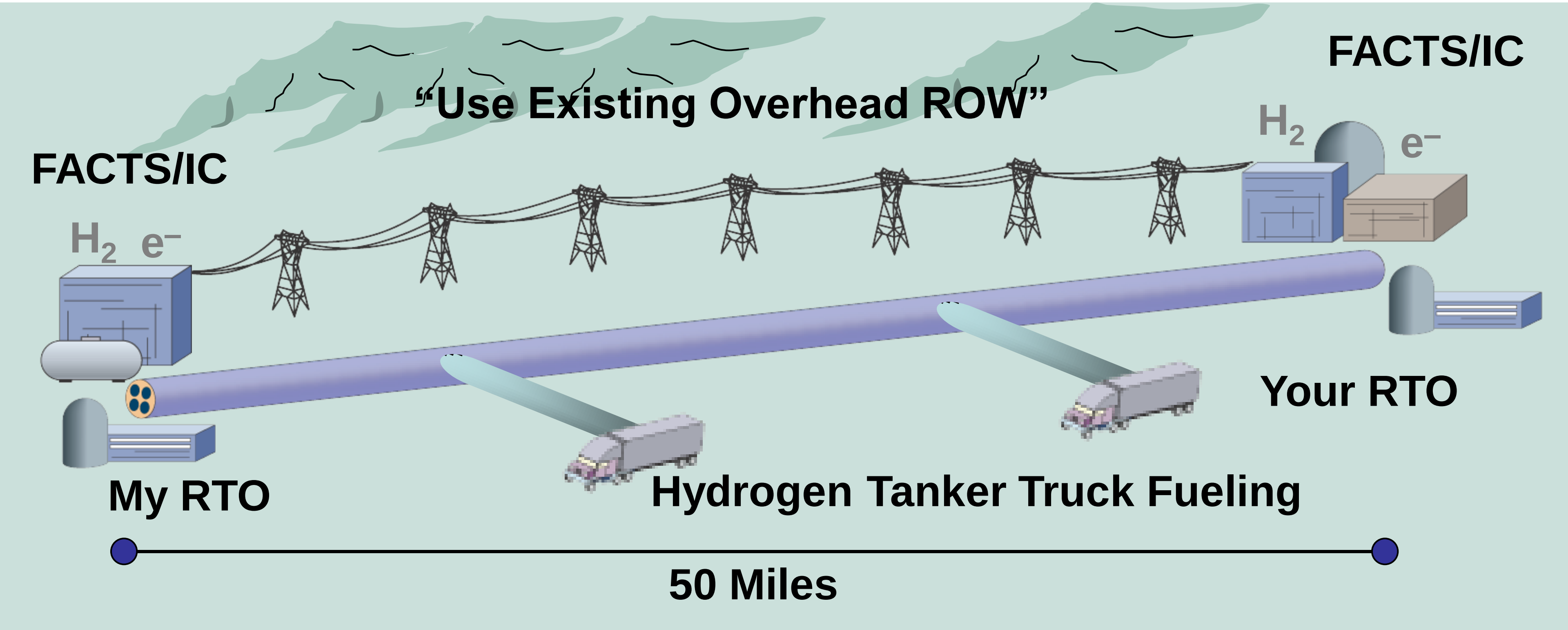
Super

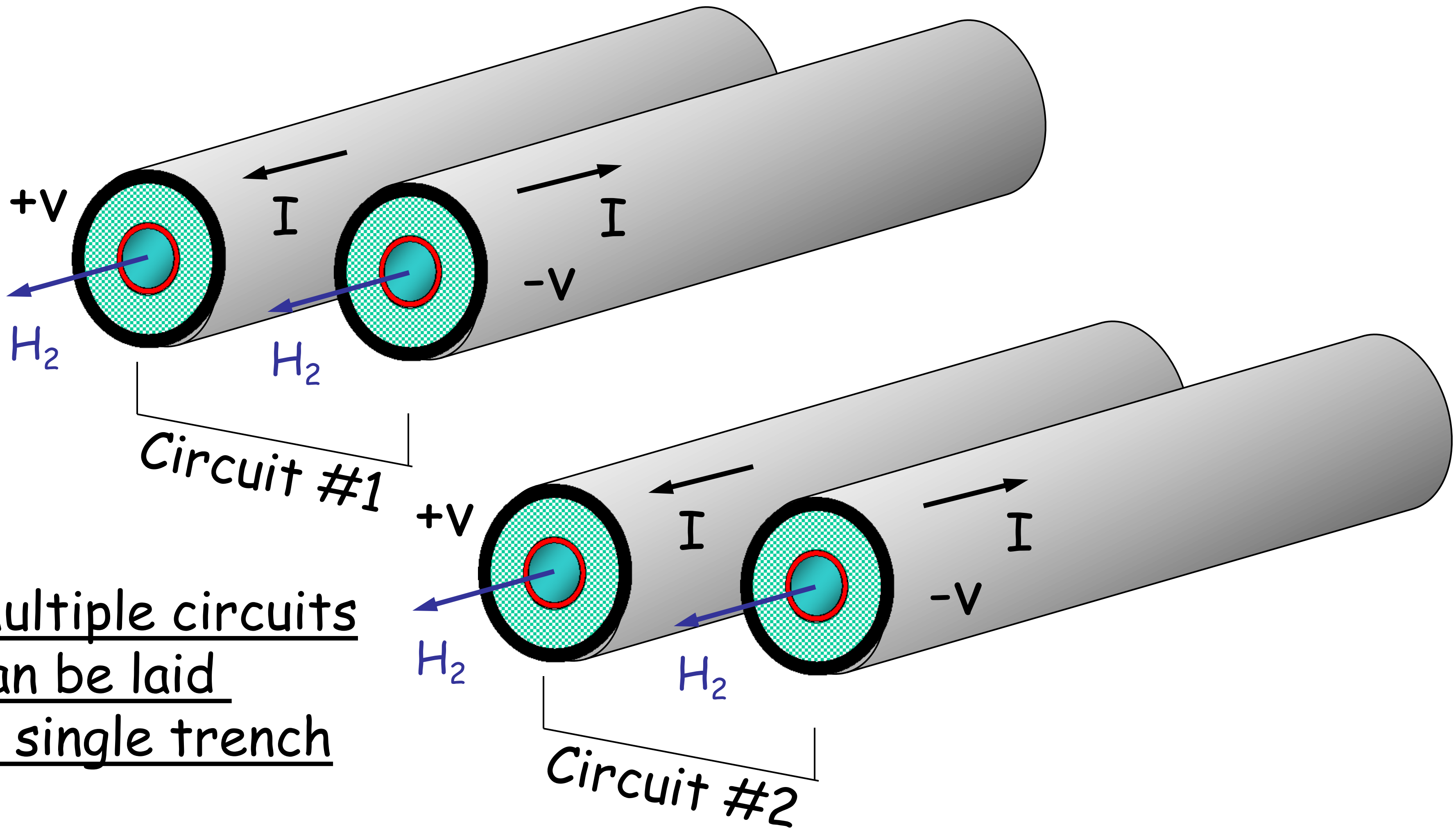
Cable

Combined Storage & Delivery of Electricity & Hydrogen

RegionGrid Interconnection

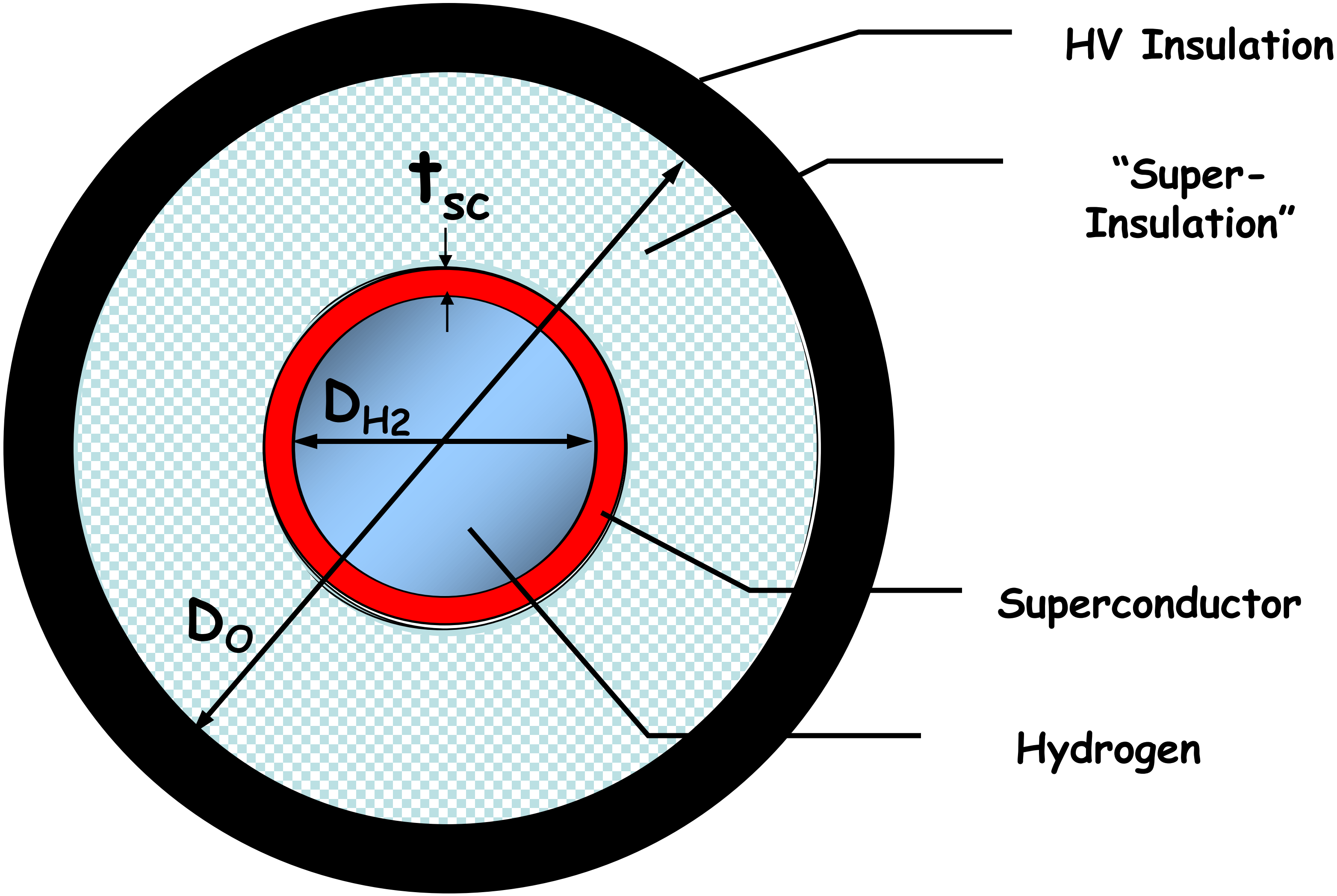


