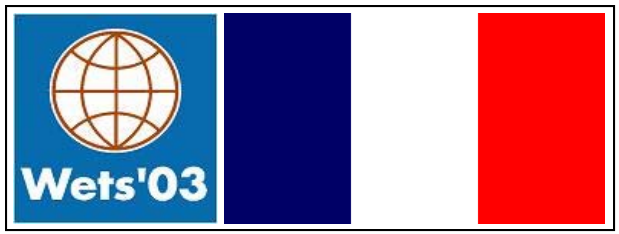
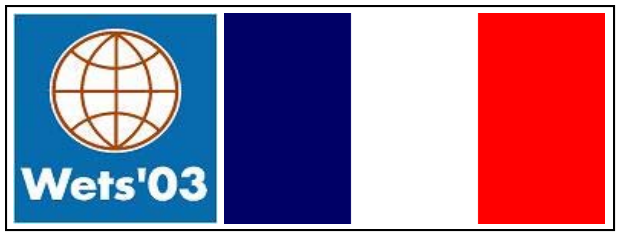


26 Juin 2003 Meudon, France

The SuperGrid: Combined Delivery and Storage of Electricity and Hydrogen

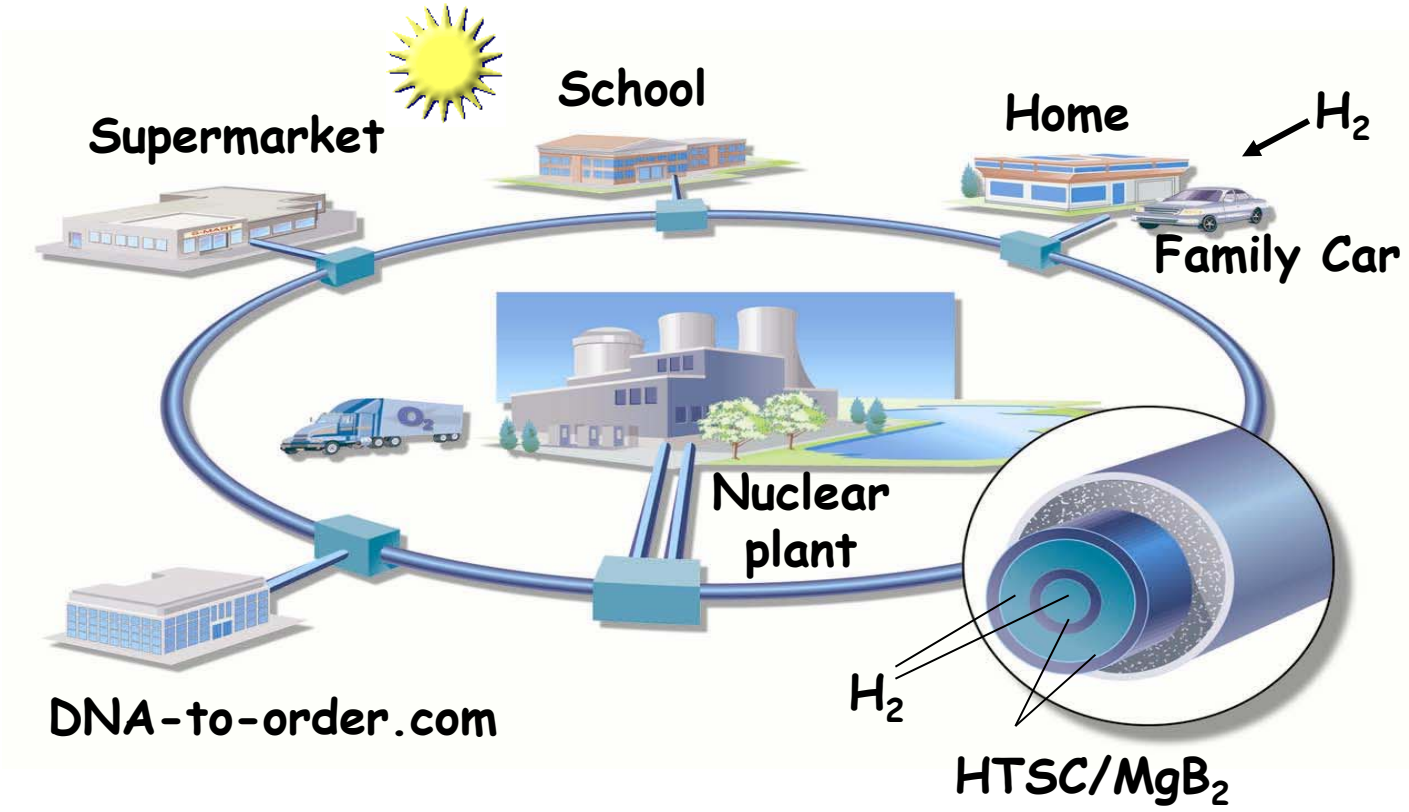
P. M. Grant, (Electric Power Research Institute)
pgrant@epri.com

