Cryo-Delivery Systems for the Co-Transmission of Chemical and Electrical Power

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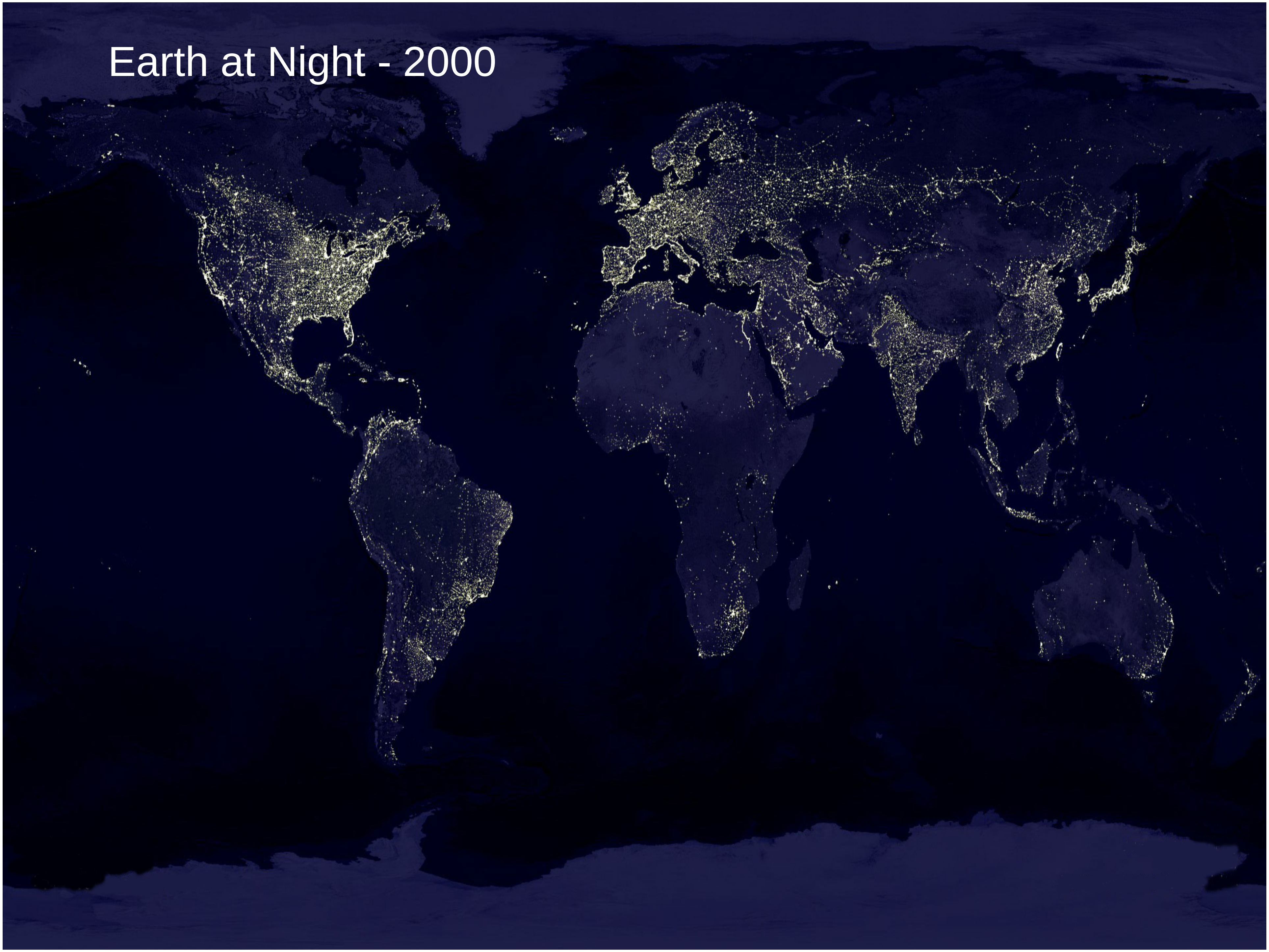
www.w2agz.com/cec-icmc05.htm


Earth at Night - 2000

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

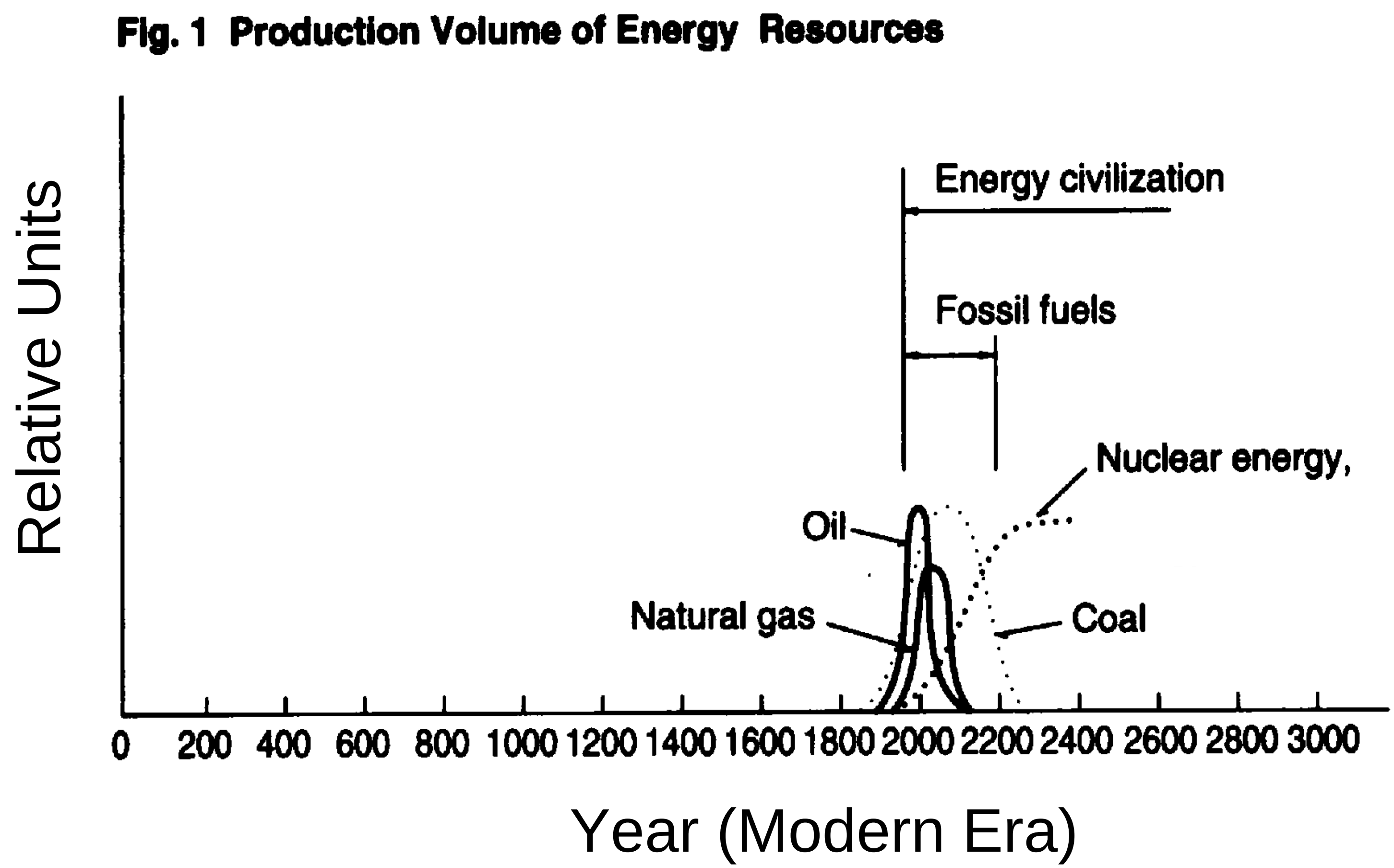
<u>Nuclear/Hydrogen/Superconductivity</u>

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

SuperCities & SuperGrids

SuperCables !

