Physics Colloquium

SuperCities and SuperGrids

A Vision for Long-term Sustainable and Environmentally Compatible Energy Independence for North America

SuperCities and SuperGrids

A Vision for Long-term Sustainable and Environmentally Compatible Energy Independence for North America

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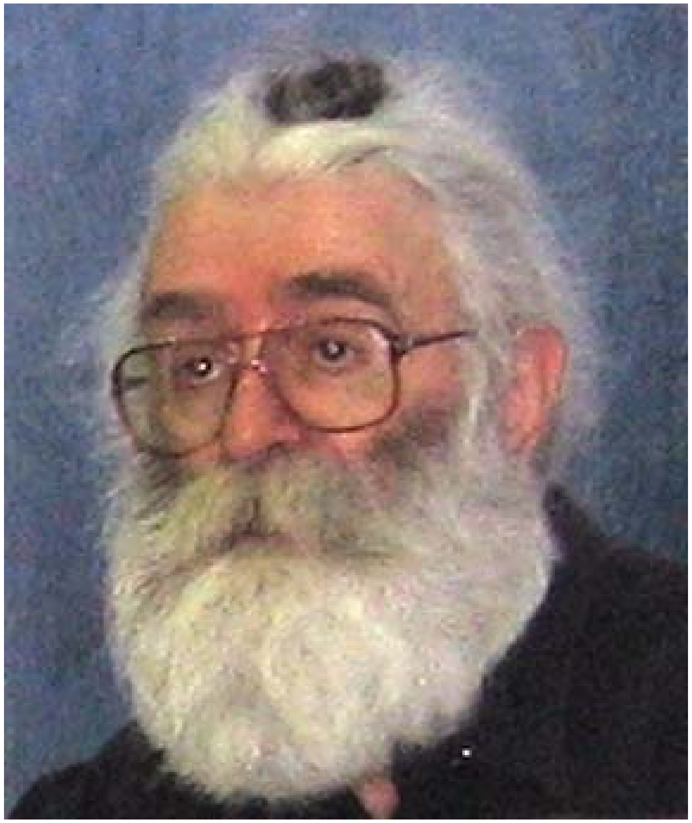
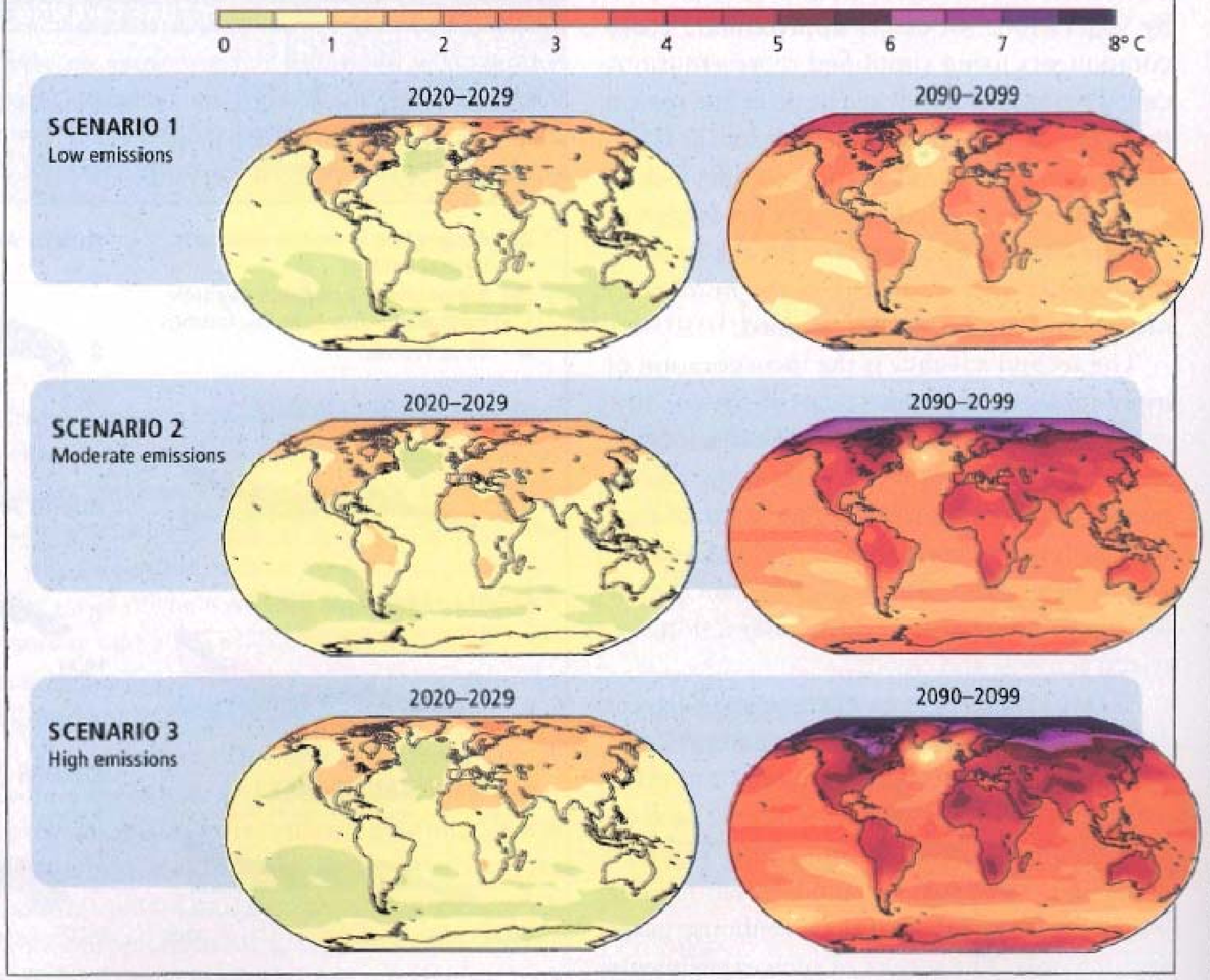
http://www.w2agz.com/ucdpc08.htm

