# The Energy SuperGrid

*…a vision by Chauncey Starr and Paul Grant*

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Panel on Future Transmission System Options for Long-Term Energy Sustainability
IEEE PES General Meeting, Denver CO
8 June 2004

# The Energy SuperGrid

A Workshop Sponsored by
The Lounsbery Foundation
&
EPRI

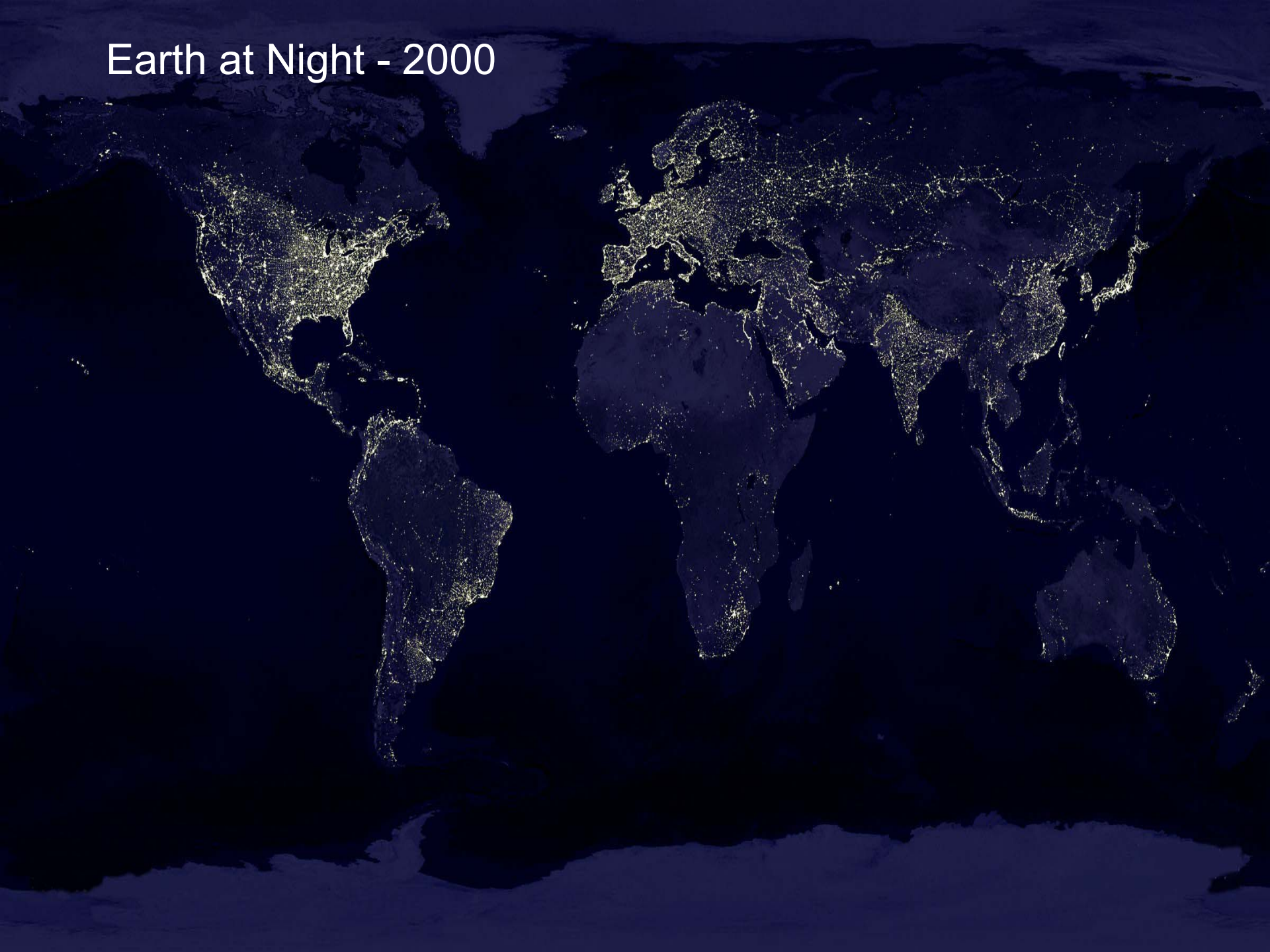
25 – 27 October 2004

University of Illinois, Urbana – Champaign
Contact Tom Overbye for Details

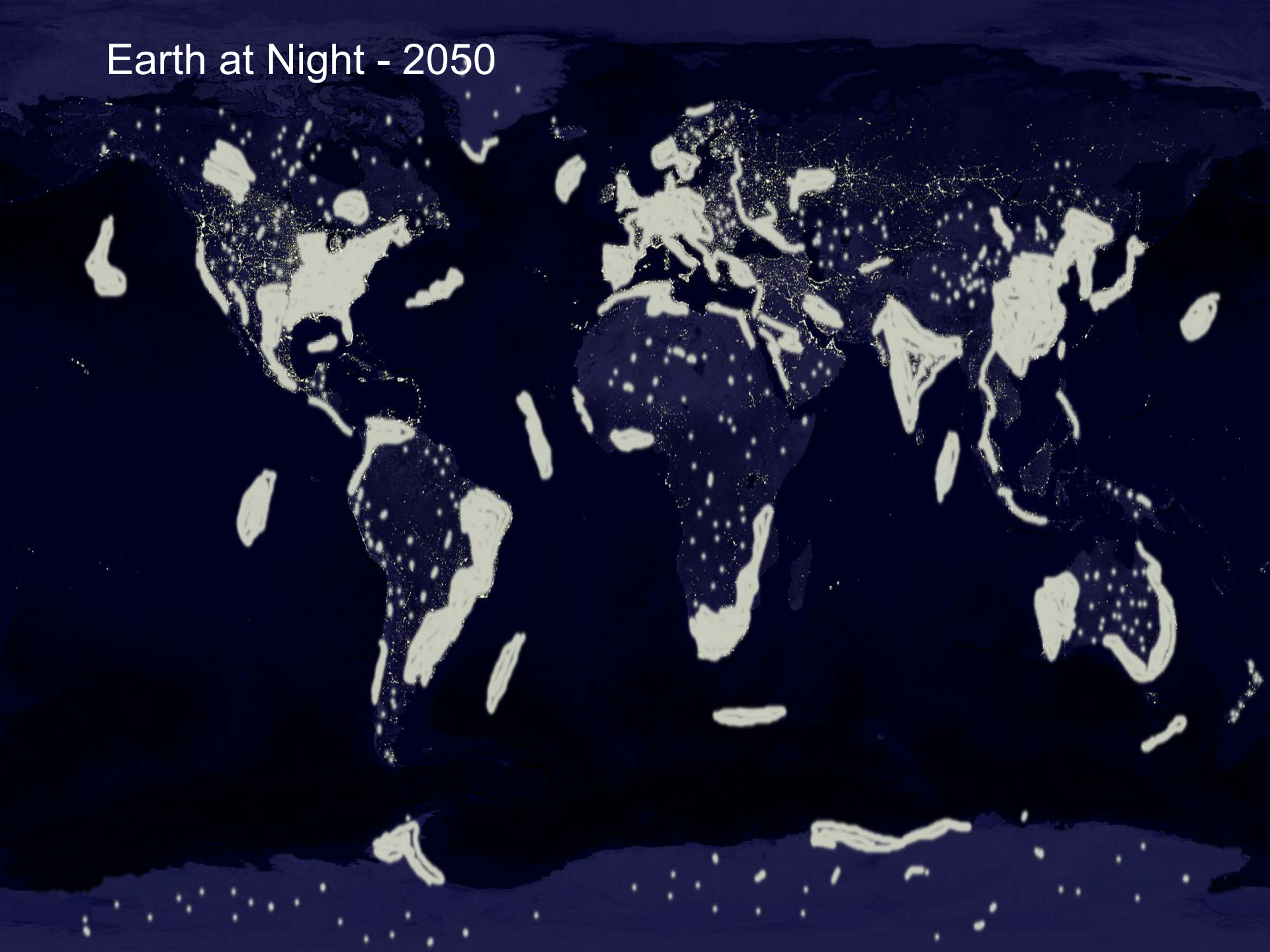
# “The Great Communicator”