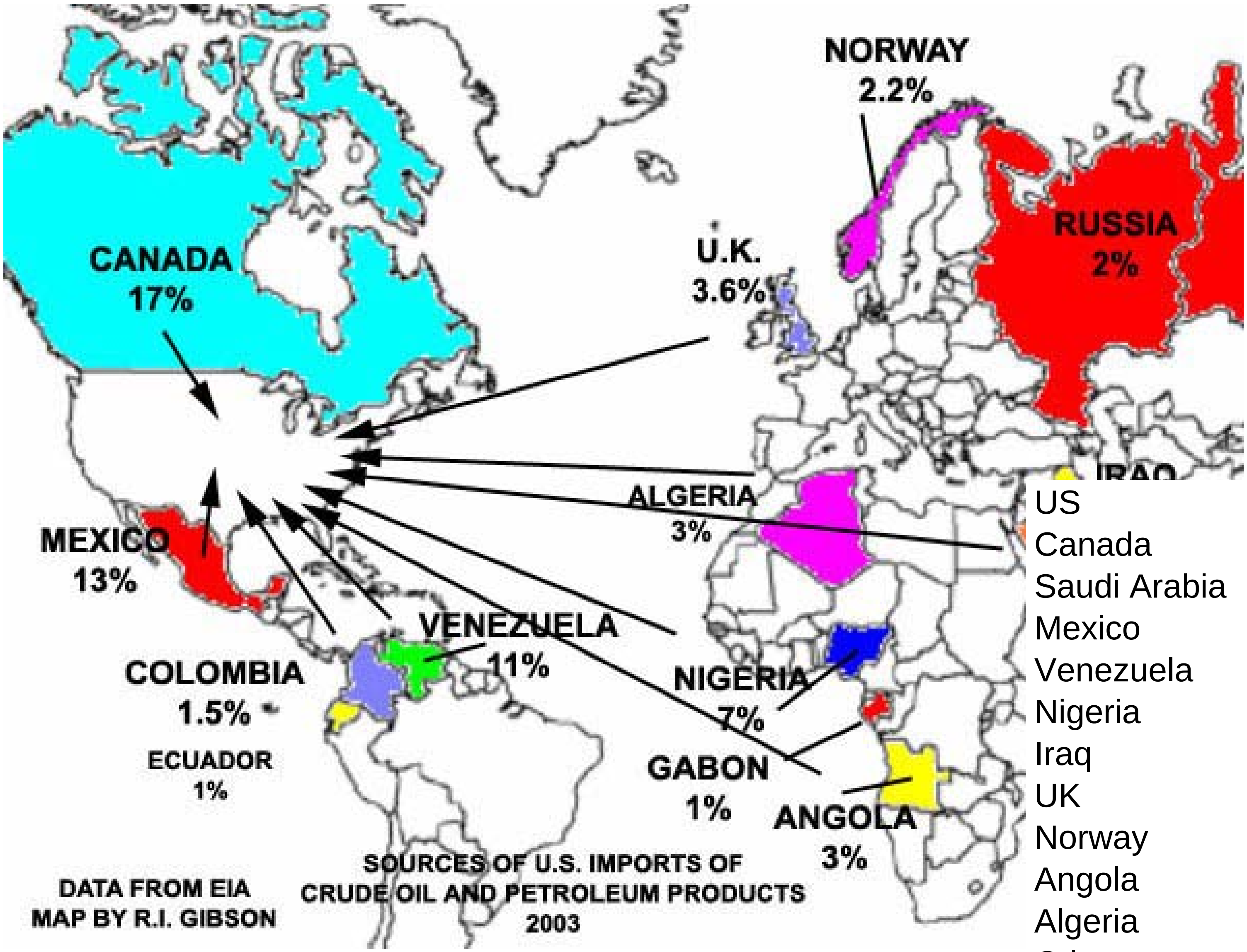
Past & Future Energy Supply



US Energy Consumption (2001)

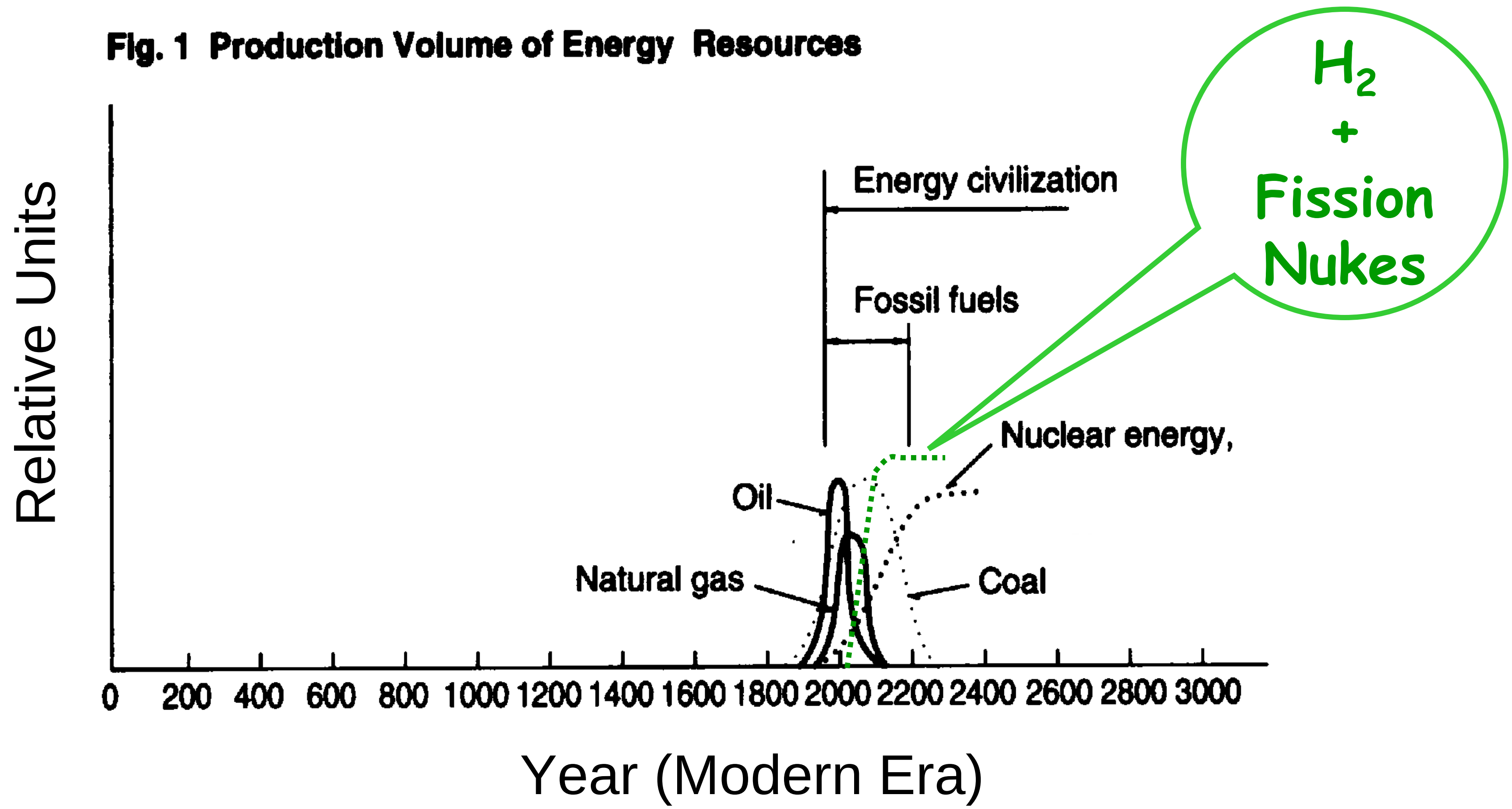
Energy Source	Percentage of total
Petroleum	42%
Coal	24%
Natural Gas	20%
Nuclear	8%
Hydro power	2%
Solar, Wind, etc.	2%

US Oil Imports (2003)

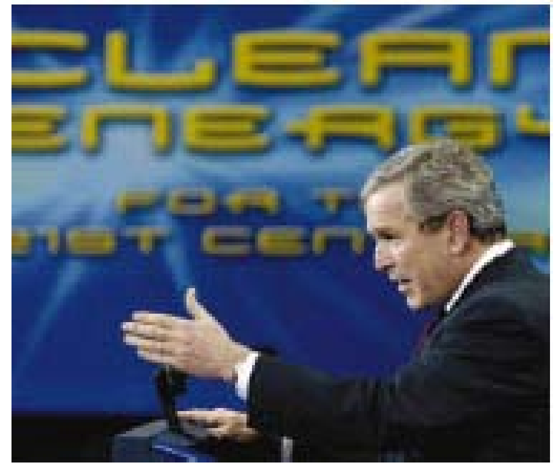


US	39%
Canada	13%
Saudi Arabia	10%
Mexico	10%
Venezuela	9%
Nigeria	4%
Iraq	4%
UK	3%
Norway	3%
Angola	2%
Algeria	2%
Other	2%