Aging IBM Pensioner

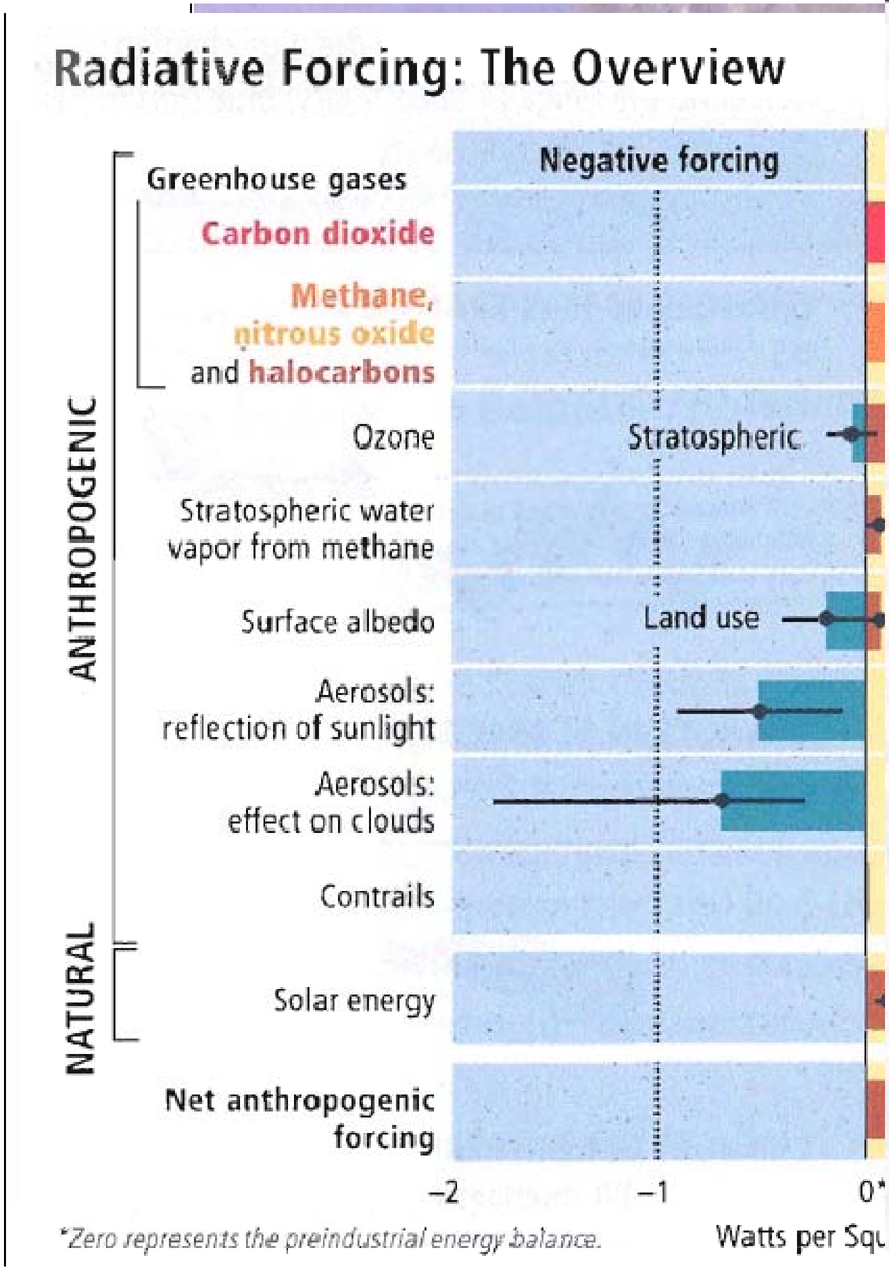
I AM NOT **Radovan Karadzic**!