*Alan Schriesheim, Director of Argonne National Laboratory, demonstrates superconductivity to the President, Chief of Staff Howard Baker, Secretary of Defense Caspar Weinberger, Secretary of State George Shultz and Secretary Herrington.*

# Earth at Night - 2000



# Earth at Night - 2050



# “The Present Grid”


Wired Magazine, June 2001

# 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!***

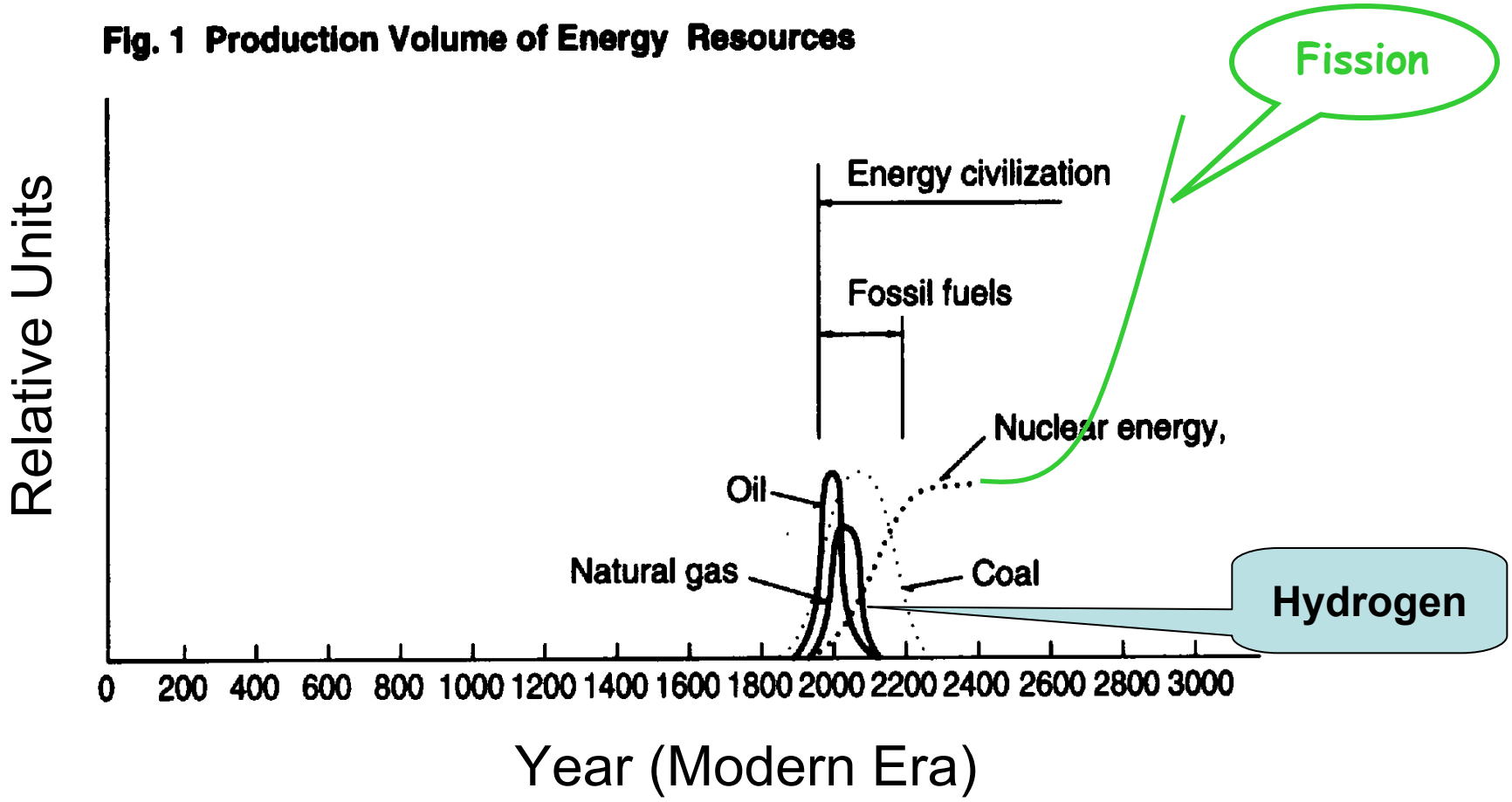