SuperCables



Multiple circuits
can be laid
in single trench

LH_2 SuperCable



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

Electric & H_2 Power

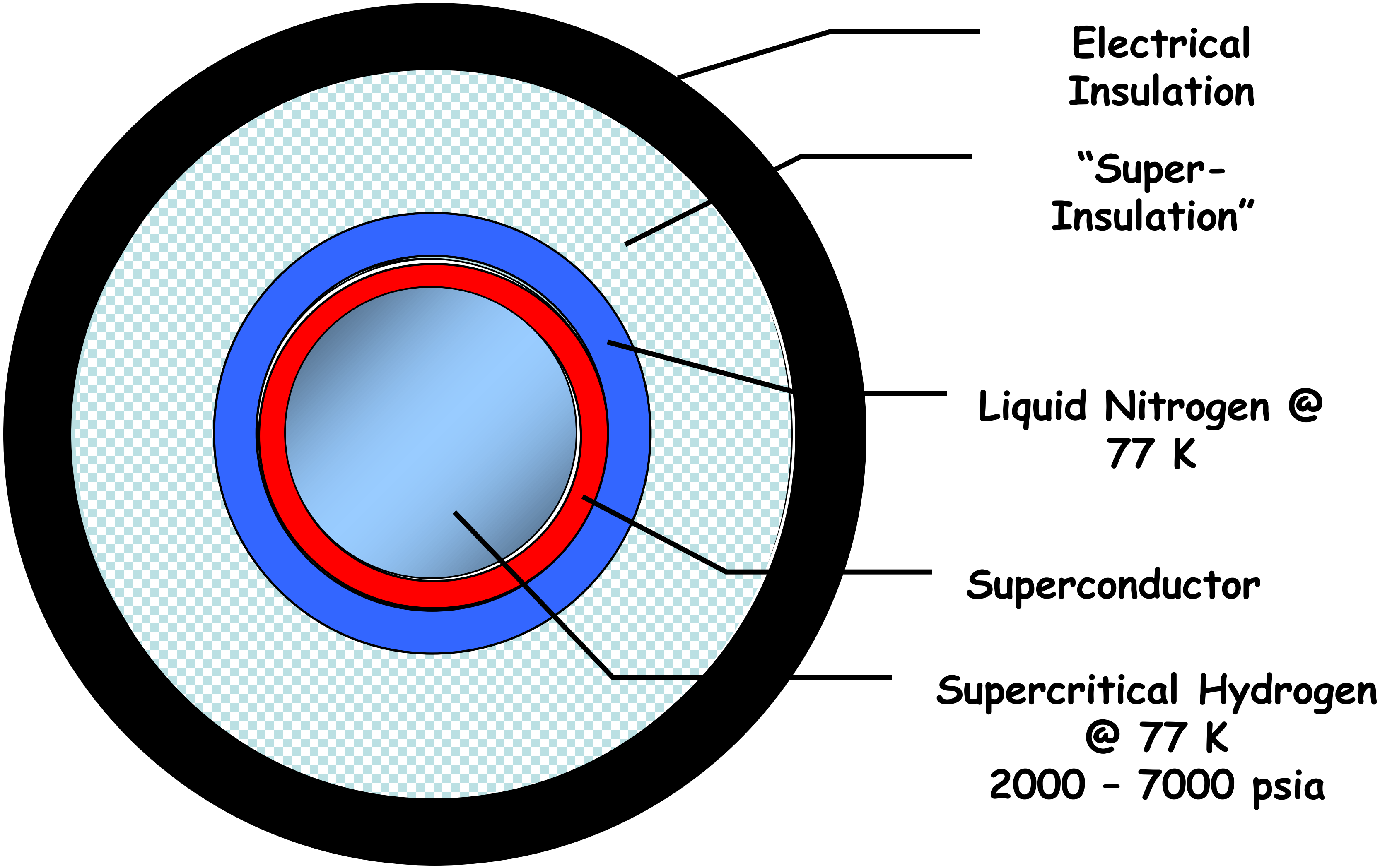
Electricity