Past & Future Energy Supply



The Hydrogen Economy

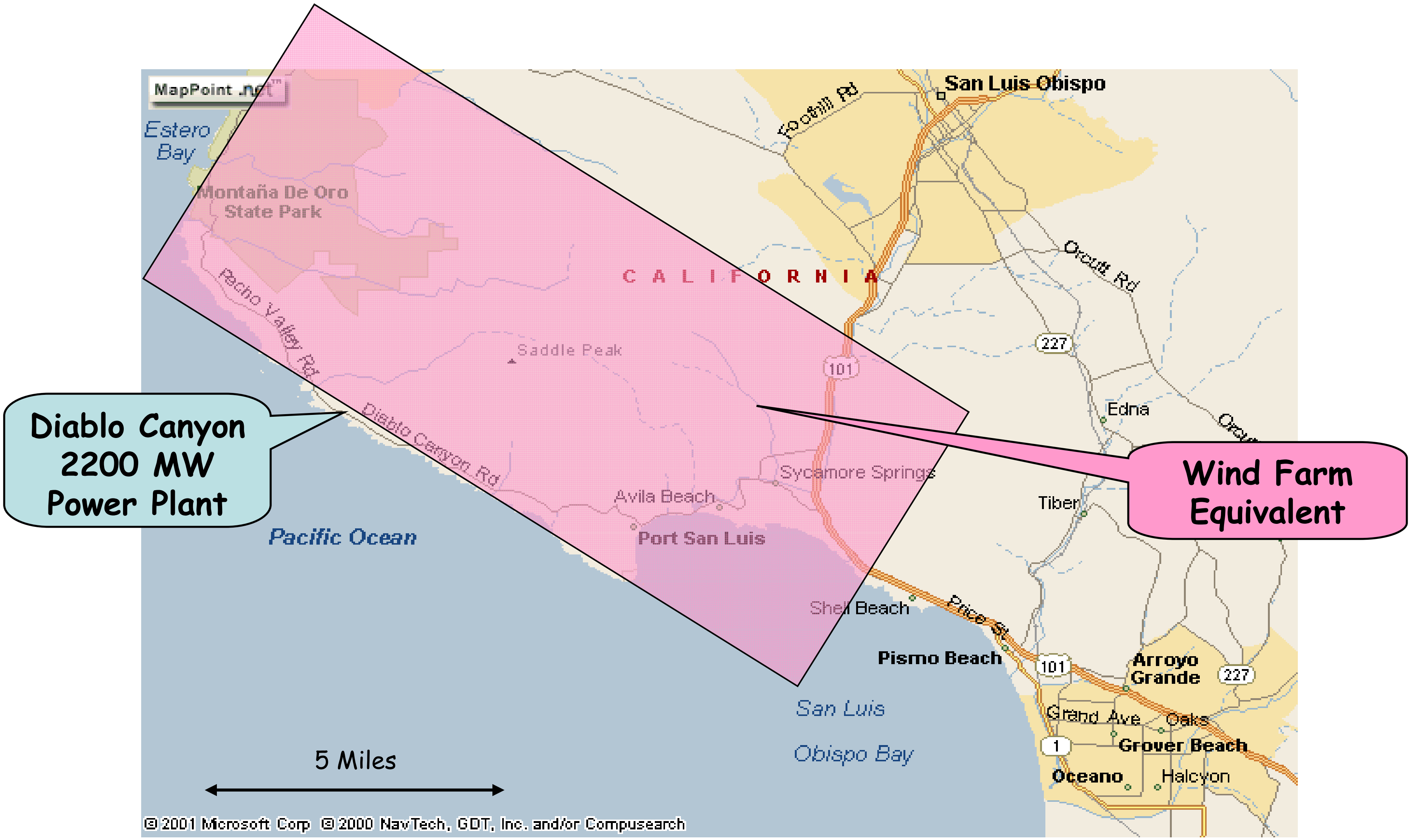


- You have to make it, just like electricity
- Electricity can make H_2, and H_2 can make electricity ($2H_2O \Leftrightarrow 2H_2 + O_2$)
- You have to make a lot of it
- You can make it cold, - 419 F (21 K)

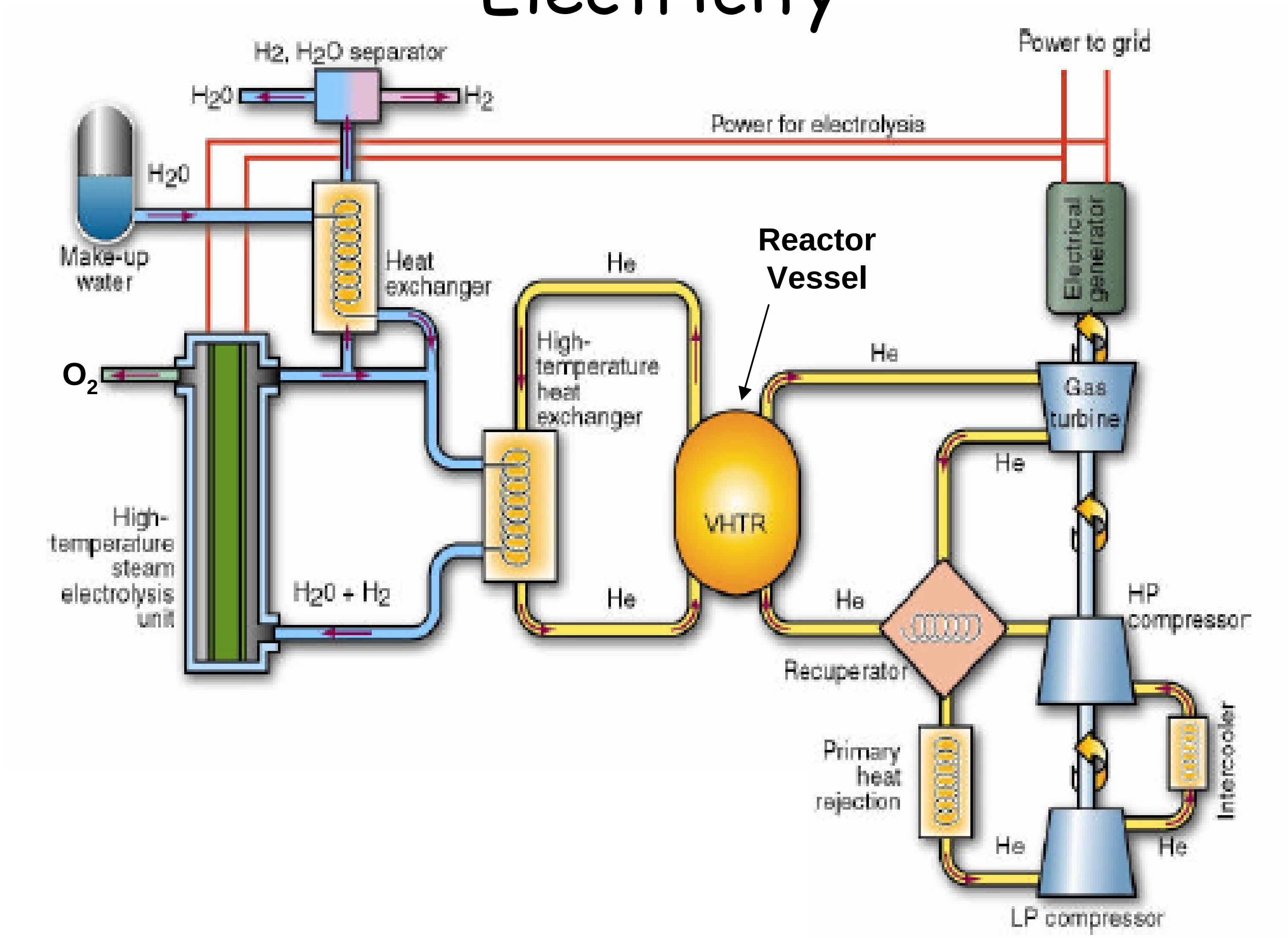
P.M. Grant, "Hydrogen lifts off…with a heavy load," Nature 424, 129 (2003)