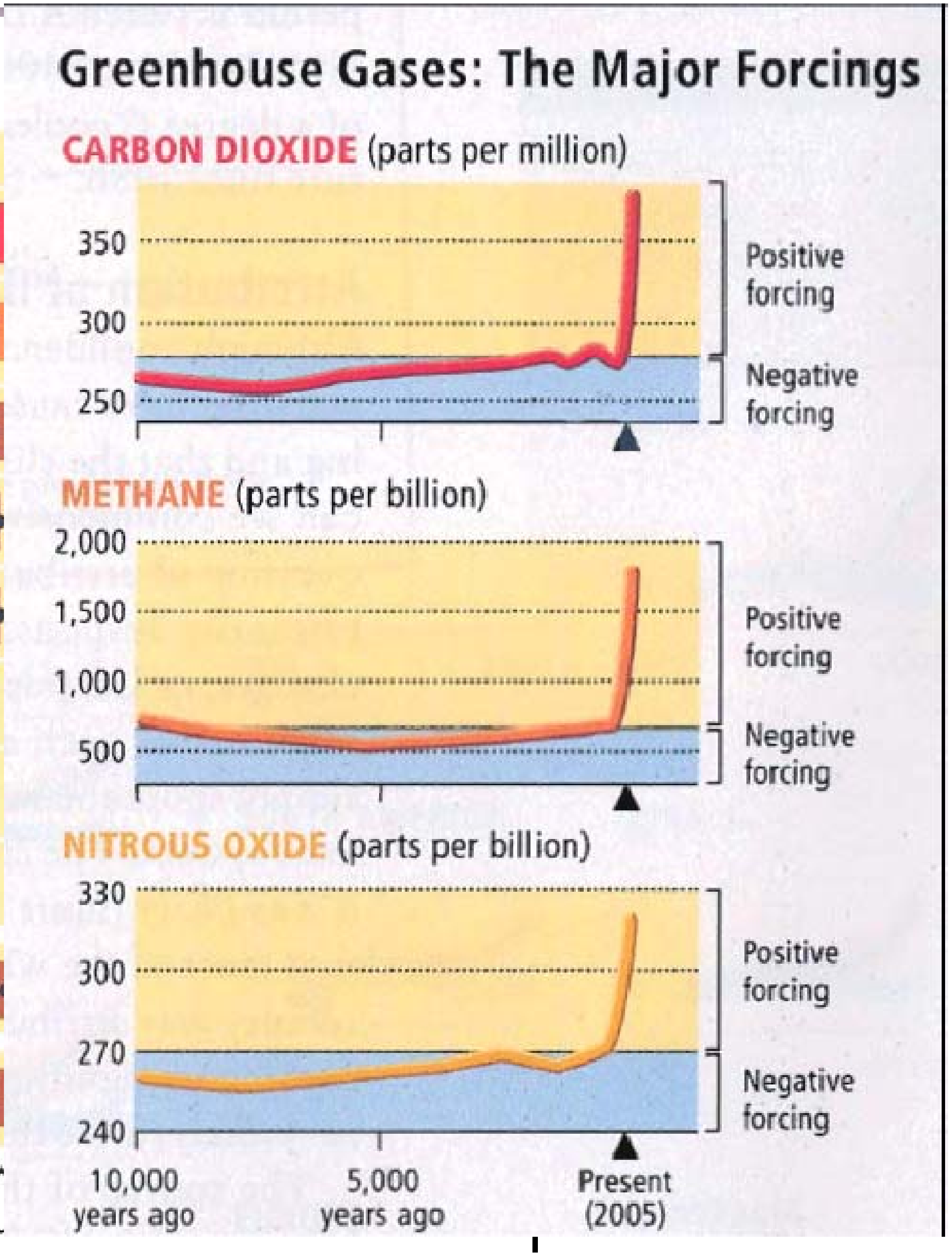
DANIELA NAOMI MOLNAR; SOURCE: *CLIMATE CHANGE 2007: THE SCIENTIFIC BASIS, SUMMARY FOR POLICYMAKERS*, INTERGOVERNMENTAL PANEL ON CLIMATE CHAN