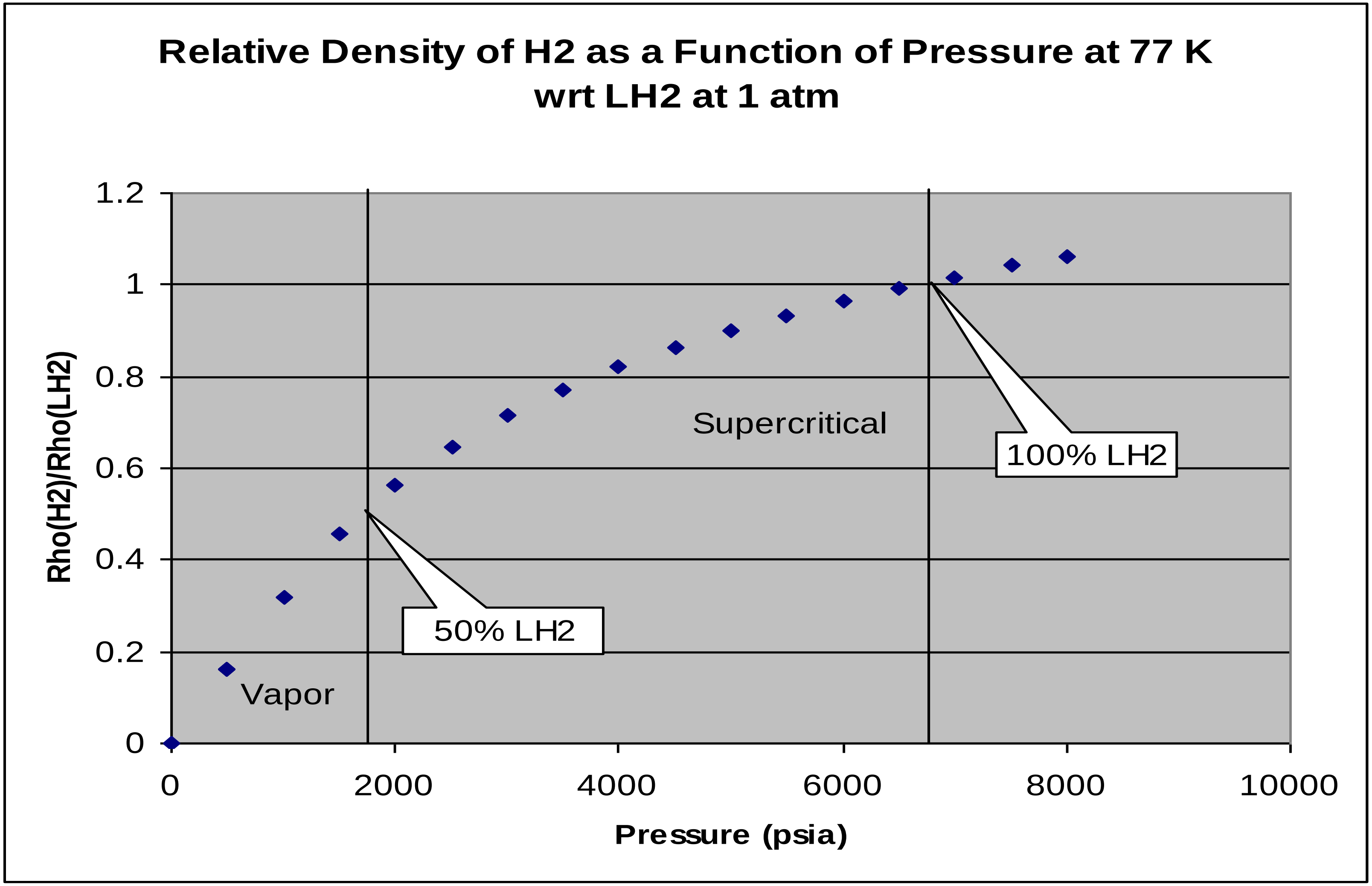
Power (MW)	Voltage (V)	Current (A)	Critical Current Density (A/cm^2)	Annular Wall Thickness (cm)
1000	+/- 5000	100,000	25,000	0.125

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

H_2 - Gas SuperCable





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

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

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

$W_R = 3.6\ W/m$

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

Remaining Issues

Current stabilization via voltage control

- AC interface (12 phase)
- Ripple suppression
  - Filters
  - Cable impedance
- Charge/Discharge cycles