Diablo Canyon

California Coast Power

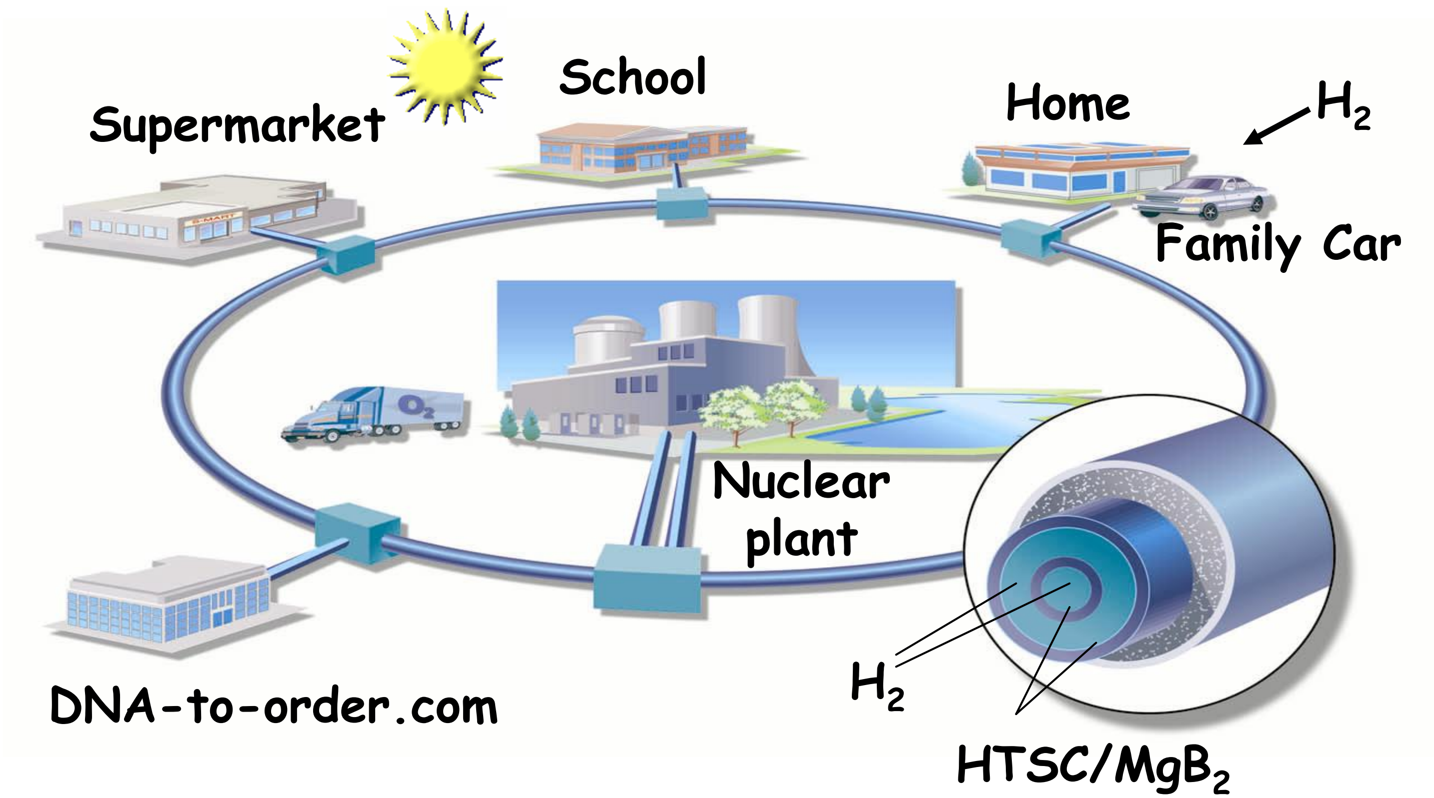


Co-Production of Hydrogen and Electricity



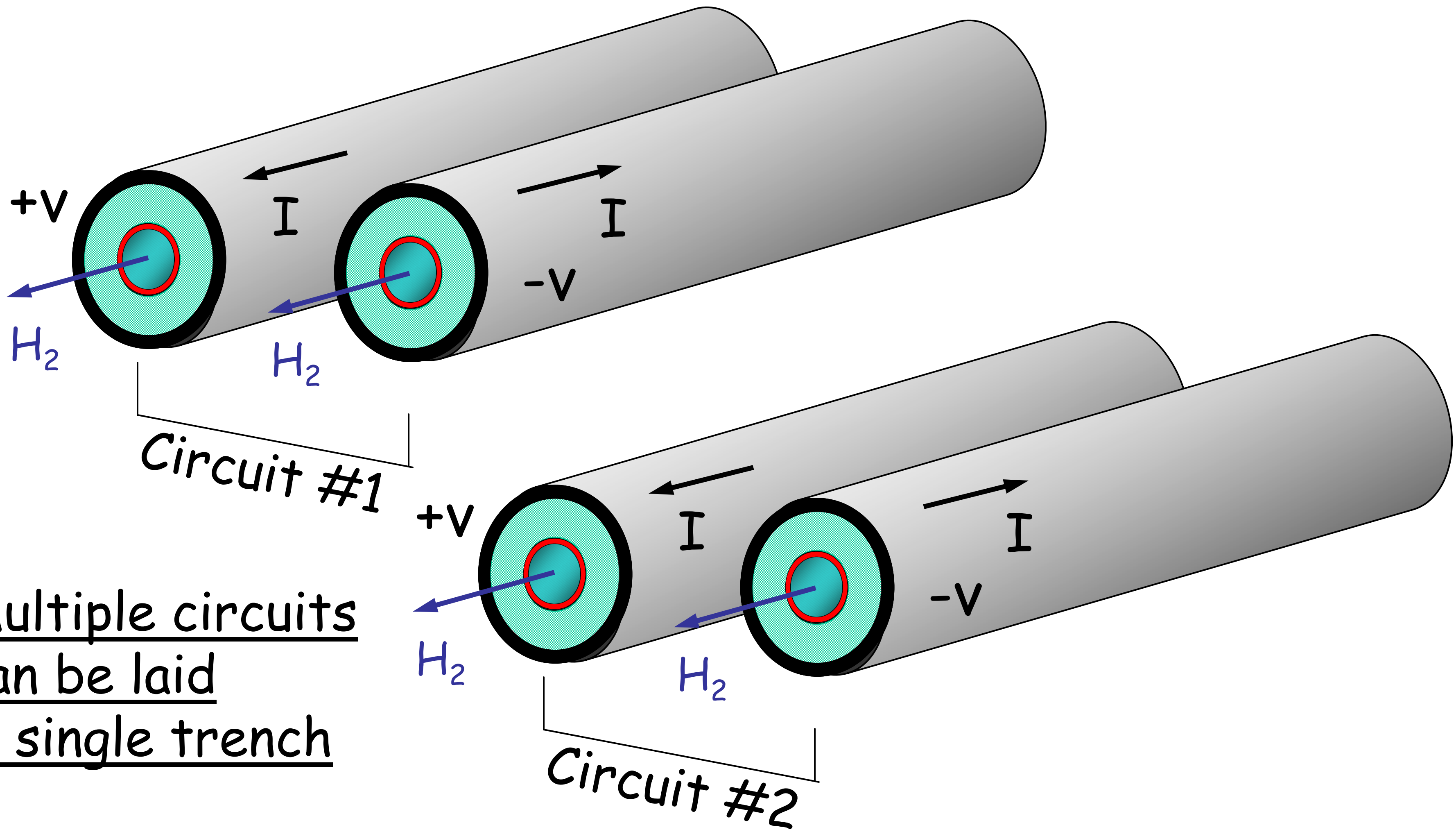
Source: INEL & General Atomics

SuperCity



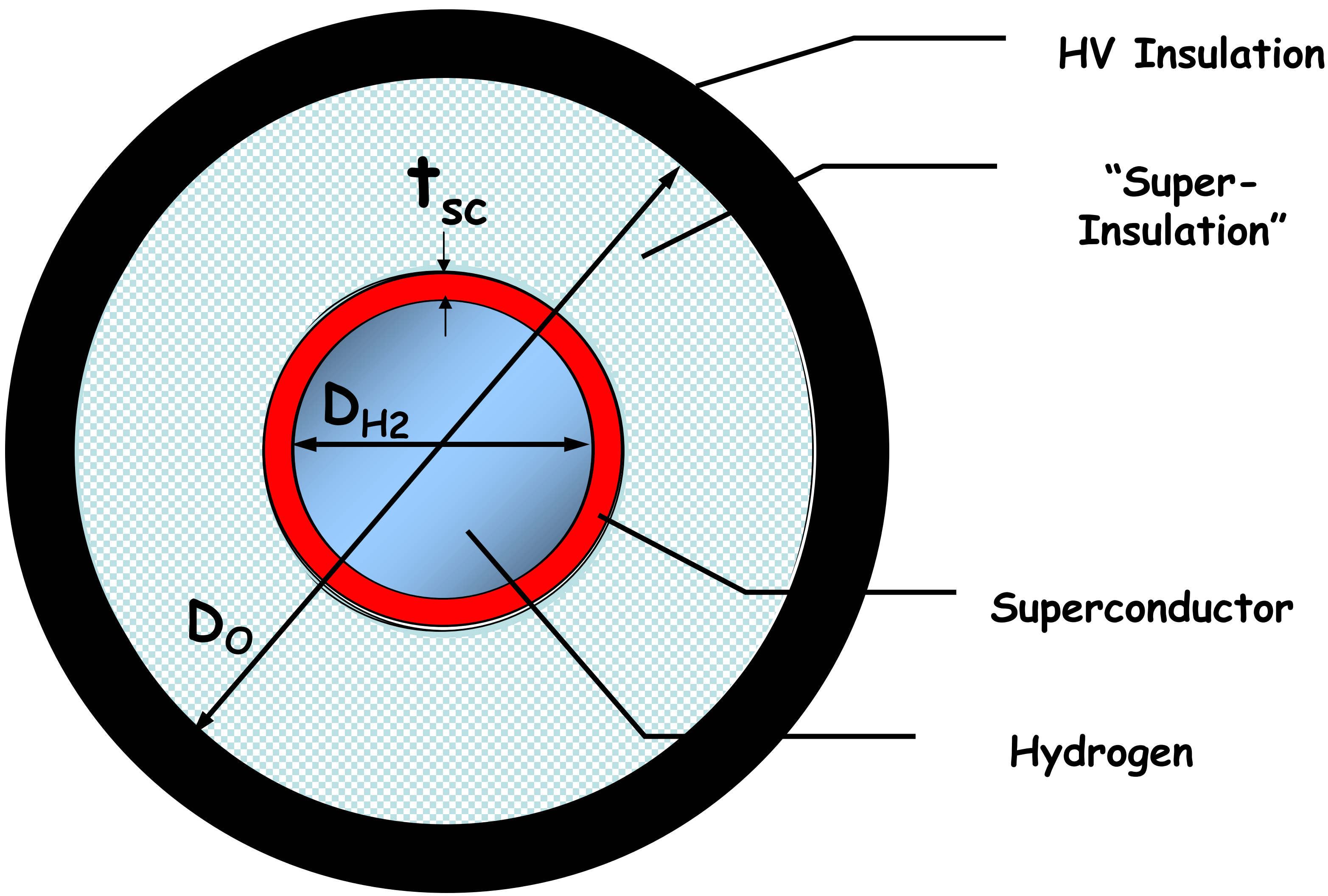
P.M. Grant, The Industrial Physicist, Feb/March Issue, 2002

"Hydricity" SuperCables



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

SuperCable Monopole



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

Hydricity Scaling Factor

Dimensionless, geometry-independent scaling factor defines relative amounts of electricity/hydrogen power flow in the SuperCable:

$$R_{e/h} \equiv \left(J / Q\rho \right) \left(\left| V \right| / \nu \right)$$

"Energy Density"

"Pressure"

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

Thermal Losses

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

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

$W_R = 3.6\ W/m$

Radiation Losses

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

n = number of layers

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

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

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

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 $dT/dx = 1.89\times10^{-5}$ K/m,
Or, 0.2 K over a 10 km distance