ftp://grant:marulo@ftp.epri.com/Nat%20Lab%20SuperGrid%20Proposal/



26 Juin 2003 Meudon, France

SuperCity



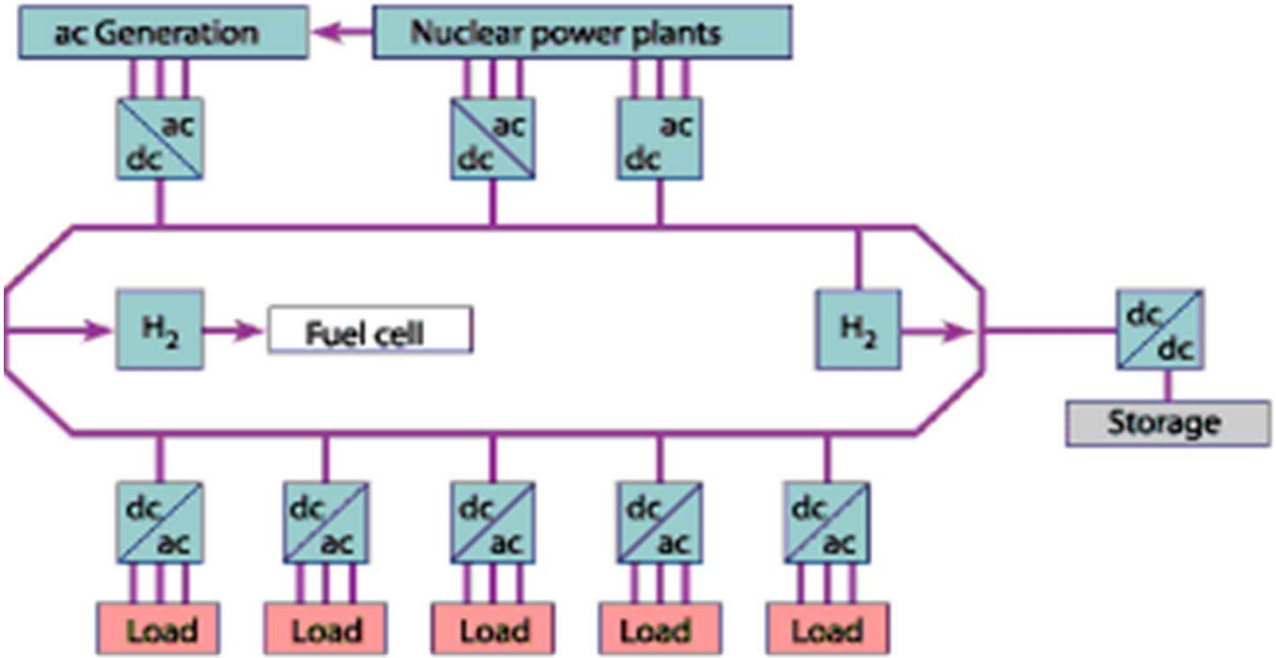
P.M. Grant, The Industrial Physicist, Feb/March Issue, 2002

ftp://grant:marulo@ftp.epri.com/Nat%20Lab%20SuperGrid%20Proposal

Wets'03

26 Juin 2003 Meudon, France

SuperGrid



Continental SuperGrid

"Continential SuperGrid Workshop," UIUC/Rockefeller U., Palo Alto, Nov. 2002

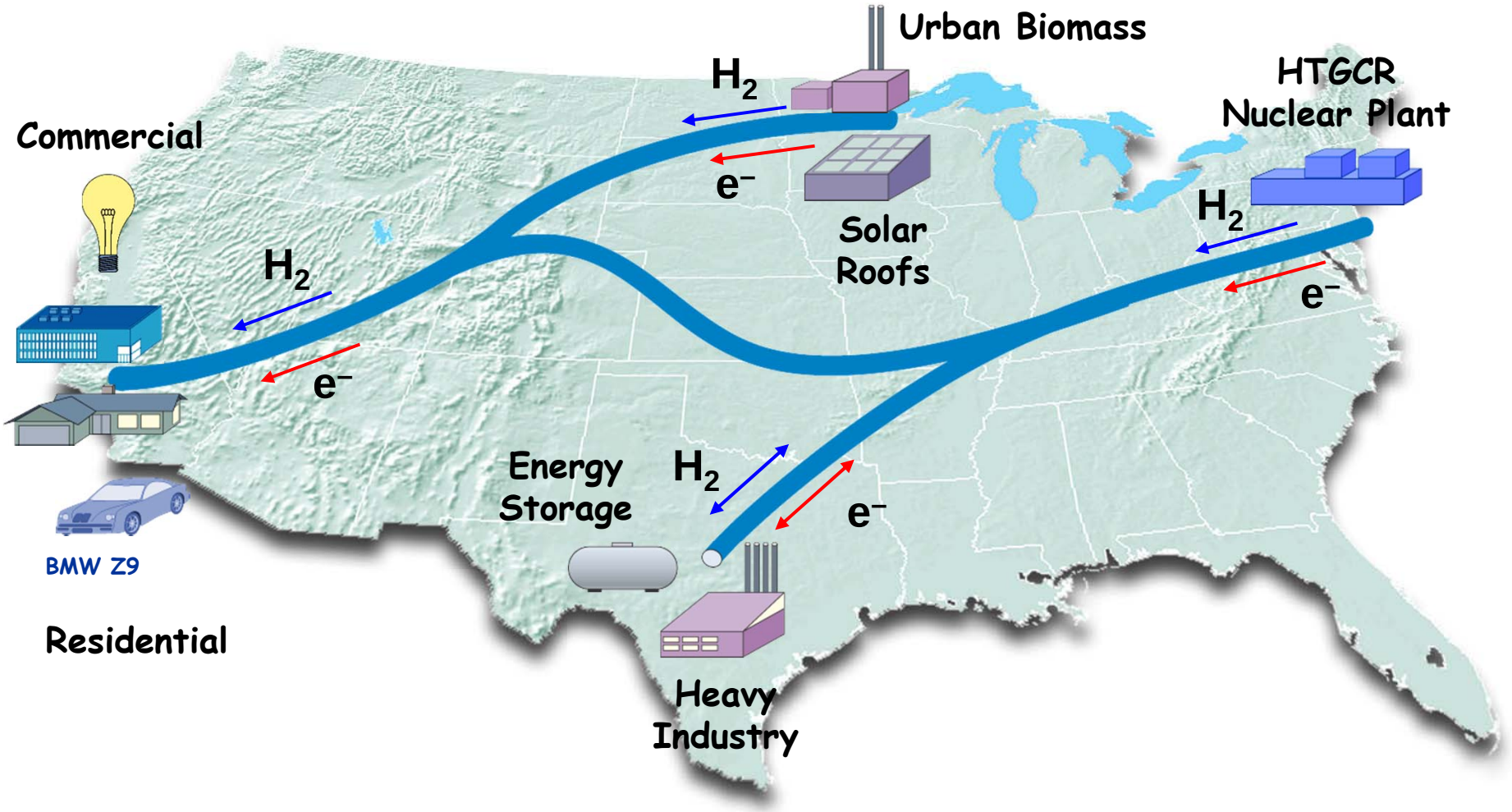
ftp://grant:marulo@ftp.epri.com/Energy%20SuperGrid%20Workshop%20Proceedings/