# Its Solution

***A Symbiosis of***

***Nuclear/Hydrogen/Superconductivity***

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

# Past & Future Energy Supply

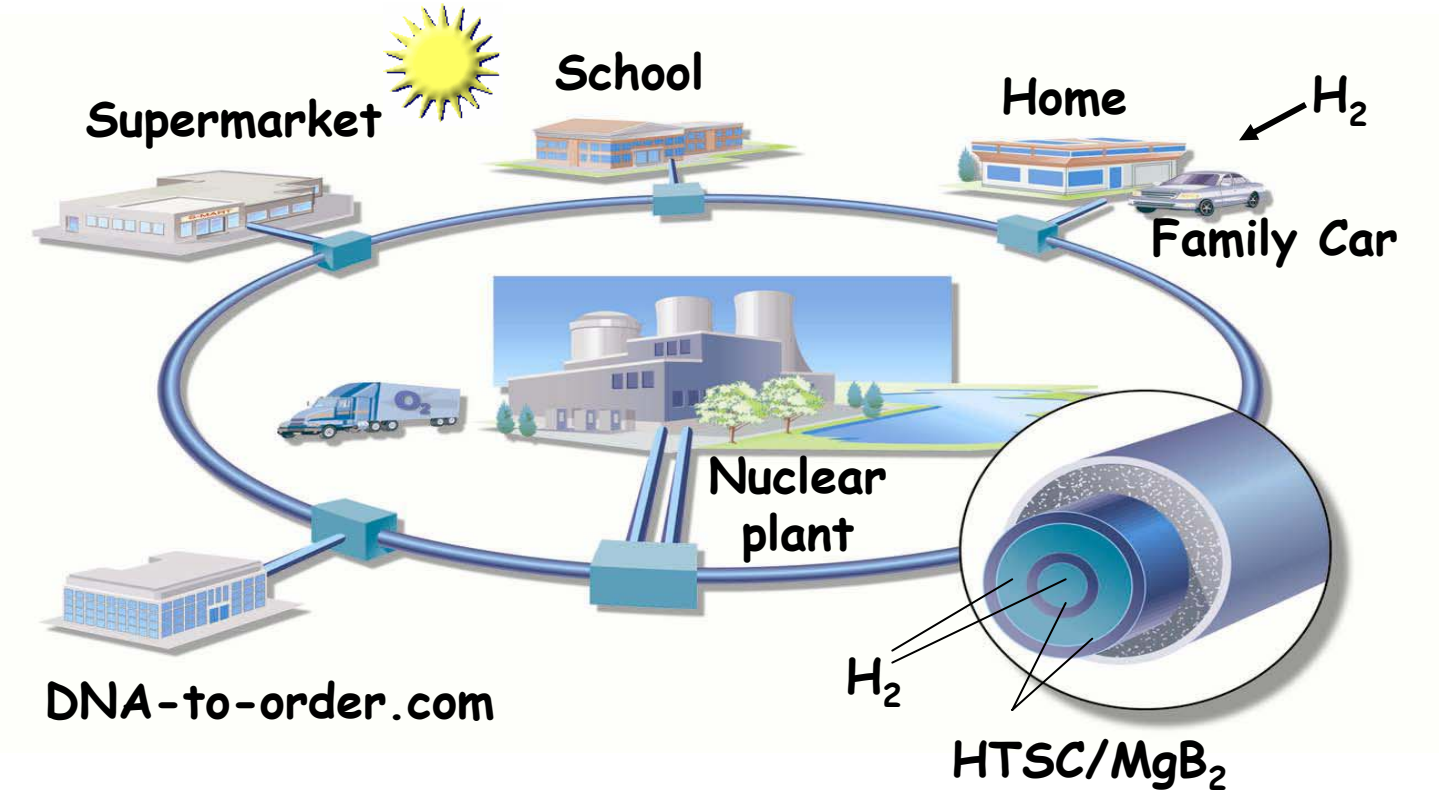


# The Hydrogen Economy

- 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)**

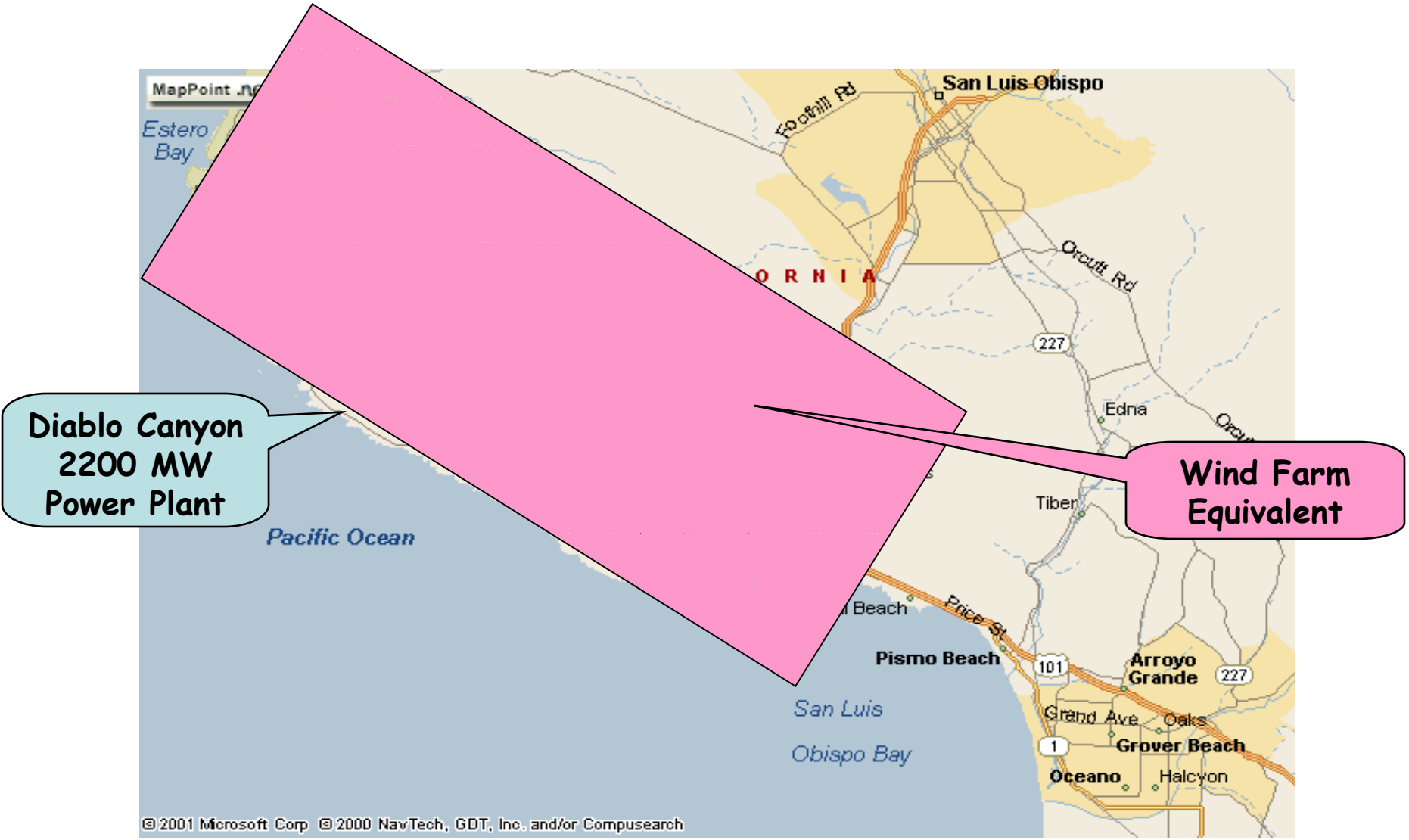
# SuperCity



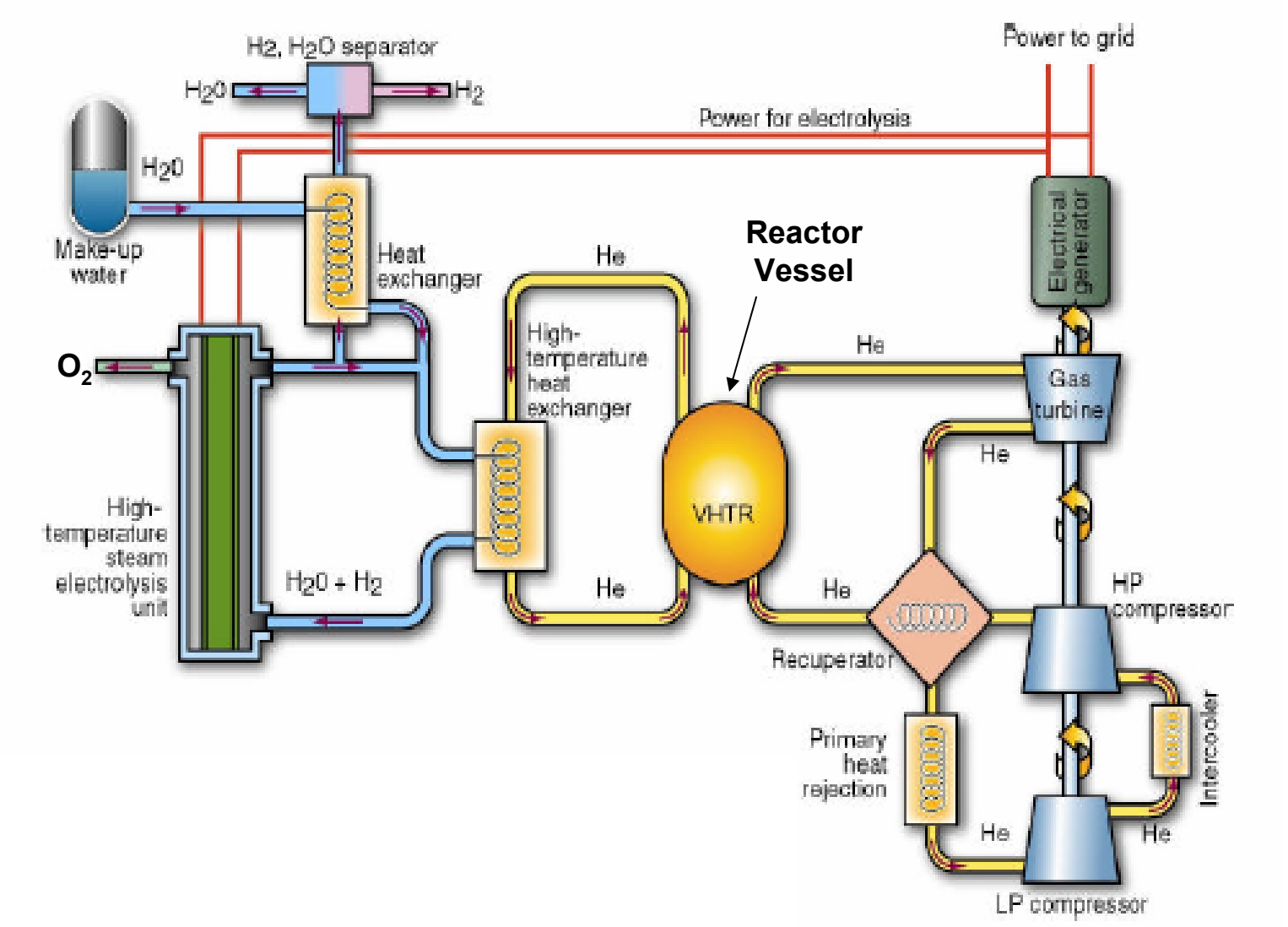