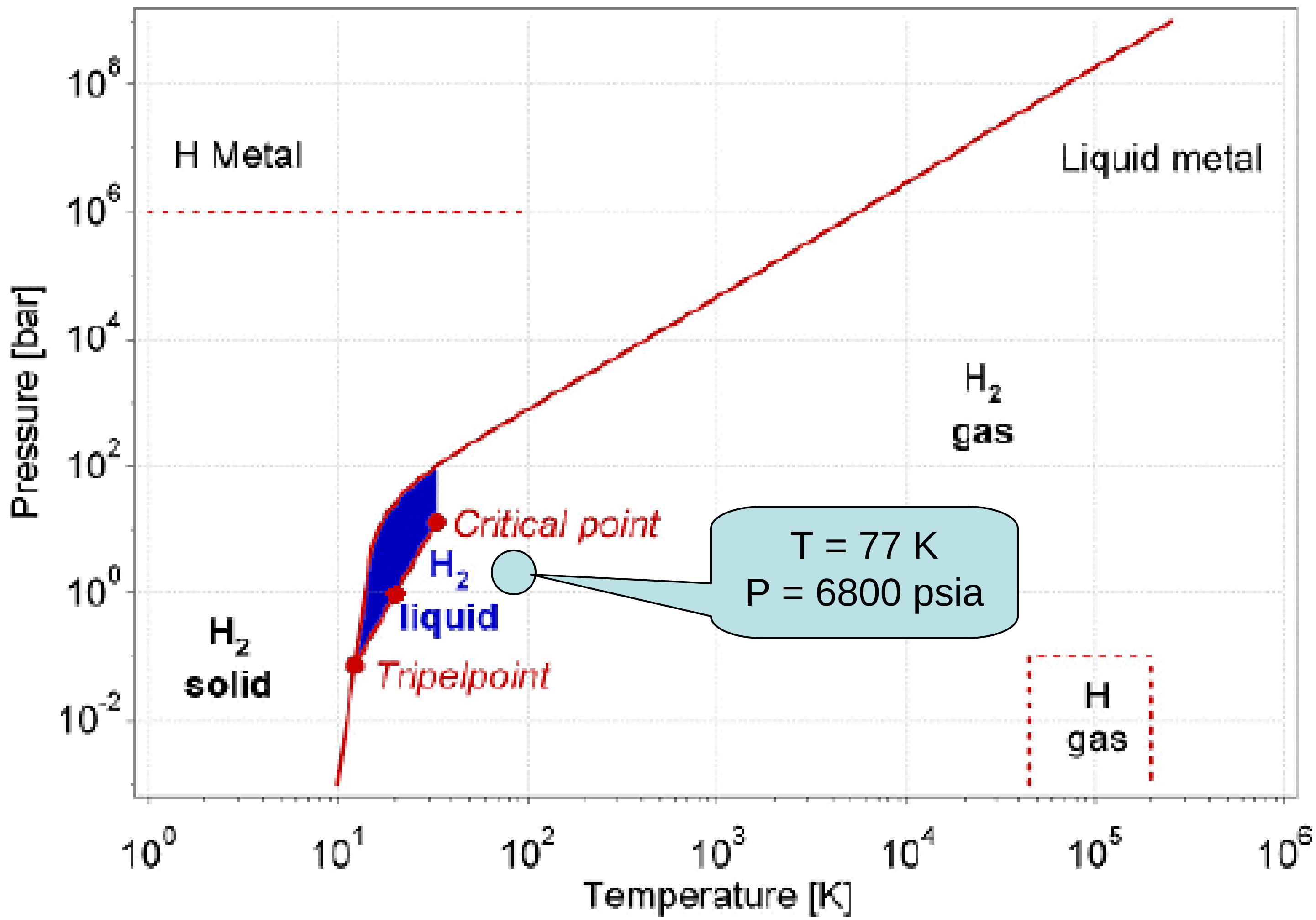
SuperCable H_2 Storage

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

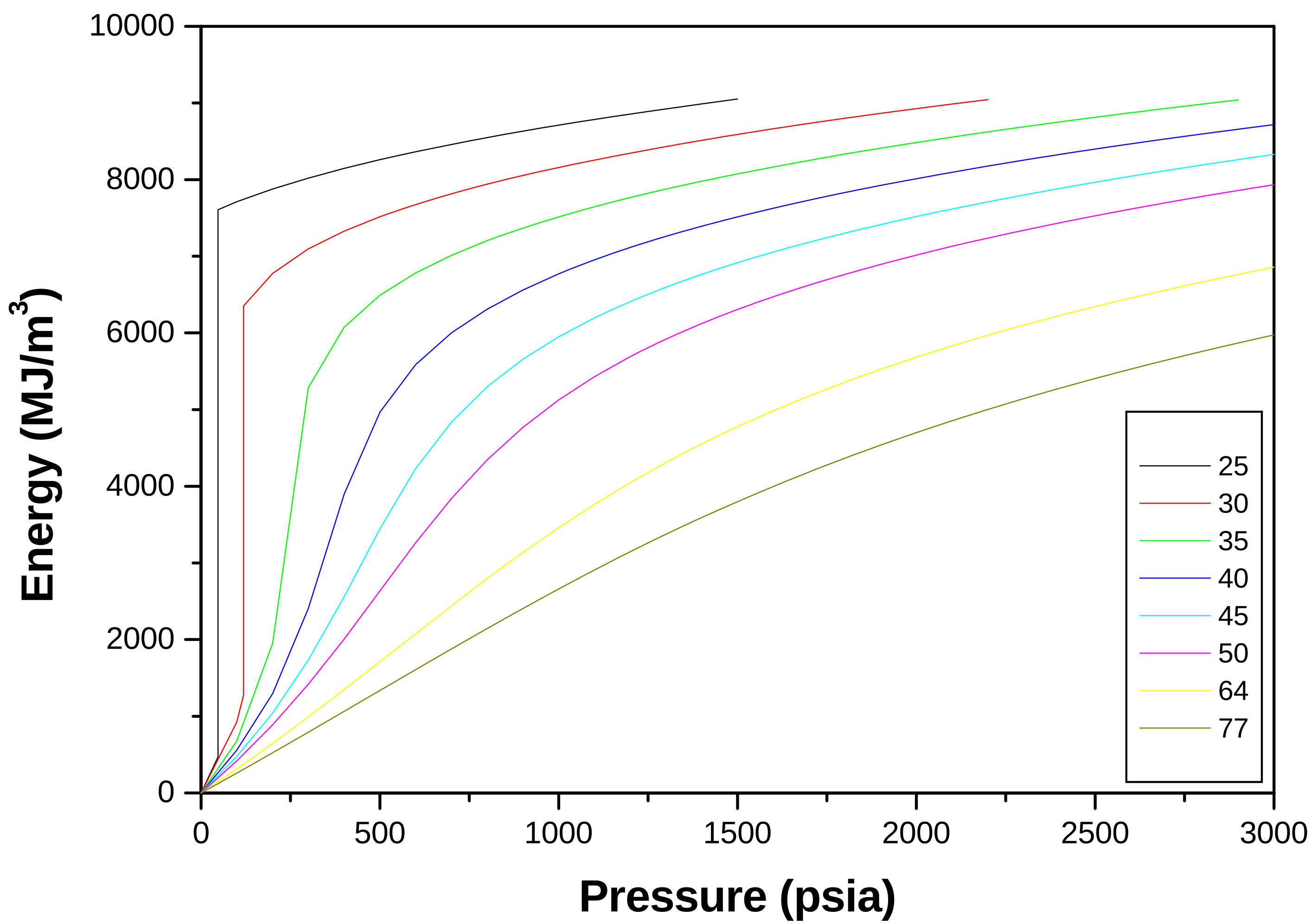
One Raccoon Mountain = 13,800 cubic meters of LH2

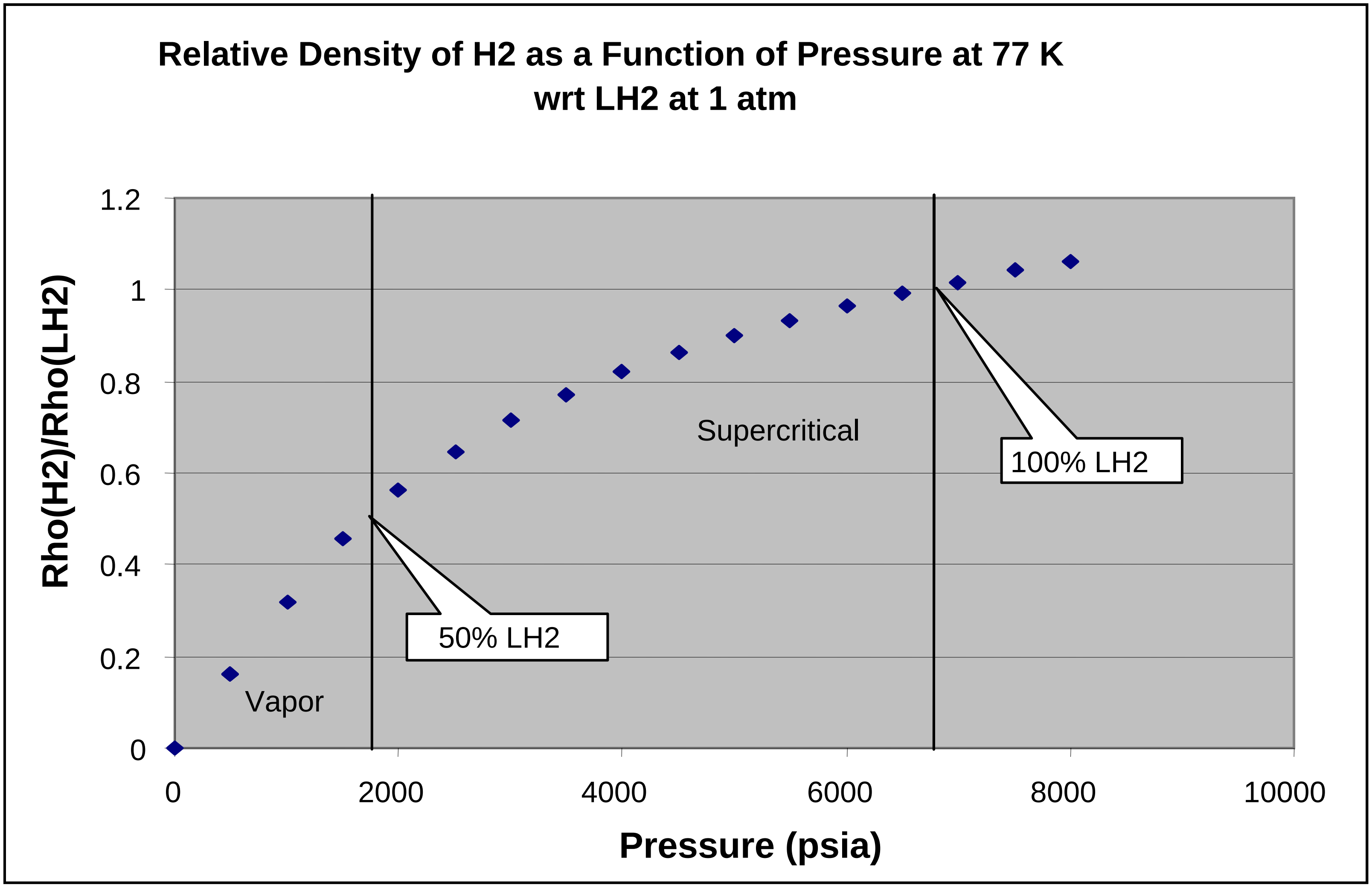
LH_2 in 10 cm diameter, 250 mile bipolar SuperCable
= Raccoon Mountain