http://www.epri.com/journal/details.asp?doctype=features&id=511

Wets'03

26 Juin 2003 Meudon, France

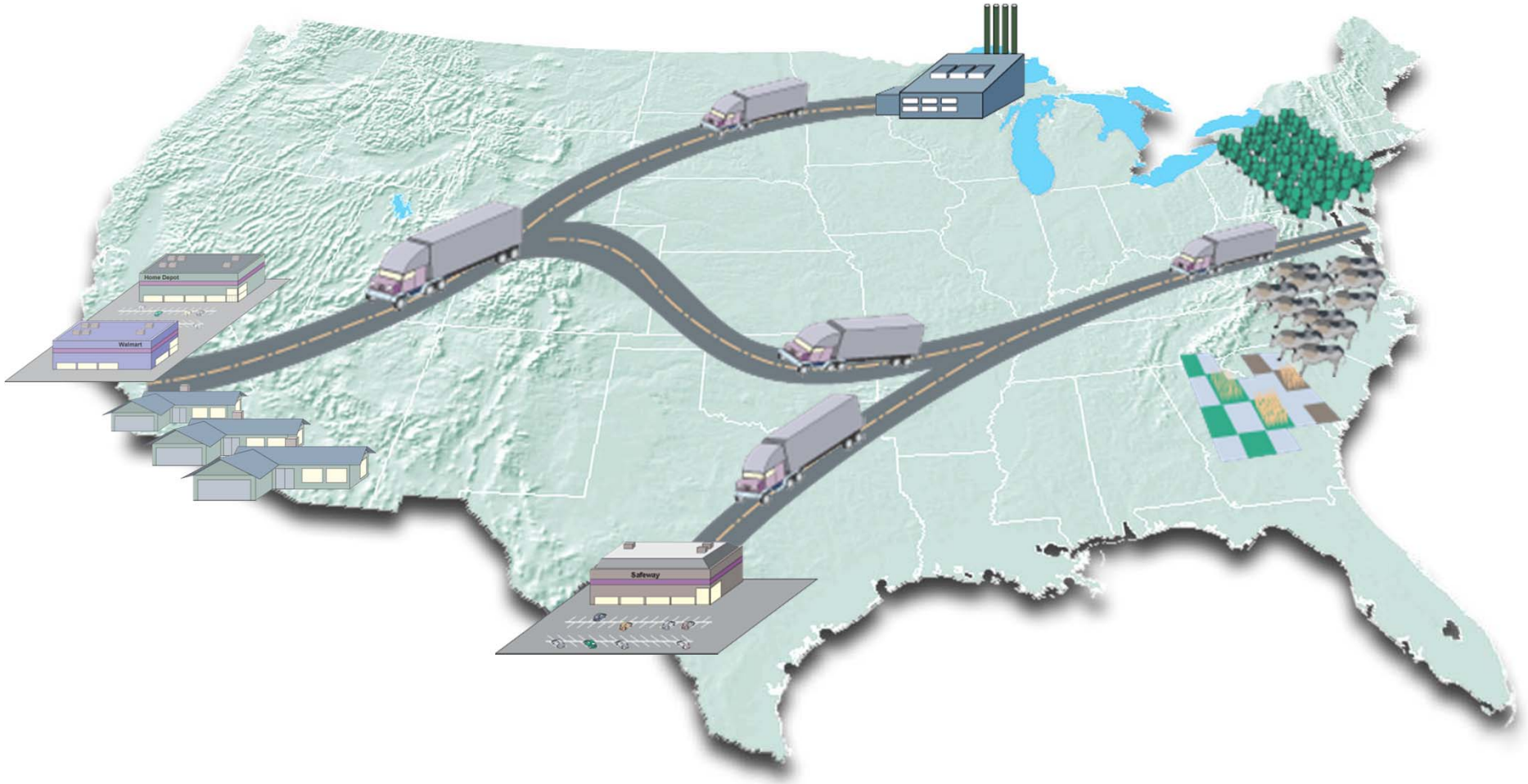
North American 21st Century Energy SuperGrid

