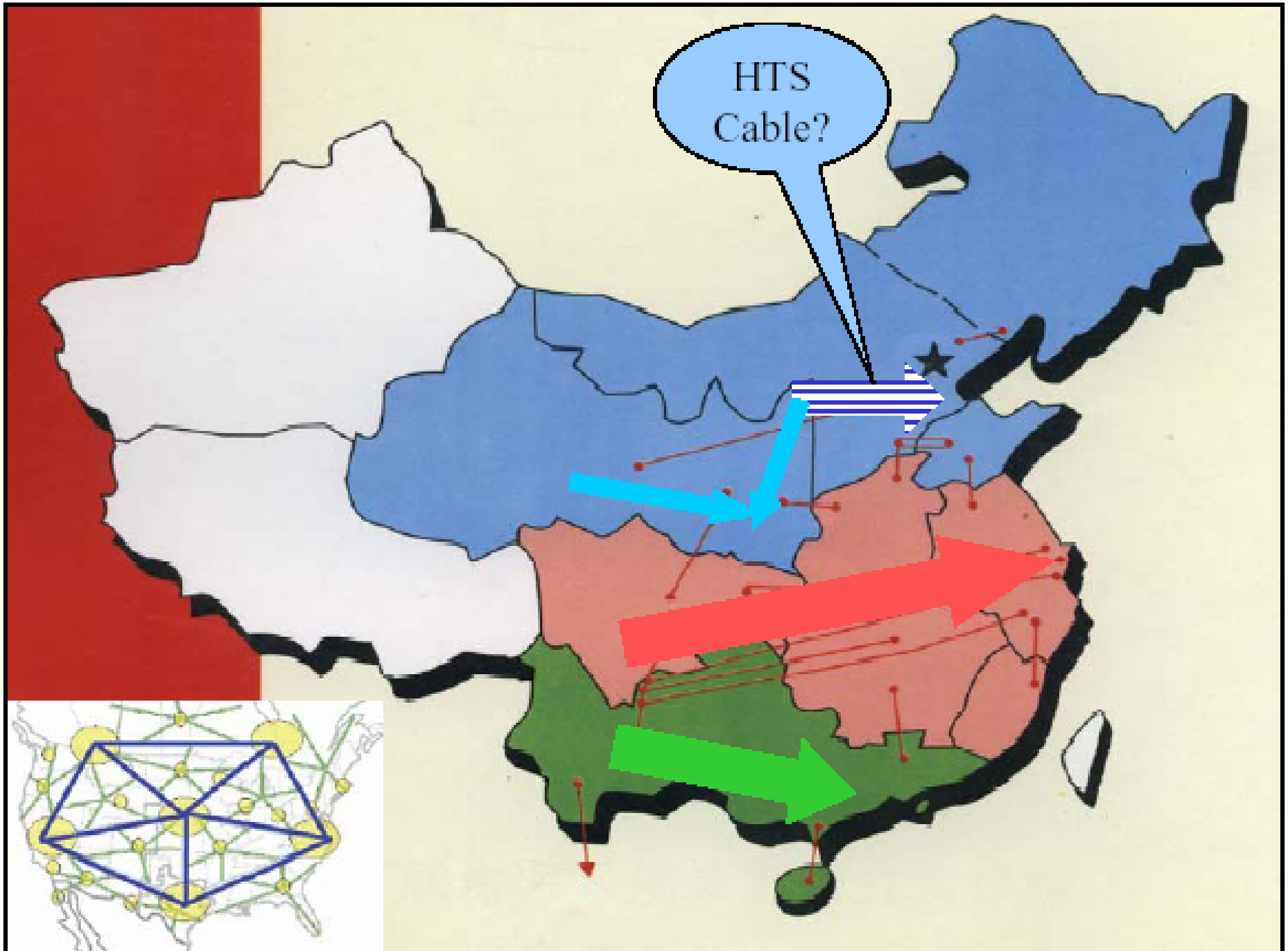
Regional Grids Interconnection in 2015-2020



西电东送规模 ,GW

水平年	北通道	中通道	南通道	总计
2005	7	7	10	》20
2010	20	20	15	》50
2020	40	40	20	100
2030	50	50	40	140

Thanks to Prof. Zheng-He Han



Will China Build the World's First SuperGrid?