P.M. Grant, The Industrial Physicist, Feb/March Issue, 2002

# Diablo Canyon

# California Coast Power

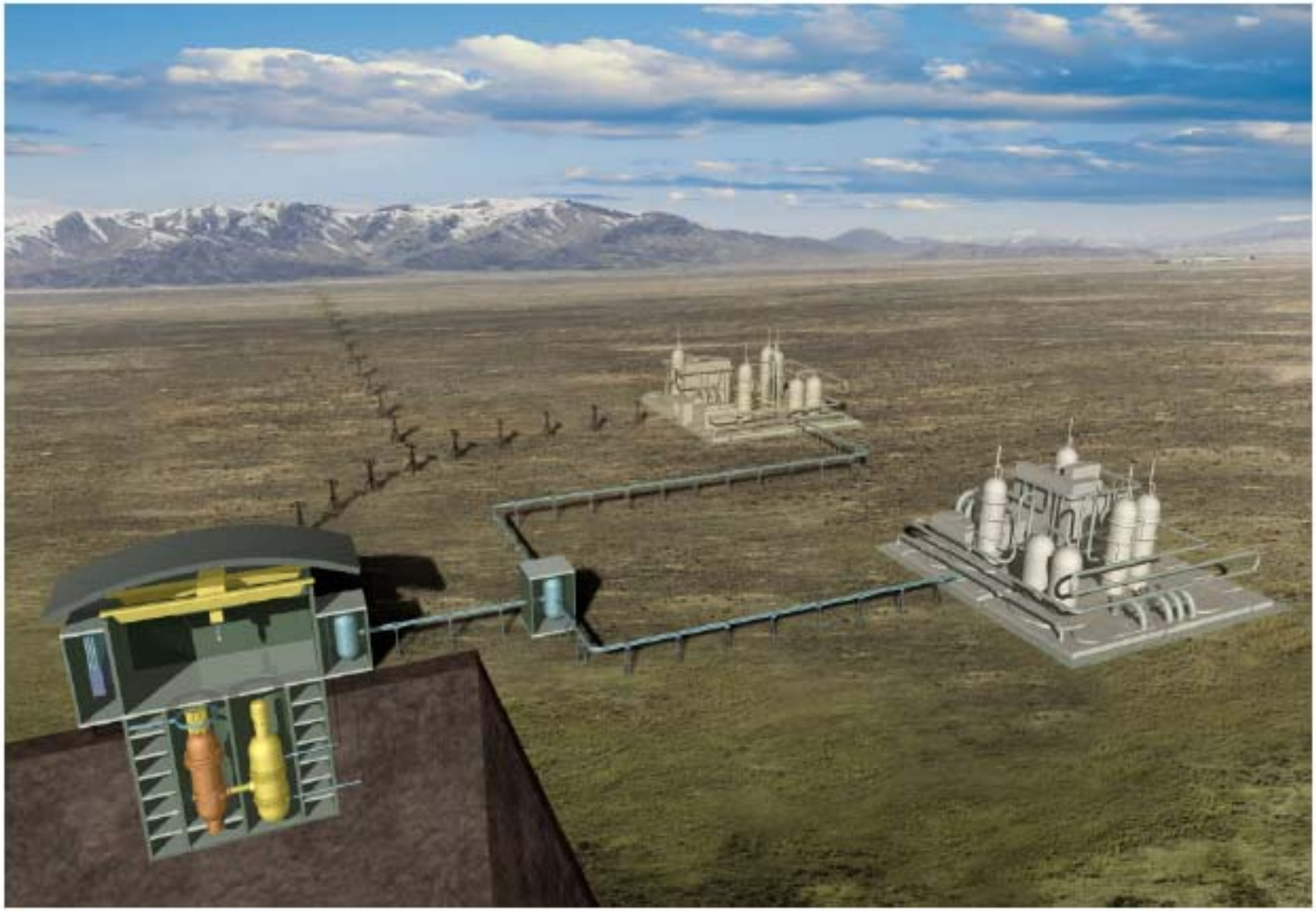


# Co-Production of Hydrogen and Electricity



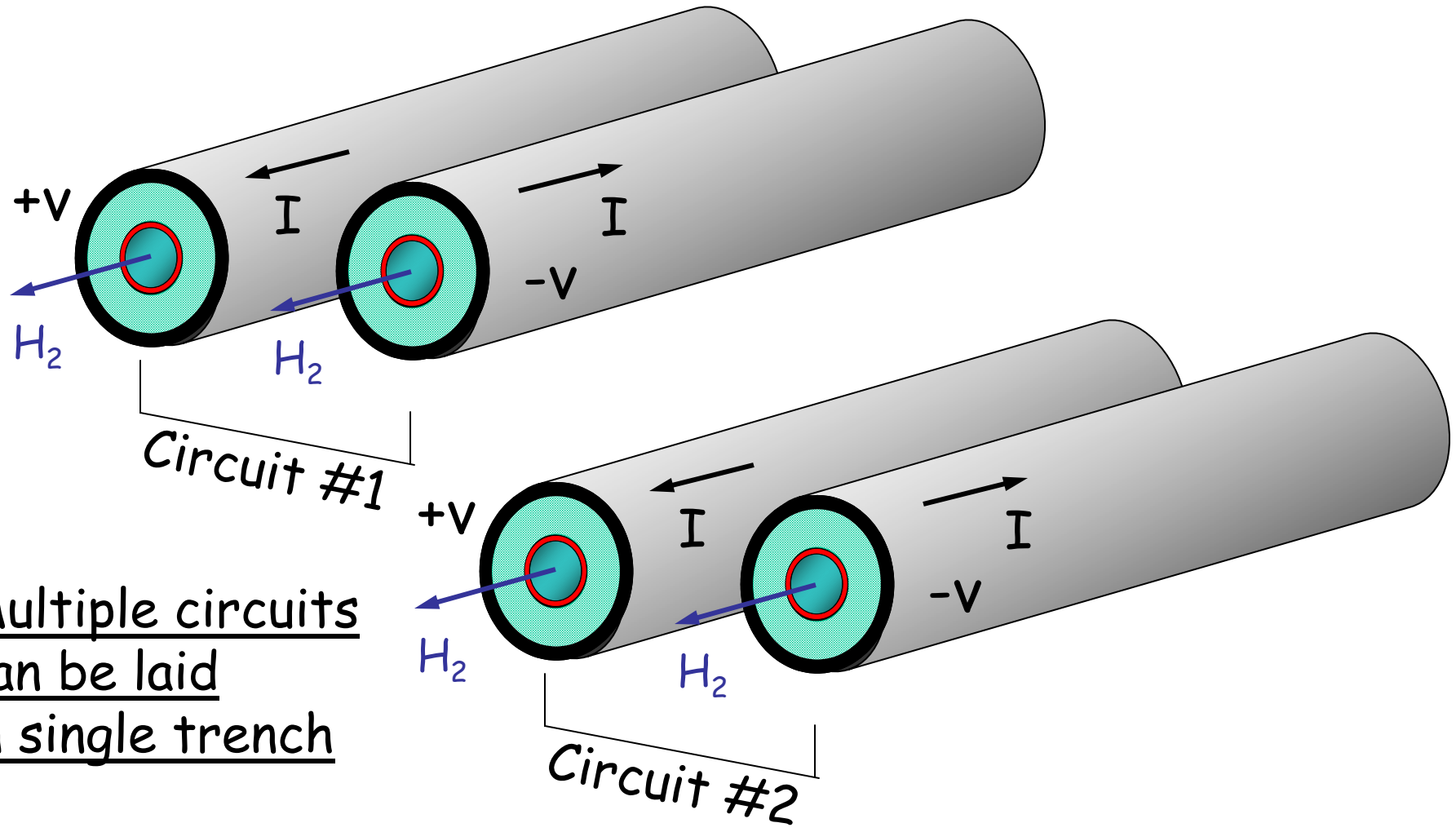

*Source: INEL & General Atomics*

# Nuclear “Hydricity” Production Farm



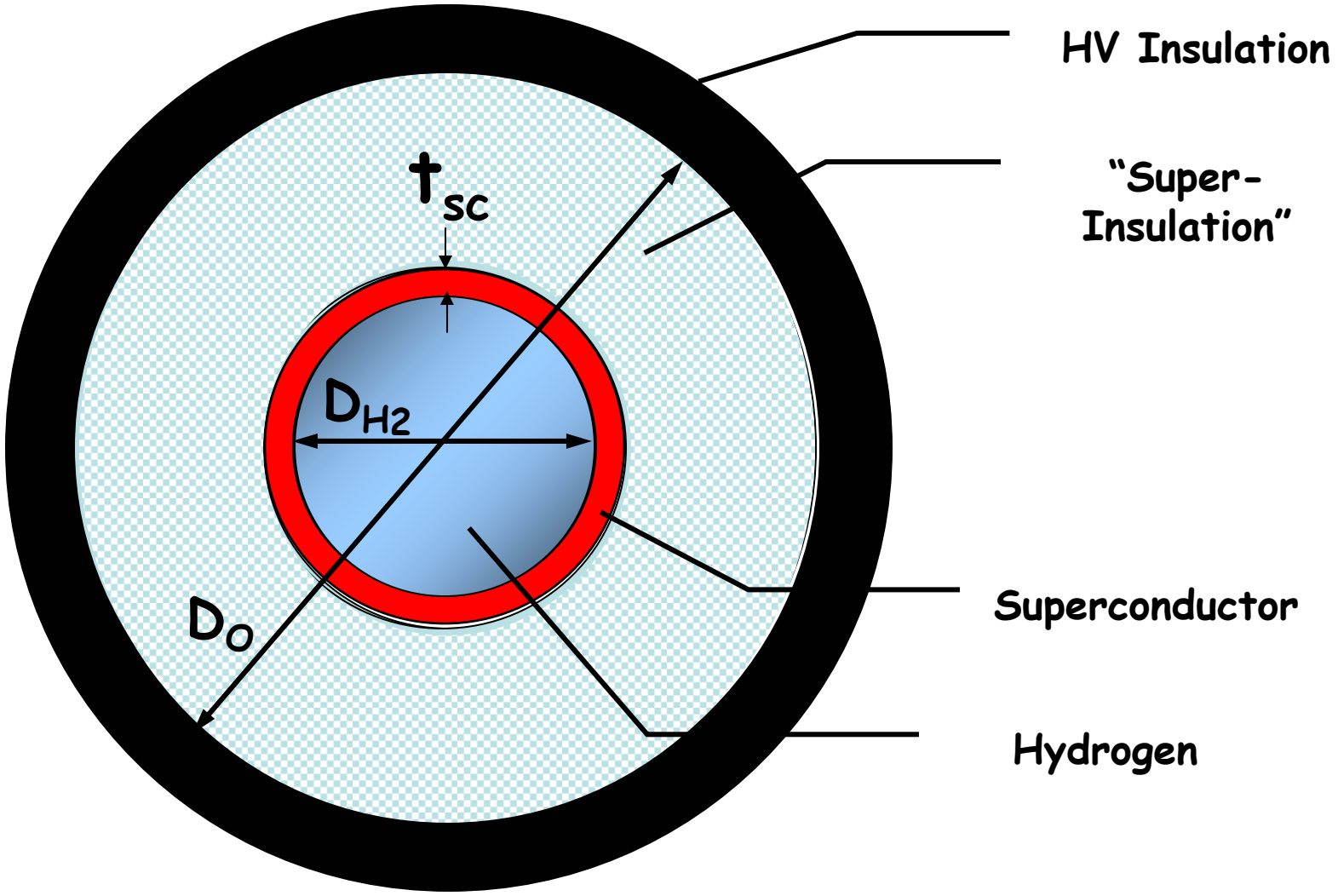
*Source: General Atomics*

# “Hydricity” SuperCables




Multiple circuits
can be laid
in single trench

# 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 $H_2$)
$\rho$ = $H_2$ 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 |

# 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$^2$K$^4$
$T_{amb}$ = 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: $W_R^f$ = 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
$\rho$ = $H_2$ 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