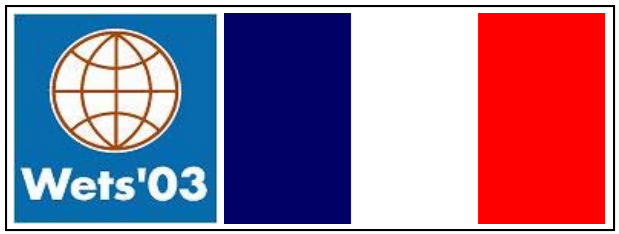


Wets'03

26 Juin 2003 Meudon, France

Interstate 80
The 20th Century Diesel Grid





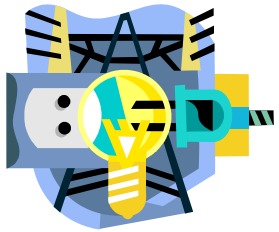
26 Juin 2003 Meudon, France

Architecture

Three Dimensions

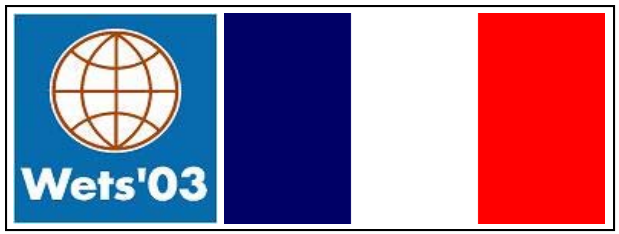
- ***SuperGrid*** **– A superconducting, H_2-cooled interstate "backbone" connecting regions coast to coast.**

- ***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.



26 Juin 2003 Meudon, France

Garwin-Matisoo (IBM, 1967)

100 GW dc, 1000 km !

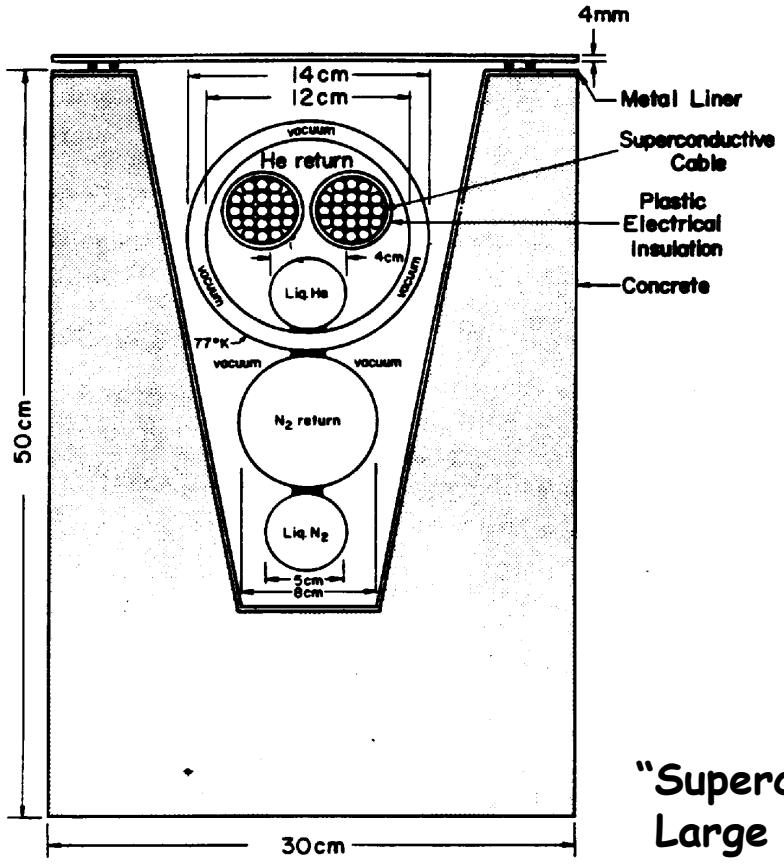
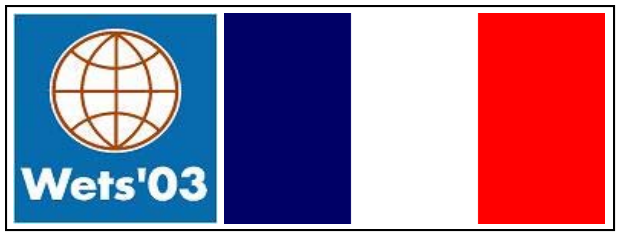


Fig. 1. Cross section of the 100-GW line.