SciAm – August, 2007 Issue



Radiative Forcing: The Overview

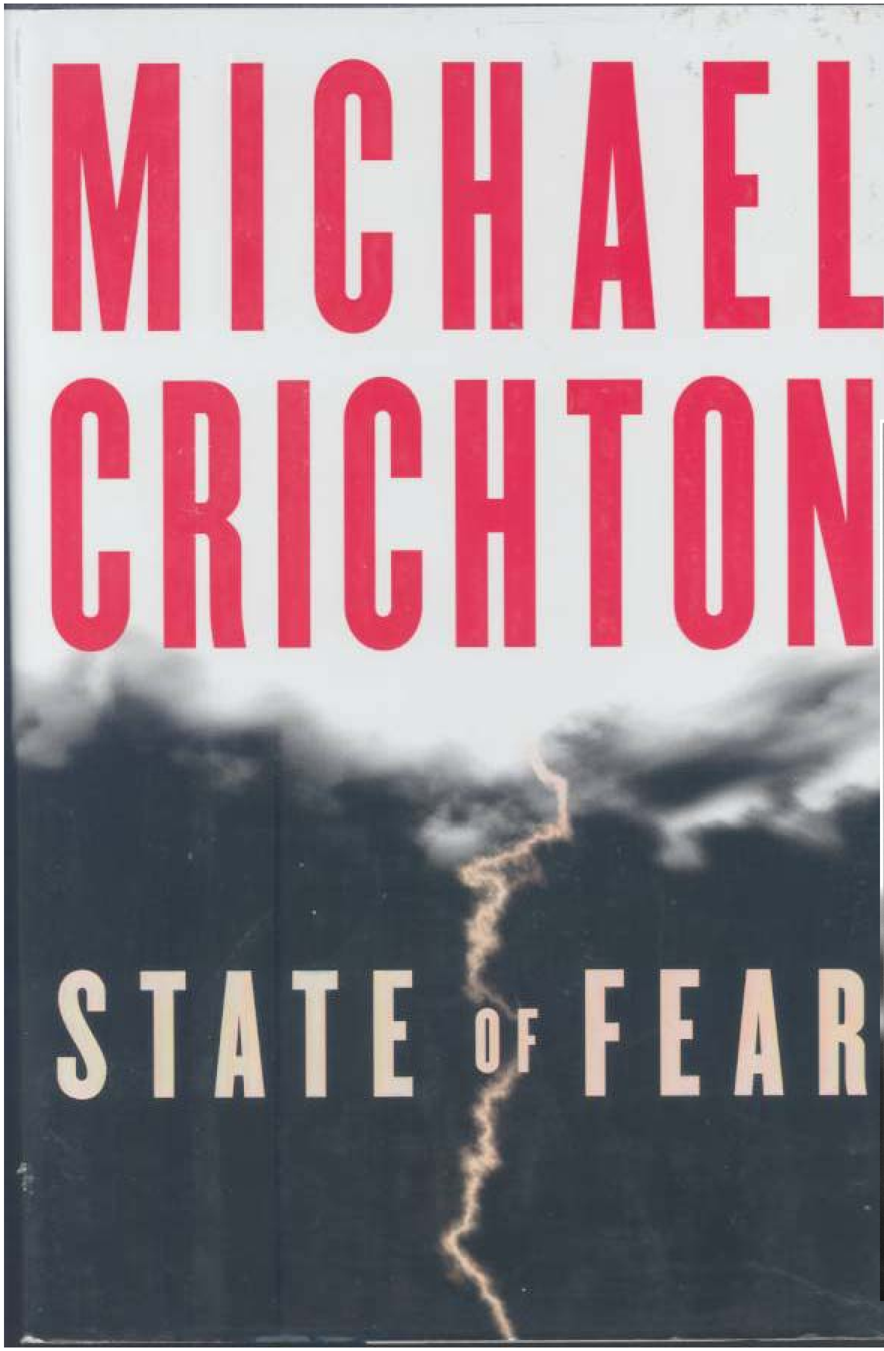
*Zero represents the preindustrial energy balance.