# 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

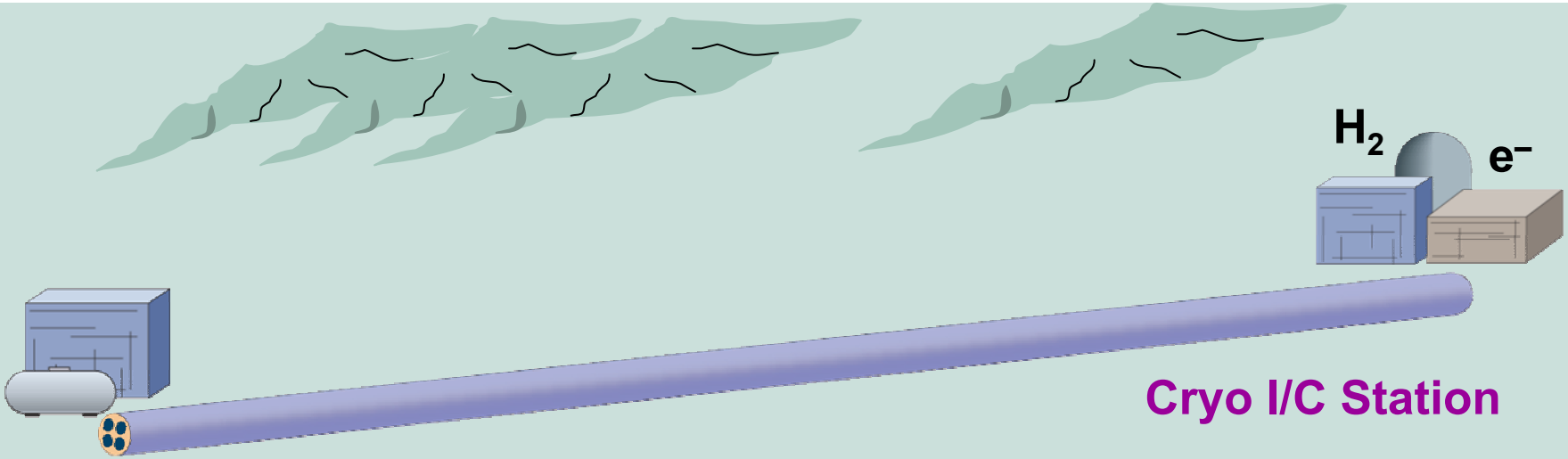
# SuperCable $H_2$ Storage

| ***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**

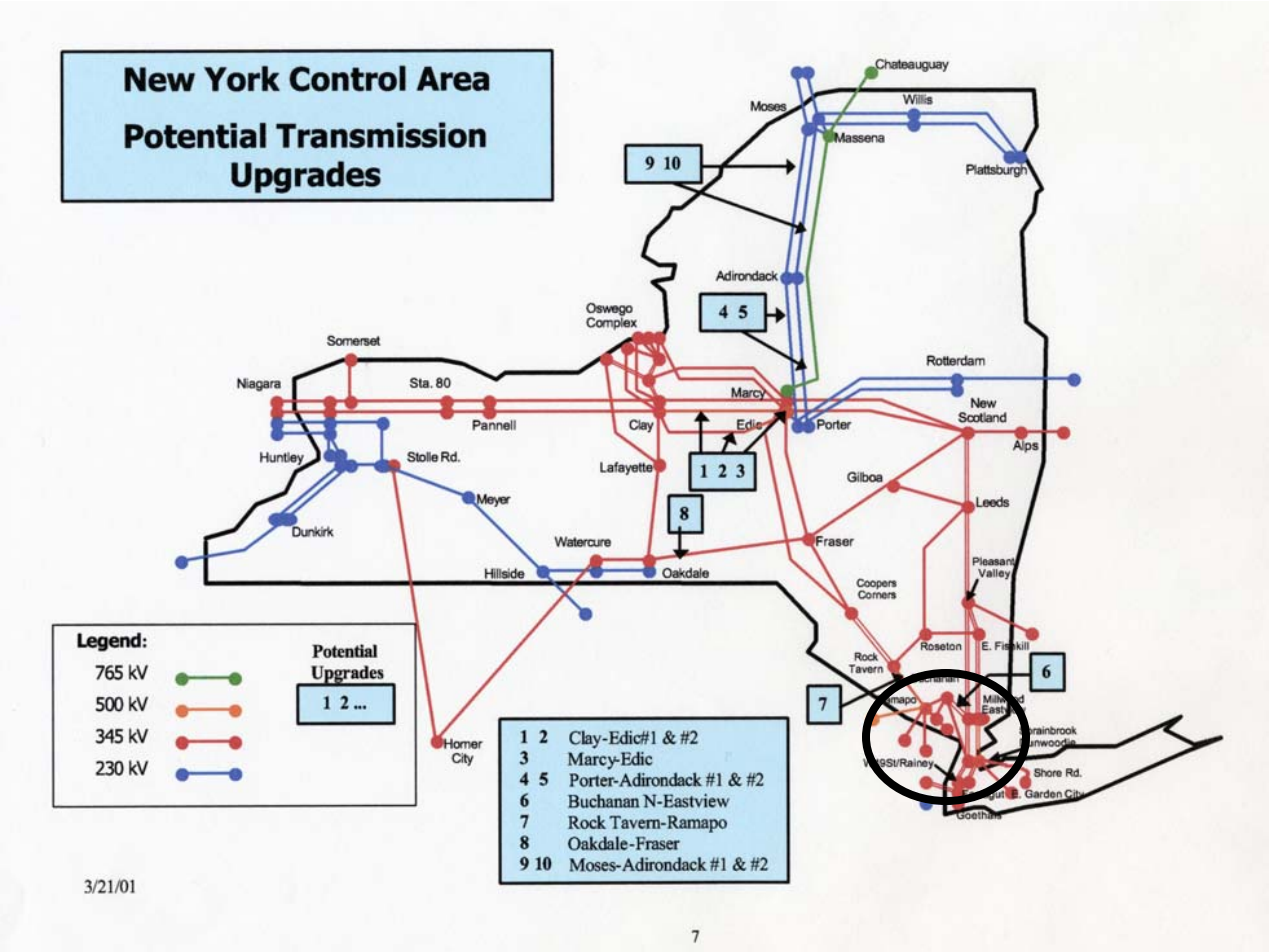
# SuperCable Prototype Project



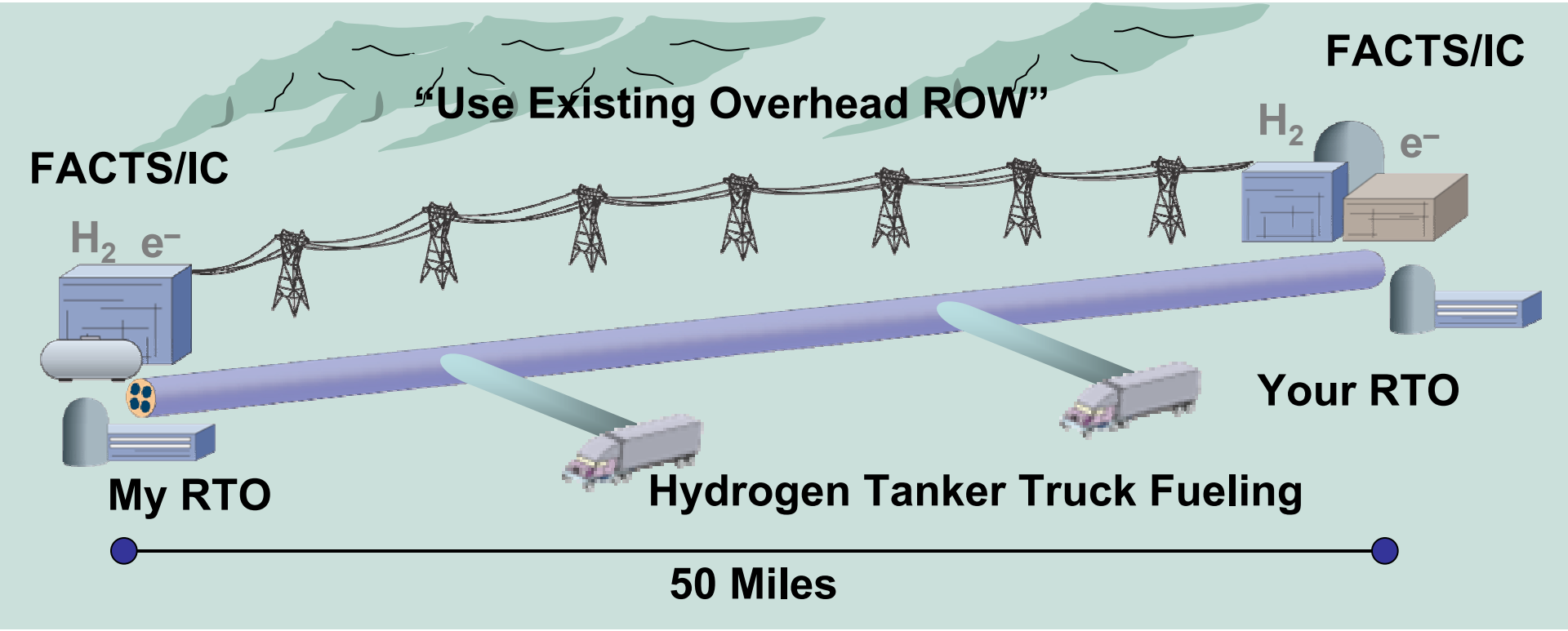