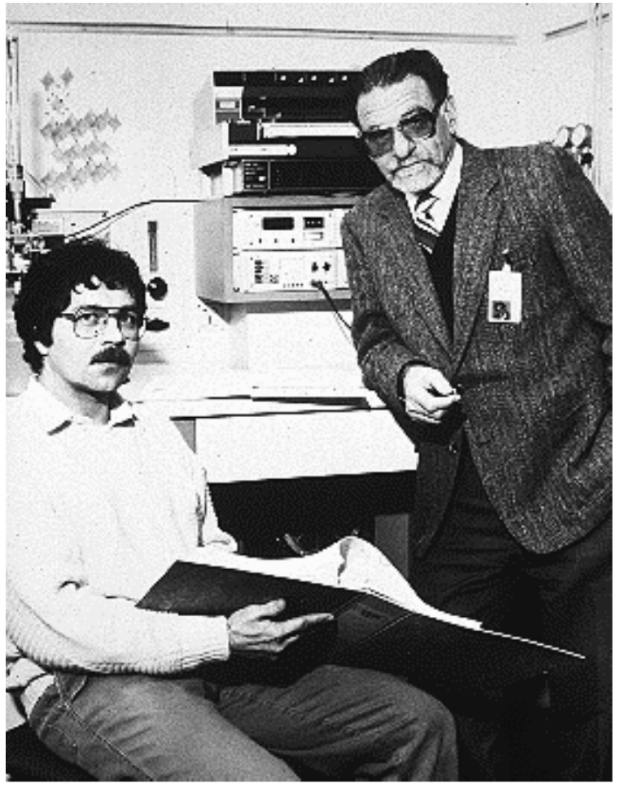
- Nb_3Sn Wire
- $T_c = 9$ K
- LHe liquid-vapor cooled
- LN_2 heat shield

"Superconducting Lines for the Transmission of Large Amounts of Electric Power over Great Distances," R. L. Garwin and J. Matisoo, Proc. IEEE 55, 538 (1967)

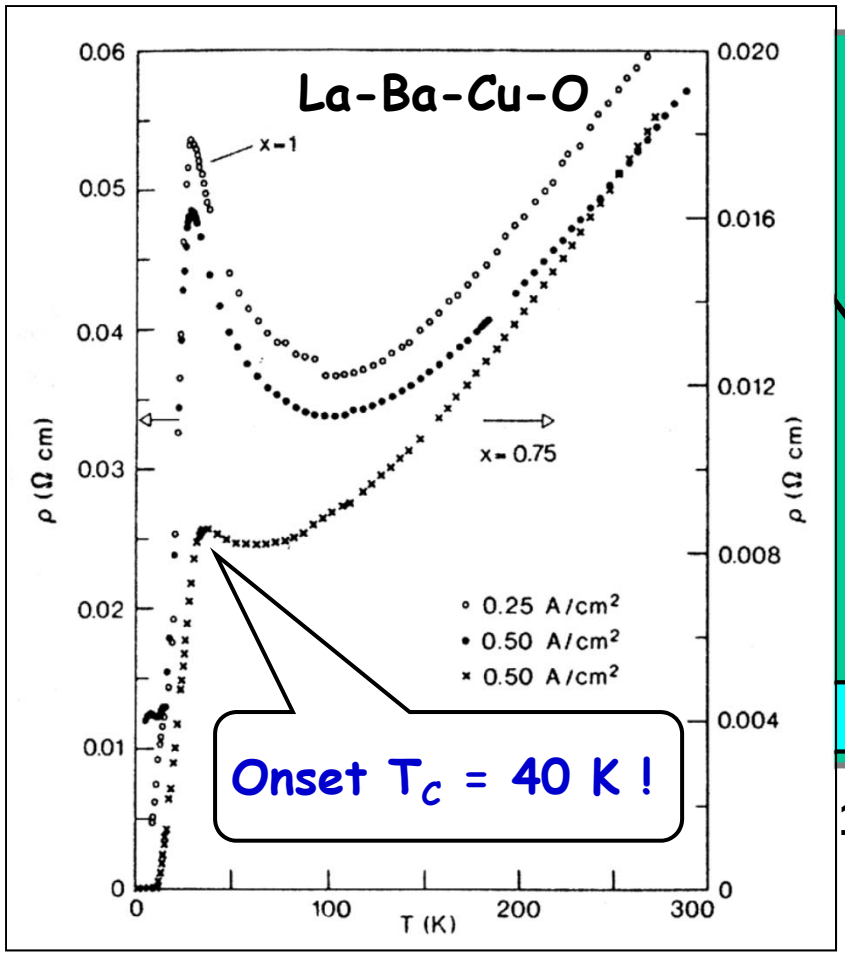


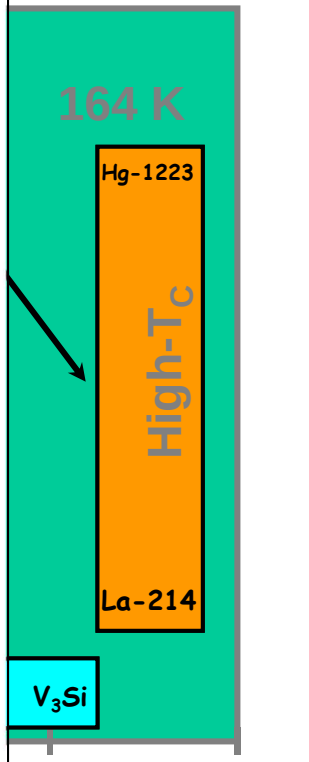
26 Juin 2003 Meudon, France

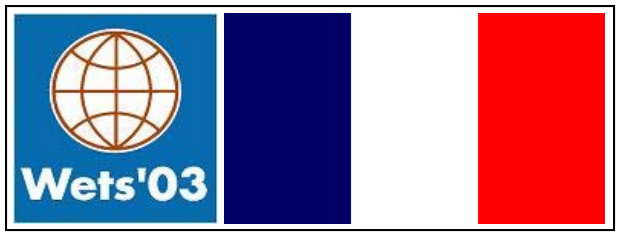
1986: A Big Surprise!