Crude Phase Diagram of H_2



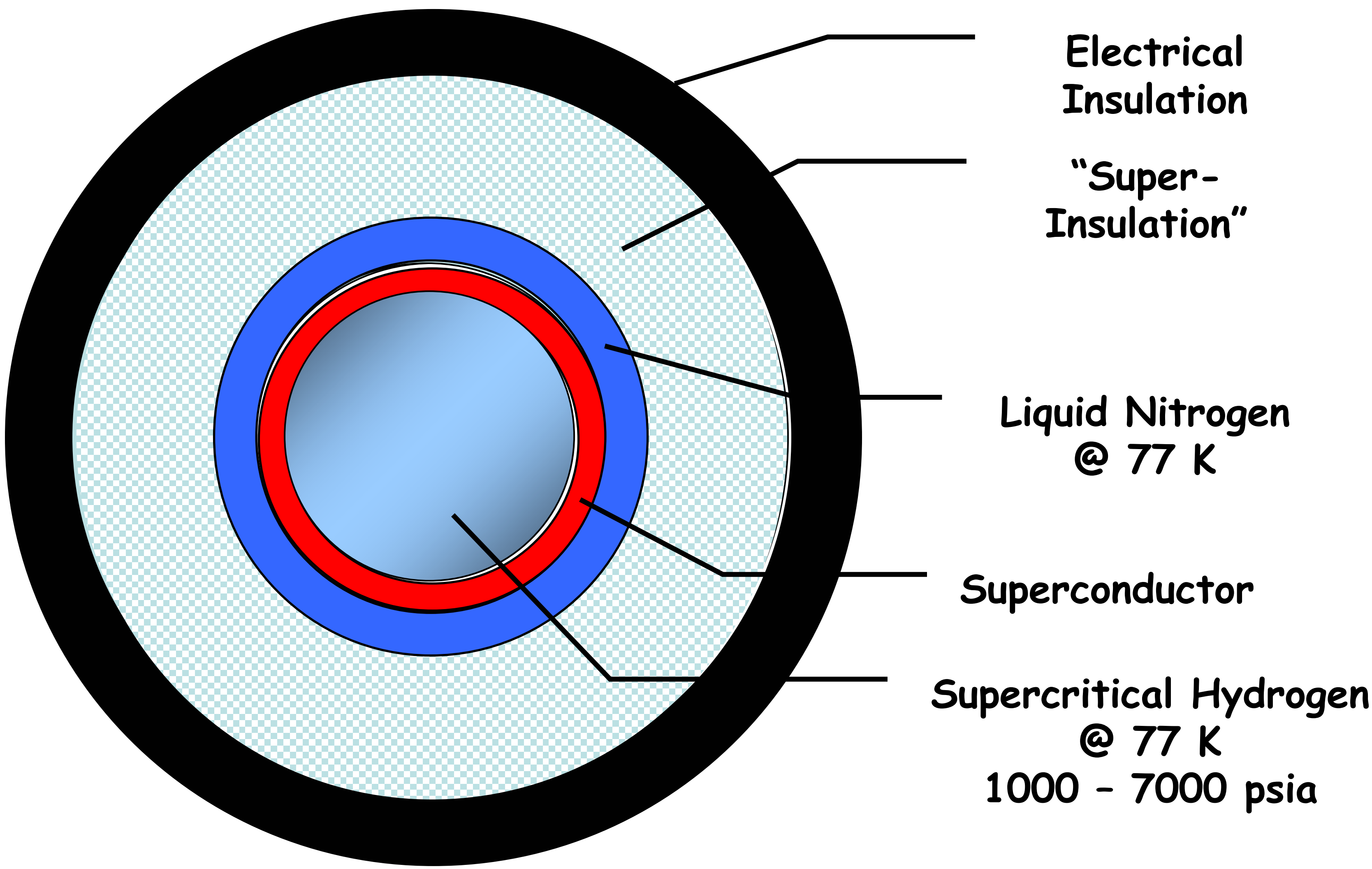
Isothermal Properties of H_2





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

Supercritical H_2 SuperCable



Fluid Properties Comparison of Liquid to Gaseous Hydrogen Transporting 500 MW_t in a 10-cm Diameter Pipe

T °K	**P** psia	ρ kg/m^3	μ μPa×s	μ^2/ρ ndyne	**V** m/s	**Re** 10^6
20	14.7	70.8	13.6	261	4	2.08
77	1850	35.4	5.6	87	8	5.06

$$\mathrm{Re} = \rho VD / \mu \approx \frac{\text{Inertial Forces}}{\text{Viscous Forces}}$$

Thus, it takes only 0.5 dynes "push" on an object with the above Reynolds Numbers on the gas to overcome viscous forces exerted by the given fluid

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)

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

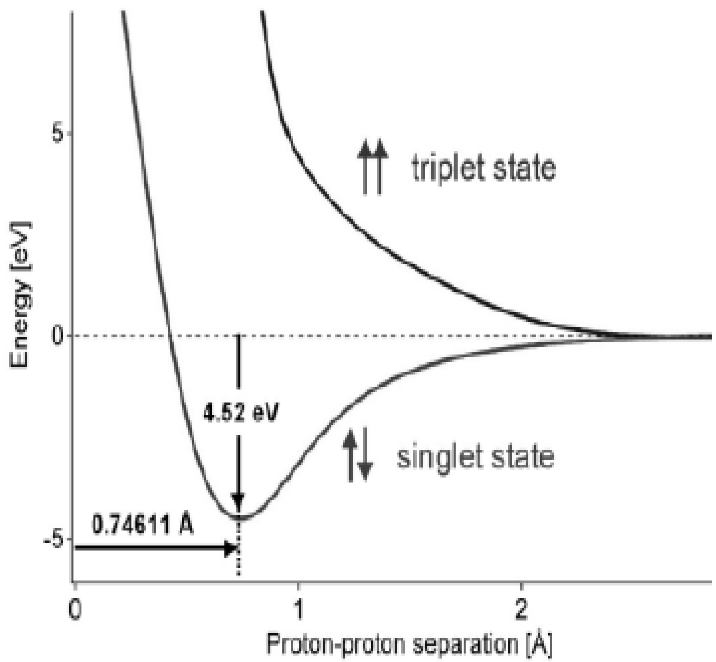
Where M = mass flow per unit length
P_{loss} = pressure loss per unit length
ρ = fluid density

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

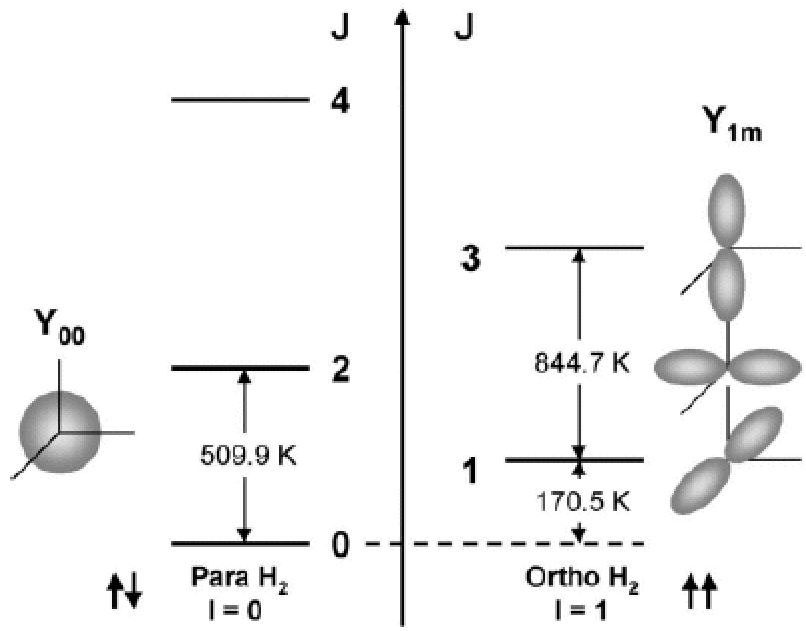
ε = 0.015 mm (stainless steel)	
	W_{loss} (W/m)
22 K	0.72
77 K	1.30