**500 m Prototype**

**"Appropriate National Laboratory"**
**2005-09**

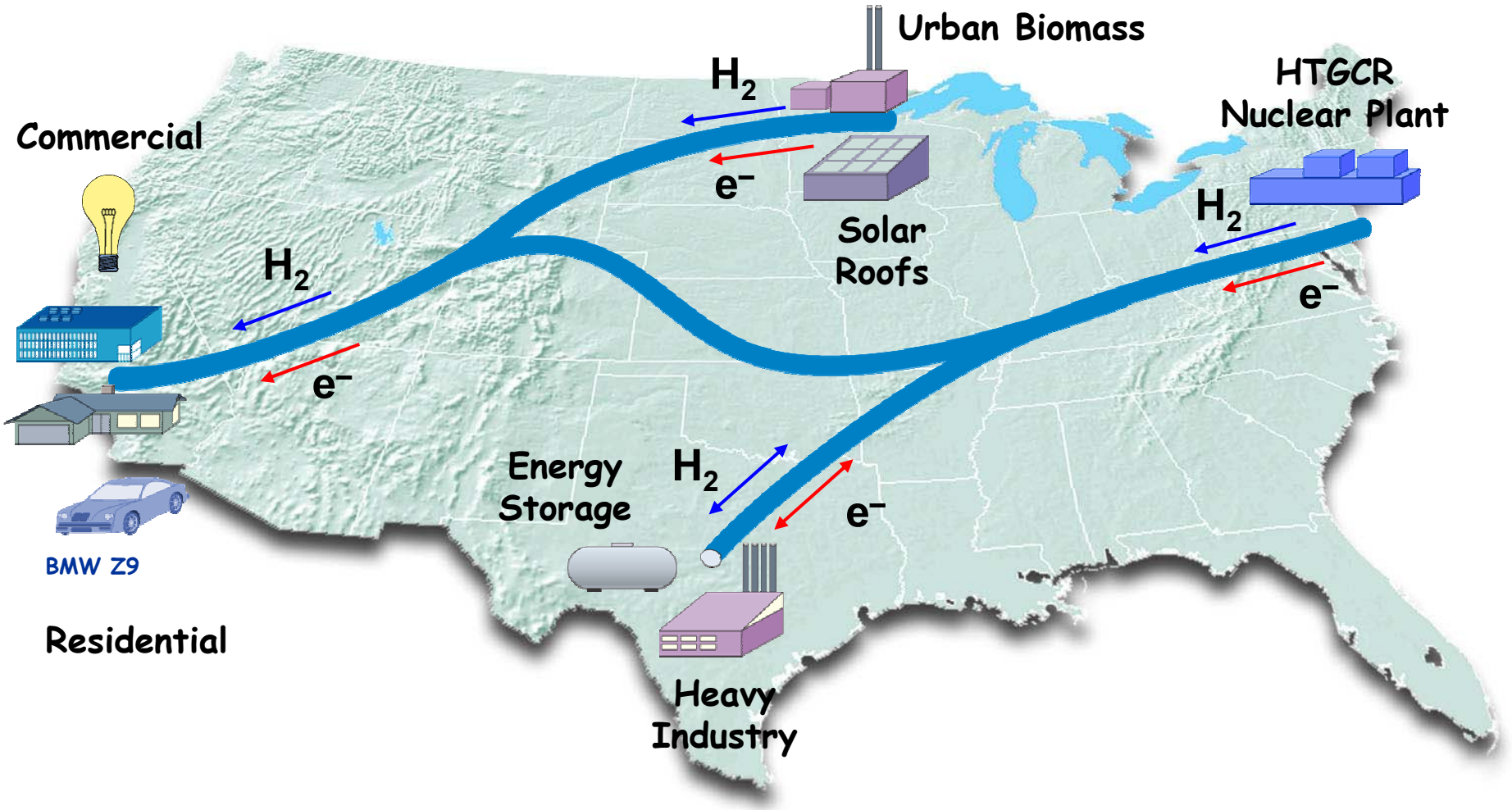
# Regional System Interconnections



# RegionGrid Interconnection



# North American 21st Century Energy SuperGrid



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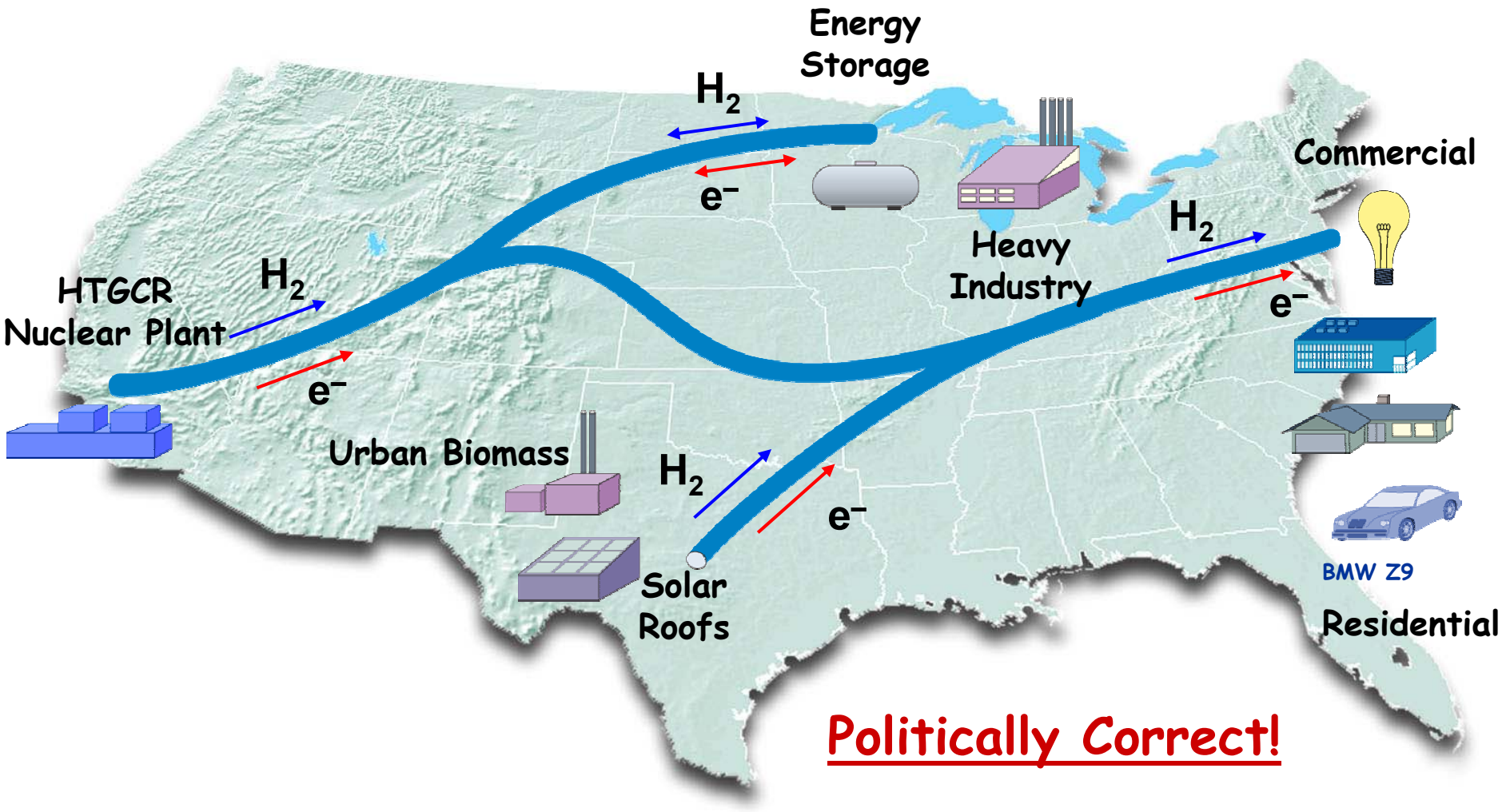


**Politically Correct!**

# Wisdom Down the Ages
# - Inspiration for the SuperGrid -

Where there is no vision,
the people perish…

*Proverbs 29:18 (1000 BCE)*

**"…an admirable work of science and patriotism."**

*Marquis de Lafayette (1825)*
…on first seeing the Erie Canal

**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!***

*Tennessee Lay Preacher (1941)*