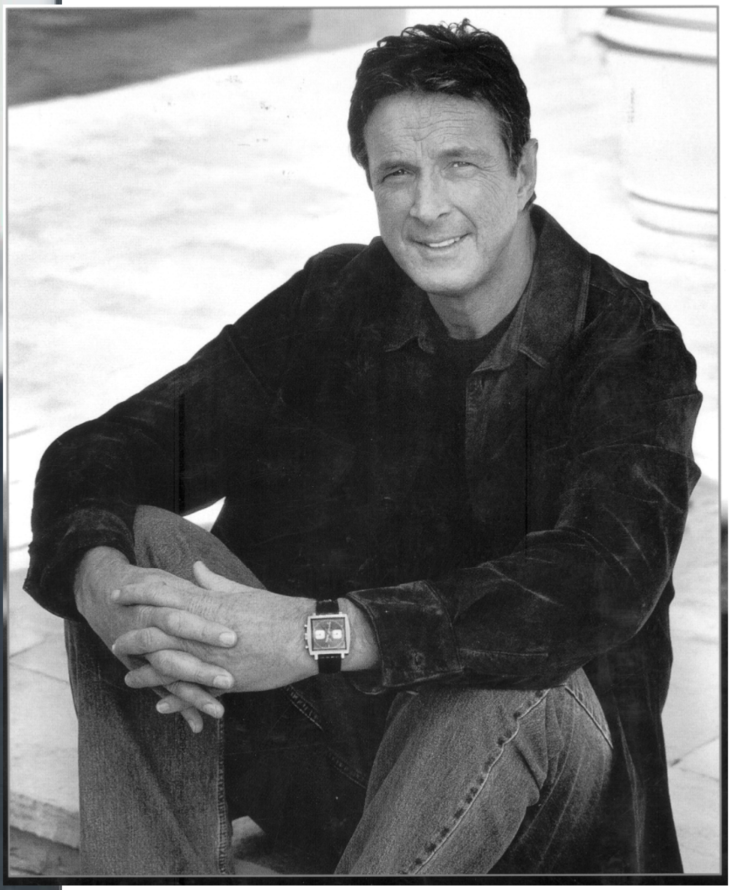
Greenhouse Gases: The Major Forcings

The Day After Tomorrow

An Inconvenient Truth


MICHAEL
CRICHTON

STATE OF FEAR



“Greenhouse Gases”

“Expert Opinion”