Singlet (Para) – Triplet (Ortho) H_2

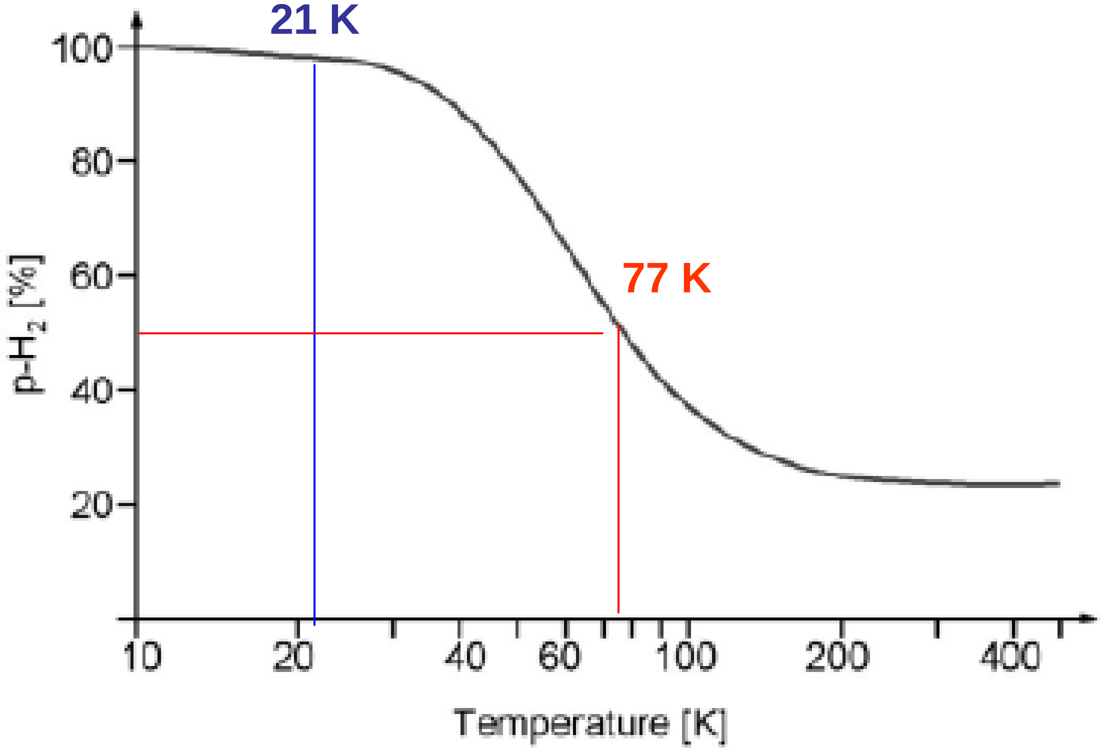
Electronic



Nuclear



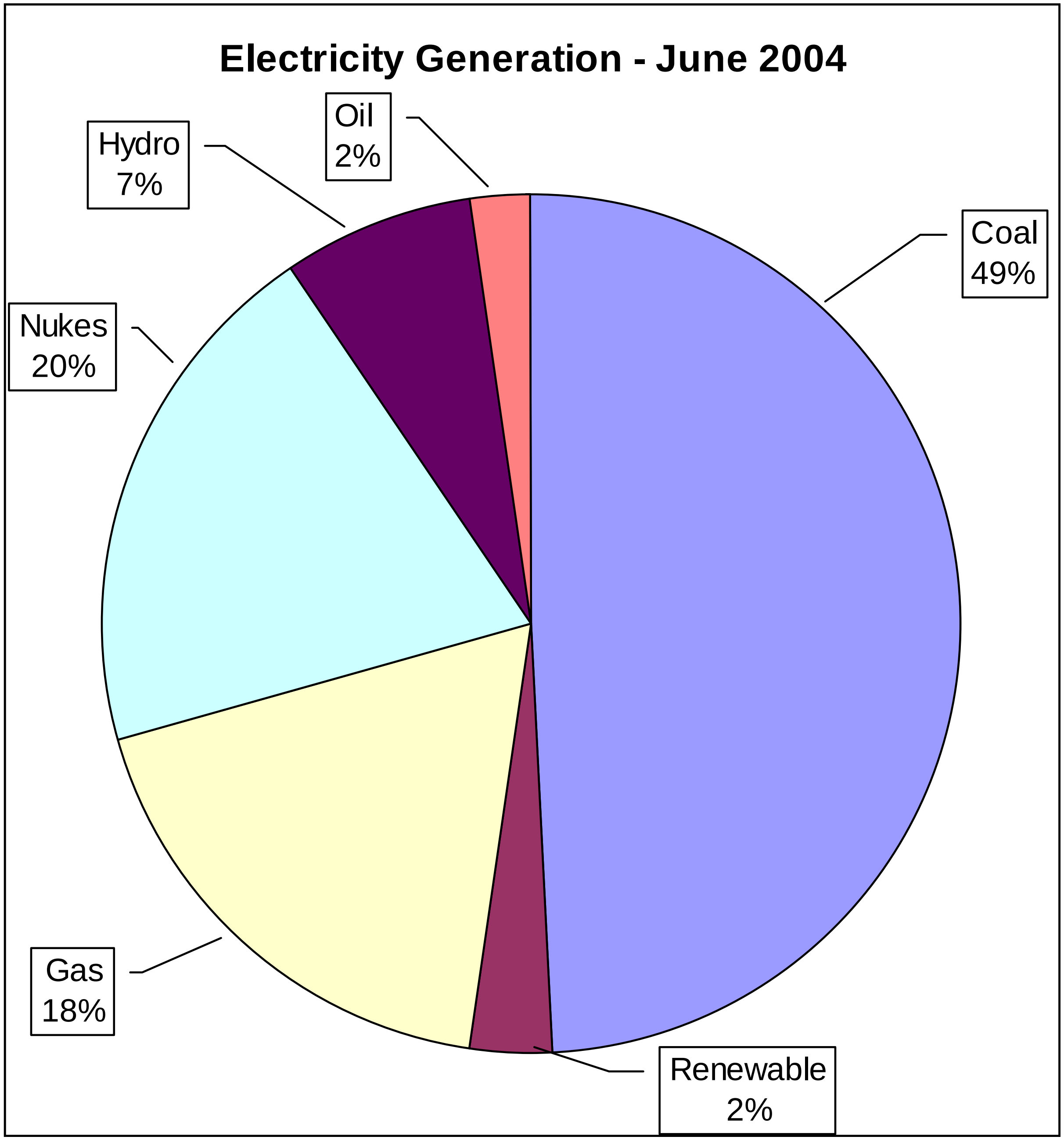
% para-H_2 in Normal H_2



$$\frac{N_o}{N_p} = \frac{(I+1)\cdot \sum_{J=odd} q_J^r}{I \cdot \sum_{J=even} q_J^r} \quad \text{with } q_J^r = (2J+1)\cdot \exp\left\{-\frac{2\cdot h^2}{8\cdot \pi^2 M \cdot r_0^2}\frac{J(J+1)}{k\cdot T}\right\}$$

An Unanswered Question (?)

- Is the para-ortho ratio dependent on magnetic field?
  - The peripheral field from a 100 kA superconductor cable can reach 1 T or greater.
  - Will this magnitude field induce a para-to-ortho spin flip? (maybe to 100% ortho?)
- At 77 K, H_2 is 50/50 para/ortho, and the ortho-para transition is exothermic with an enthalpy release of 523 kJ/kg.
- *Would a loss of electric current with concurrent magnetic field collapse result in an ortho-para transition and subsequent heating?*