Bednorz and Mueller
IBM Zuerich, 1986







26 Juin 2003 Meudon, France

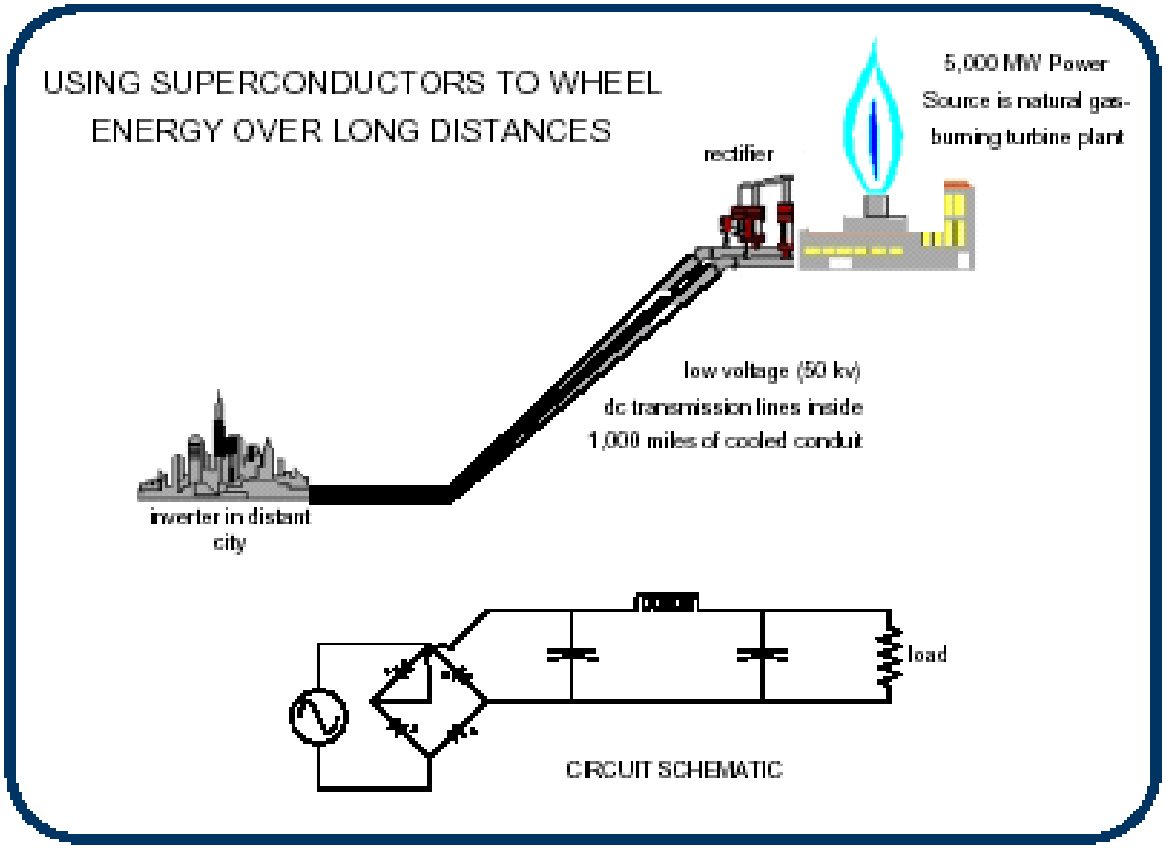
1987: "The Prize!"