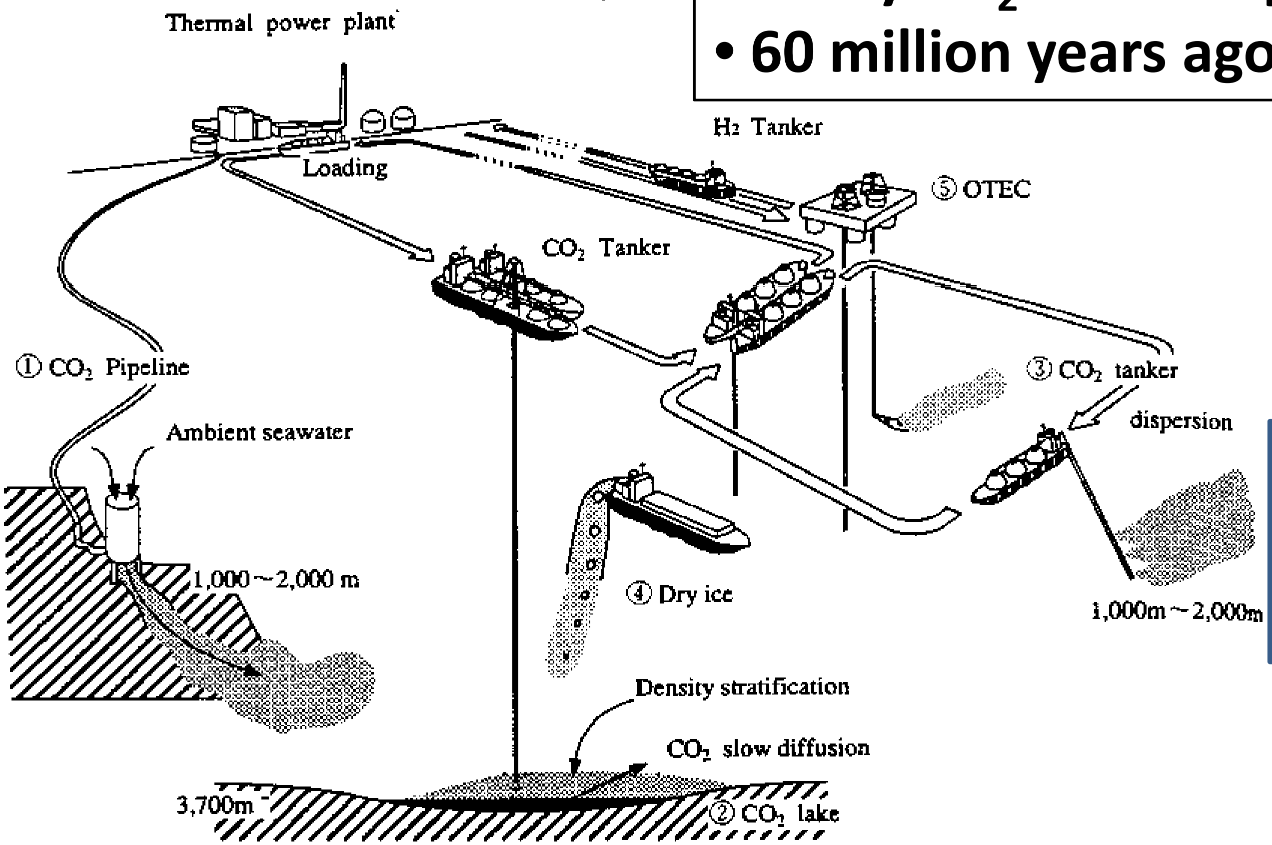
- Nate Lewis
  - Mitigation is more or less hopeless without massive skewing of the “laws of economics” through government intervention
- Bill Nordhaus
  - By 2100, the global economy will be rich enough to afford adapting to 500-600 ppm CO_2
- Fred Singer
  - No problem (GCC is good for you…)
- William Ruddiman
  - Invention of agriculture 8000 years ago and subsequent methane emissions saved the planet from undergoing a “scheduled cyclic ice age.”
- Jesse Ausubel
  - To propose significant deployment of renewables is a “heresy.”
- Sean Hannity
  - It’s all due to Al Gore, Sean Penn and Leonardo DiCaprio flying around in private jets.

“Not-so-Expert Opinion”

- Exactly what is “clean coal?”
    - Is it “heavy metal free?”
    - Is it “sulfur free?”
    - Is it “zero emissions?”
    - Is it “all of the above?”
- Don’t ask George Bush or Barack Obama, because they haven’t a clue

Carbon Dioxide – Where do we put it?