Remaining Issues

Power Electronic Discretes

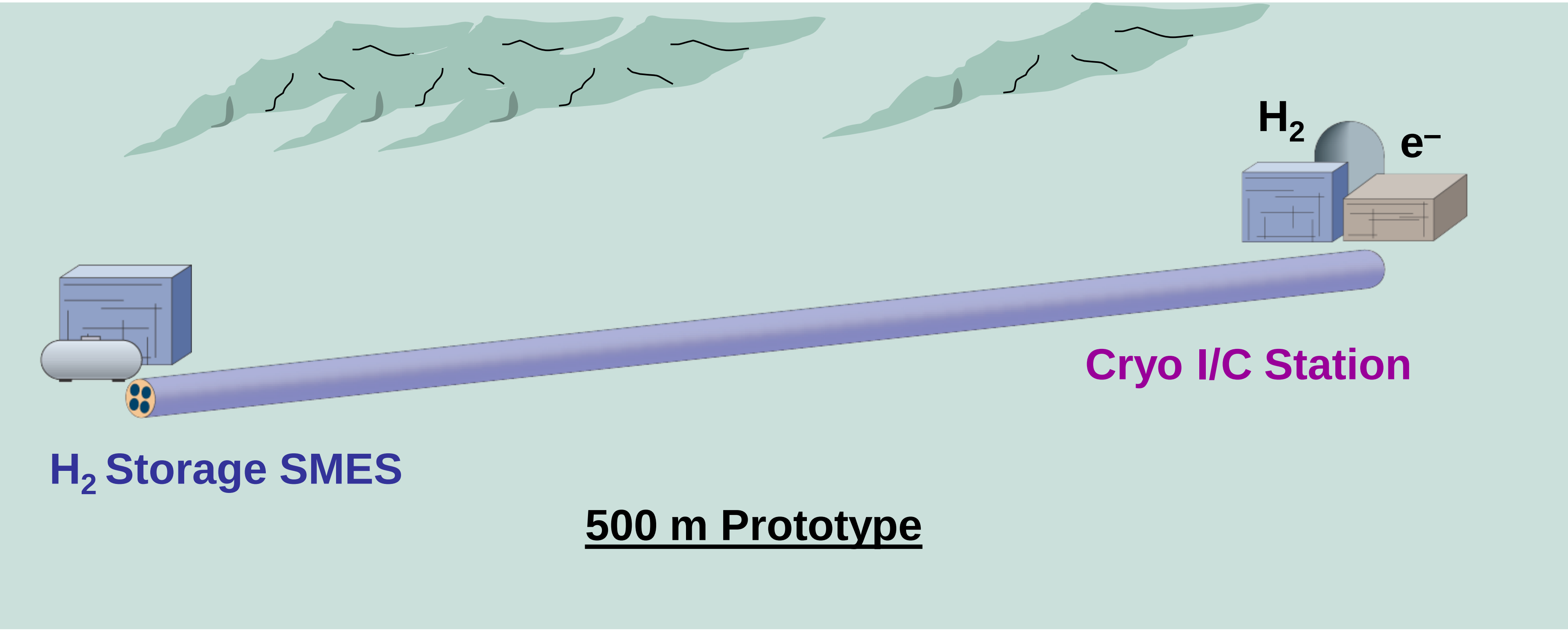
- GTOs vs IGBTs
- 12" wafer platforms
- Cryo-Bipolars
  - Minority carrier concentration
  - Doping profiles
  - Computer simulation

Remaining Issues

Hydrogen Issues

- Safety
- Generation (high pressure electrolysis)
- Cryocoolers
- Liquid vs Pressurized Gas
- Flow Rate Losses
- Storage & Delivery