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

Electricity Pipe



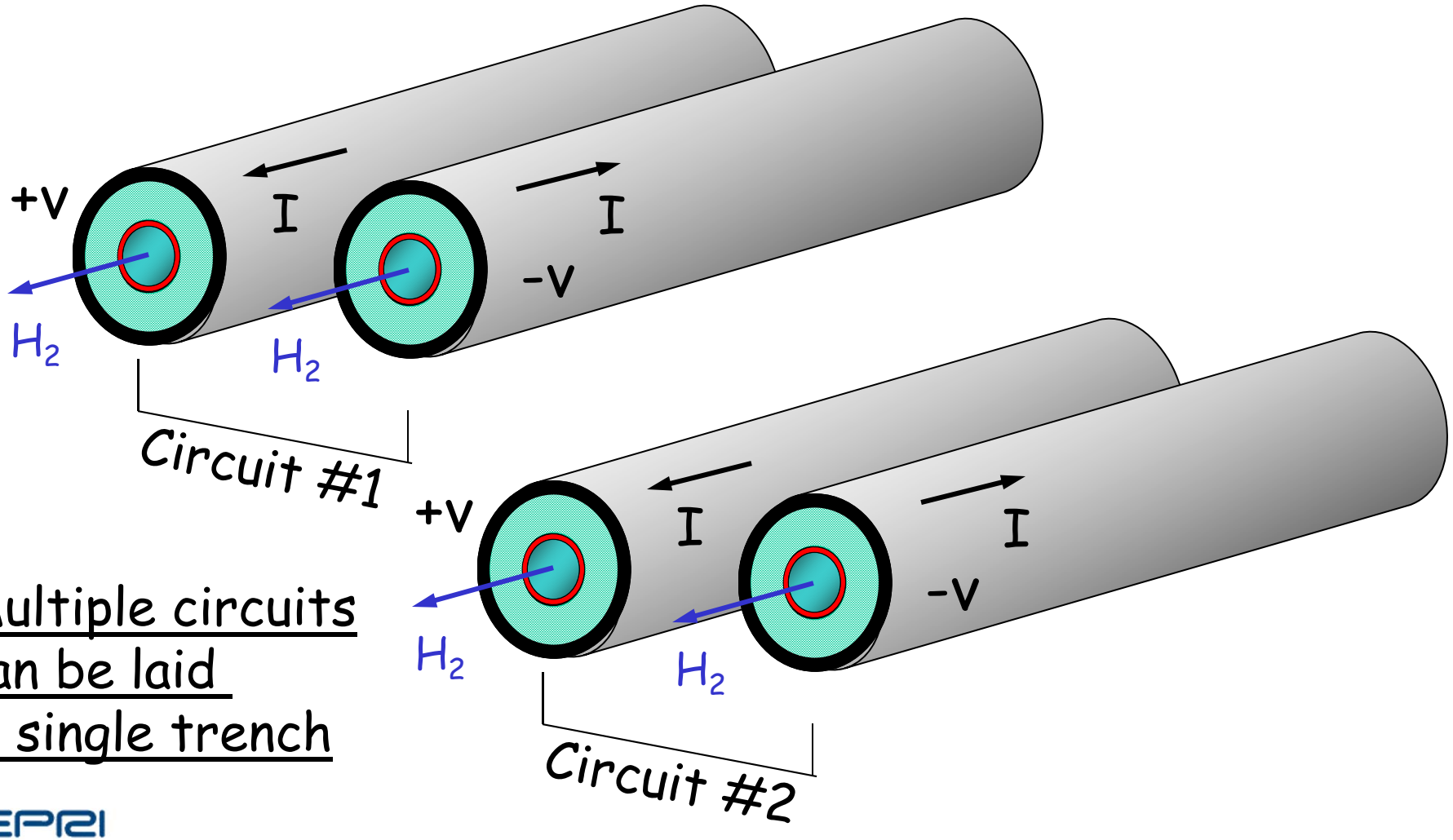
Initial EPRI study on long distance (1000 km) HTSC dc cable cooled by liquid nitrogen