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

A Canadian's View of the World

The Mackenzie Valley Pipeline

http://www.mackenziegasproject.com

1220 km

18 GW-thermal

2006 - 2009

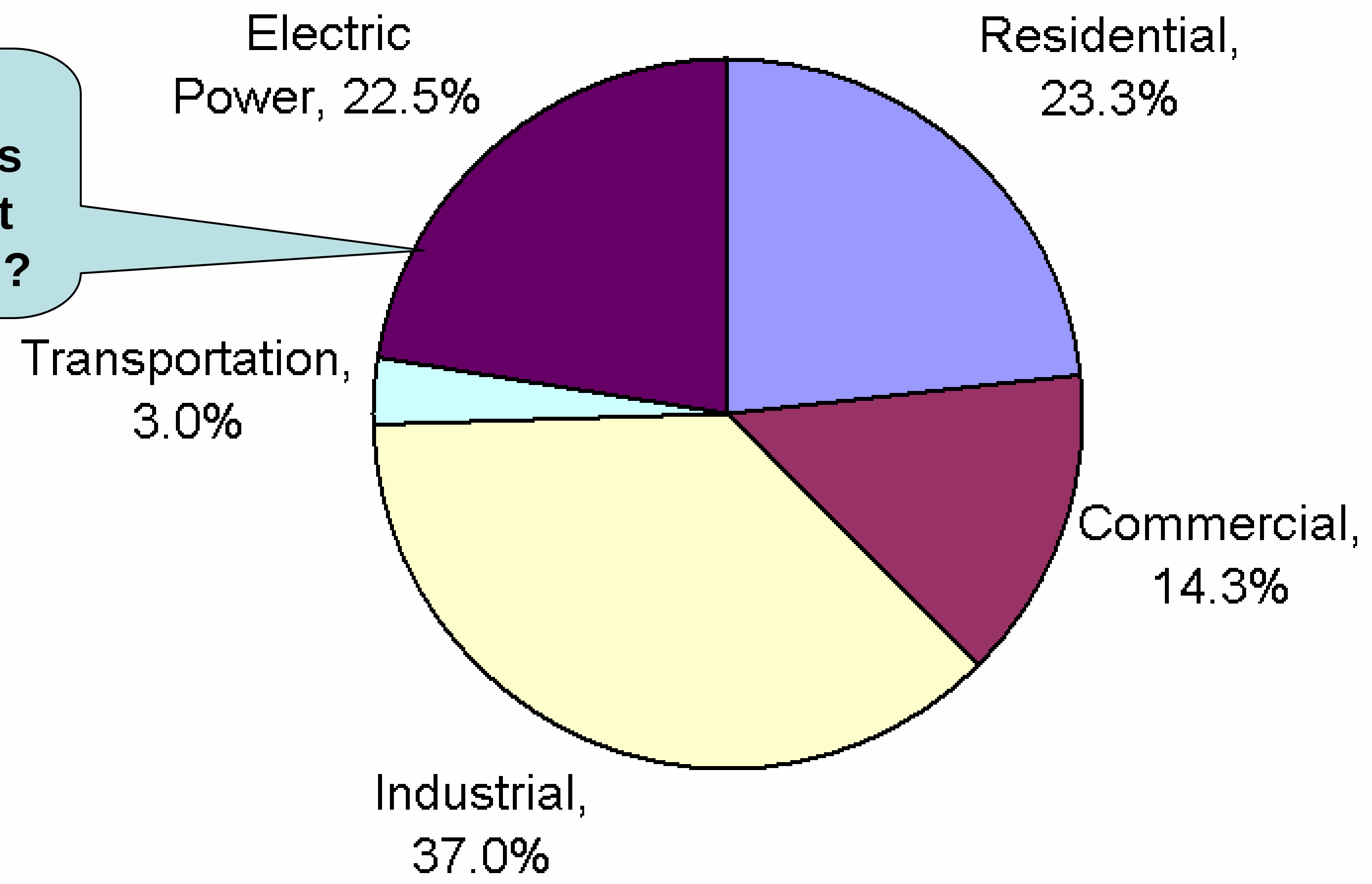
MVP Specs

Pipeline Length	1220 km (760 mi)
Diameter	30 in (76 cm)
Gas Pressure	177 atm (2600 psia)
Pressurization Stations	~250 km apart
Flow Velocity	5.3 m/s (12 mph)
Mass Flow	345 kg/s
Volume Flow	1.6 Bcf/d (525 m^3/s)
Power Flow	18 GW (HHV Thermal)
Construction Schedule	2006 - 2010
Employment	25,000
Partners	Esso, APG, C-P, Shell, Exxon
Cost	$18 B (all private)

2004 Natural Gas End Use

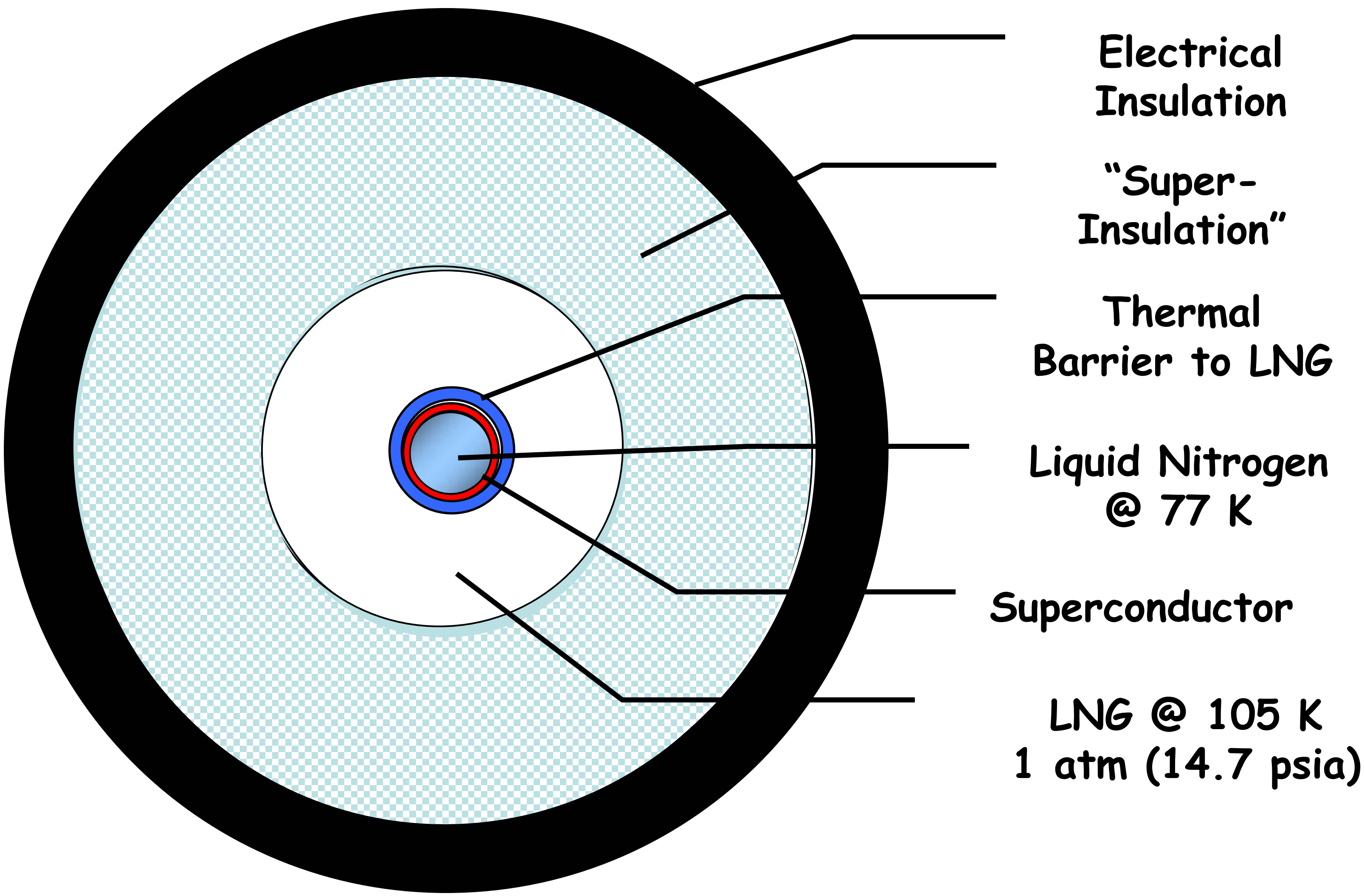
Schoenung, Hassenzahl and Grant, 1997
(5 GW on HTSC @ LN_2, 1000 km)

Why not generate this electricity at the wellhead?



LNG SuperCable

Design for eventual conversion to high pressure cold or liquid H_2



MVP Wellhead Electricity

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!*
- Build HTCGR Nukes on the well sites in the Mackenzie Delta (some of the generator infrastructure already in place)
- Use existing LNG SuperCable infrastructure to transport protons and electrons
- Electricity/H_2 split needs to be determined…*Now!*

LNG Danger To Our Communities Tim Riley Law .com 805-984-2350

Consumer Protection Attorney Tim Riley Warns About Liquefied Natural Gas

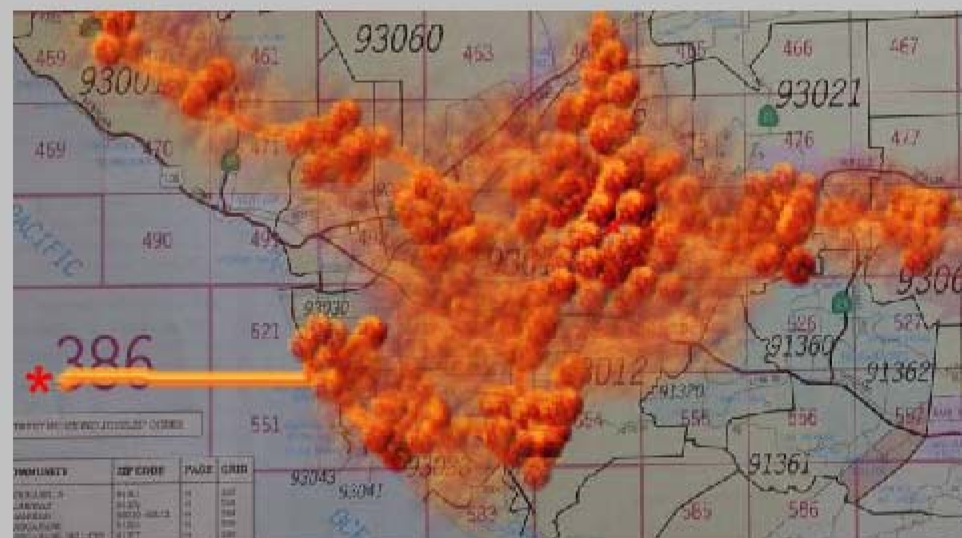
Certified Member of the Million Dollar Advocates Forum

"The Top Trial Lawyers
in the Country"

Pipelin

Something Very Dangerous

"Underfoot"



PIPELINES A CONSTANT HAZARD!

Take-Home Reading Assignment

www.w2agz.com/cec-icmc05.htm

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 @ LN_2, 1000 km)
5. Grant, 2003 ("Hydrogen Lifts Off…," Nature)
6. Grant, 2005 (The SuperCable)
7. SuperGrid Workshop, 2004 (See Bibliography)