SuperCable Prototype Project



"Appropriate National Laboratory"
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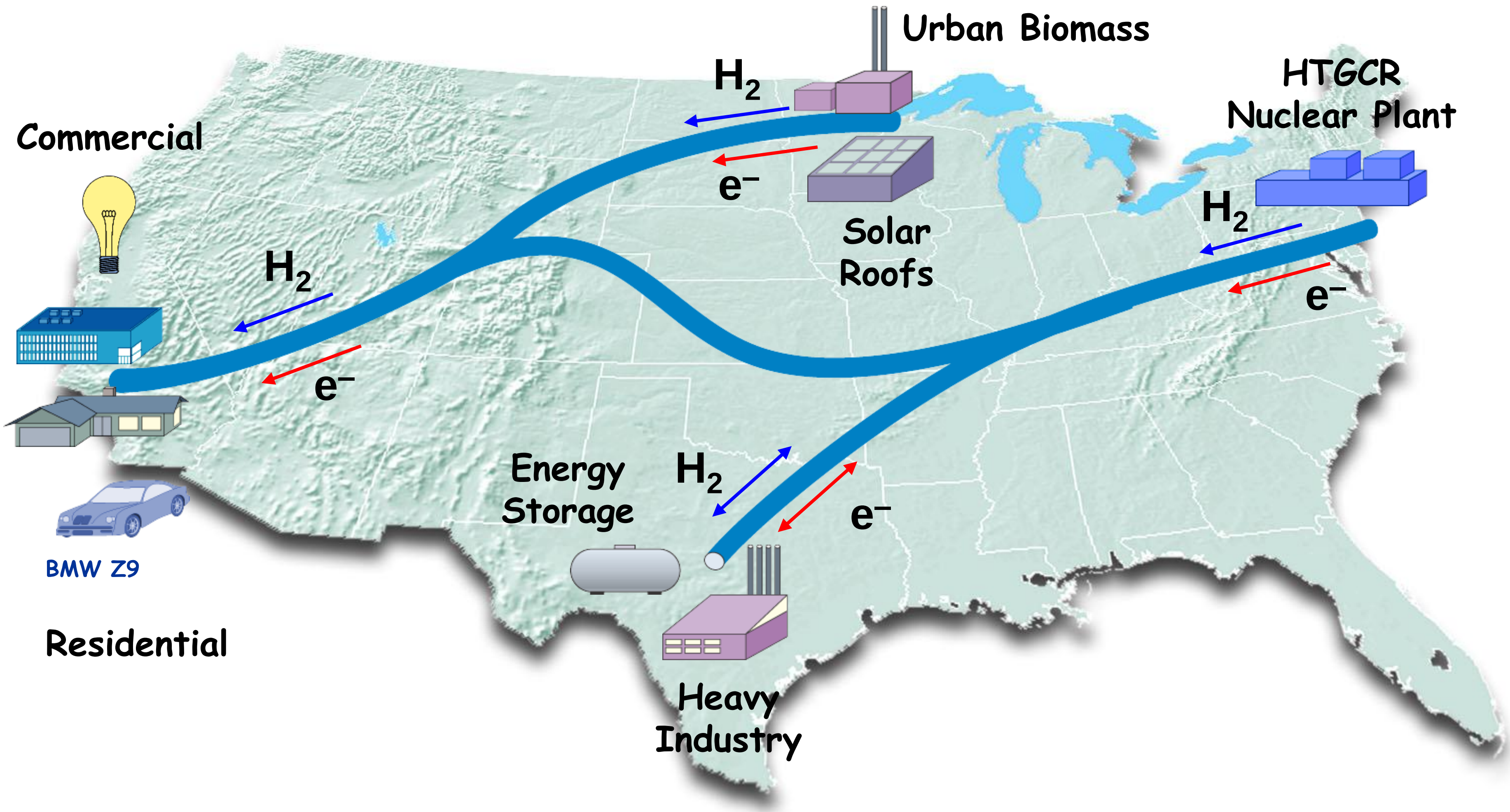
North American 21st Century Energy SuperGrid



A Vision Realized…

"…an admirable work of science and patriotism."

Marquis de Lafayette
…on first visiting the Erie Canal