-- 1997 --

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

ftp://grant:marulo@ftp.epri.com/Nat%20Lab%20SuperGrid%20Proposal

SuperCables

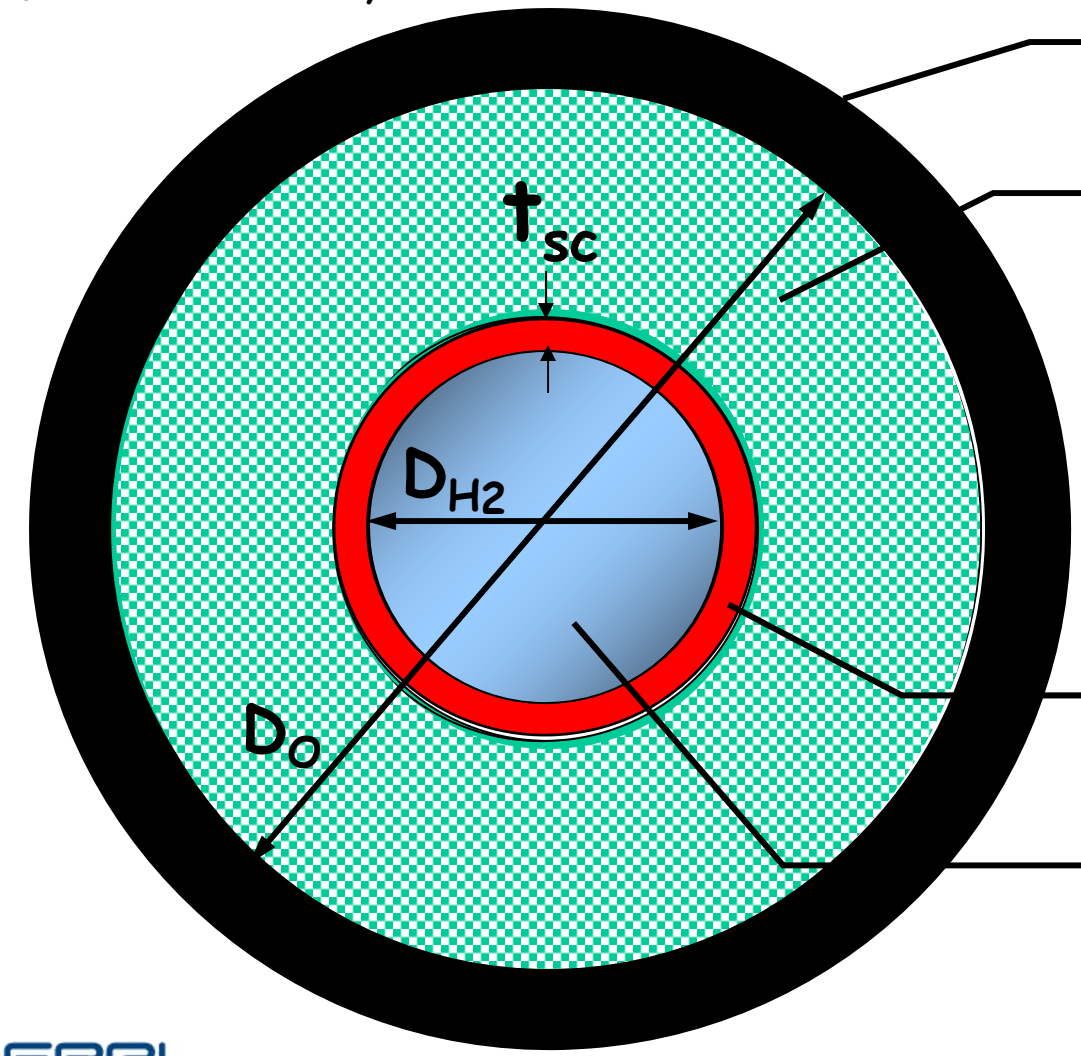


Multiple circuits can be laid in single trench

Wets'03

26 Juin 2003 Meudon, France

SuperCable

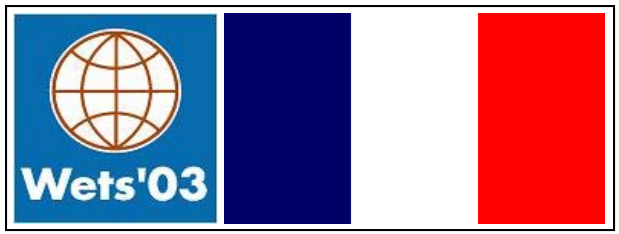


HV Insulation

"Super-Insulation"

Superconductor

Hydrogen



26 Juin 2003 Meudon, France

Power Flows

Electricity

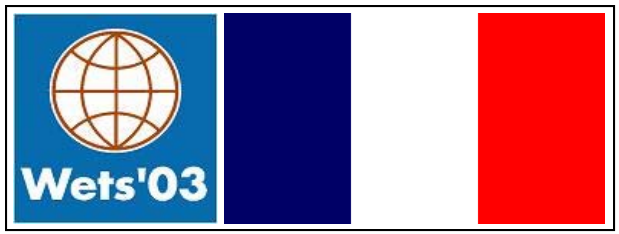
$P_{SC} = 2|V|IA_{SC}$, where

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

Hydrogen

$P_{H2} = 2(QpvA)_{H2}$, 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



26 Juin 2003 Meudon, France

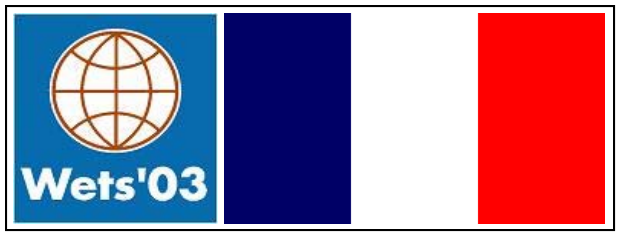
Electric & H_2 Power

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



26 Juin 2003 Meudon, France

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

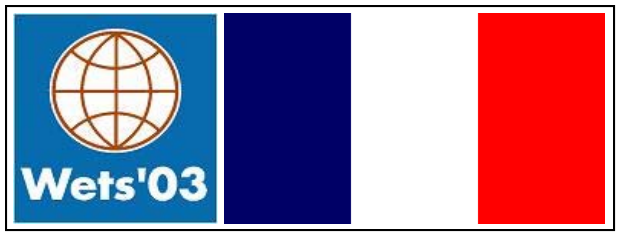
Superinsulation: $W_R^f = W_R/(n-1)$, where

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



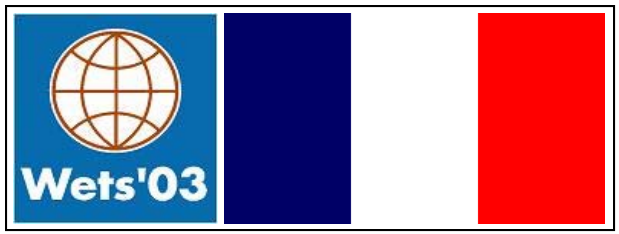
26 Juin 2003 Meudon, France

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

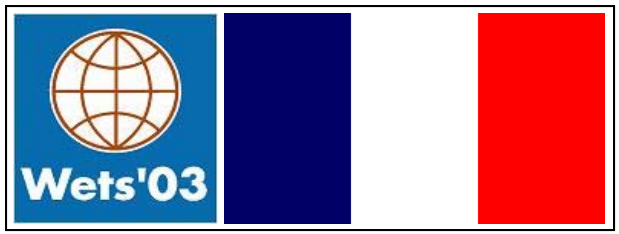
Take W_T = 1.0 W/m, then $dT/dx = 1.89 \times 10^{-5}$ K/m,
Or, 0.2 K over a 10 km distance



26 Juin 2003 Meudon, France

Remaining Issues

- Current stabilization via voltage control
- Cryogenic power electronics
- Hydrogen gas cooling and transport
- Hydrogen storage
- Prototyping
- Costs (!)
- Initial Demonstration Site



26 Juin 2003 Meudon, France

Where there is no vision, the people perish…

Proverbs 29:18

Wets'03

26 Juin 2003 Meudon, France

"You can't always get what you want..."

Wets'03

26 Juin 2003 Meudon, France

"…you get what you need!"