- **Today CO_2 is at 400 ppm**
- **60 million years ago, it was 7000!**

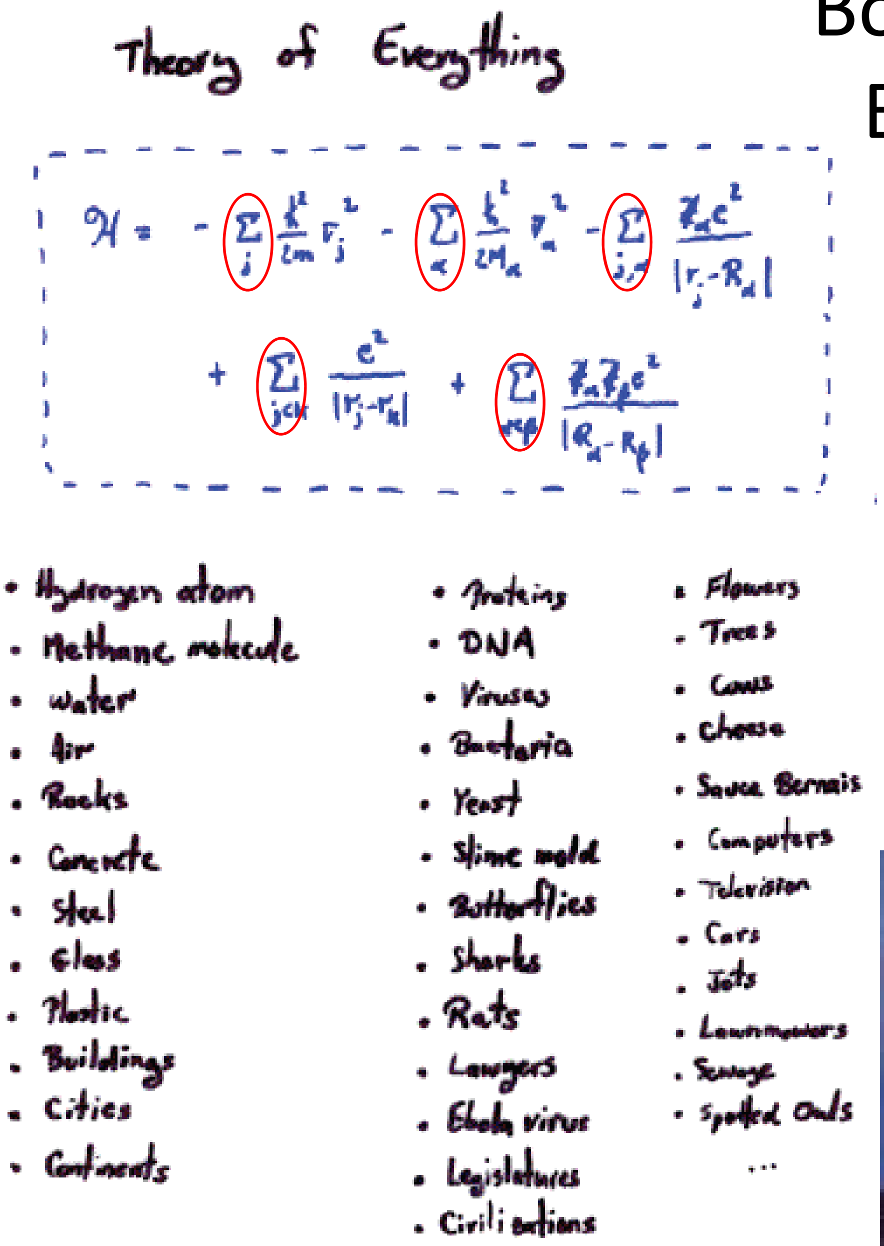


...maybe the best place is in the atmosphere☺

Carbon dioxide ocean disposal options

(Adapted from Fujioka et al, 1997)

Bob Laughlin’s “Theory of Everything” (that’s important!)



Theory of Everything

$$\mathcal{H} = -\sum_j \frac{\hbar^2}{2m}\nabla_j^2 - \sum_\alpha \frac{\hbar^2}{2M_\alpha}\nabla_\alpha^2 - \sum_{j,\alpha}\frac{Z_\alpha e^2}{|\mathbf{r}_j - \mathbf{R}_\alpha|} + \sum_{j<k}\frac{e^2}{|\mathbf{r}_j - \mathbf{r}_k|} + \sum_{\alpha<\beta}\frac{Z_\alpha Z_\beta e^2}{|\mathbf{R}_\alpha - \mathbf{R}_\beta|}$$

- Hydrogen atom
- Methane molecule
- water
- Air
- Rocks
- Concrete
- Steel
- Glass
- Plastic
- Buildings
- Cities
- Continents
- Proteins
- DNA
- Viruses
- Bacteria
- Yeast
- Slime mold
- Butterflies
- Sharks
- Rats
- Lawyers
- Ebola virus
- Legislatures
- Civilizations
- Flowers
- Trees
- Cows
- Cheese
- Sauce Bernais
- Computers
- Television
- Cars
- Jets
- Lawnmowers
- Sewage
- Spotted Owls

...

- 3 -> 10^2
  - Chemistry
- 10^2 <-> 10^3
  - Thermodynamics
- 10^3 <-> 10^{10}
  - Cooperative Phenomena
- 10^{10} <-> 10^{20}
  - Emergent Behavior (Us)

- > 10^{20}
  - CLIMATE !
- **SIZE MATTERS !**

Overture

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

Chauncey Starr
1912 - 2007

Obituary, Nature, 14 June 2007

Boundary Conditions

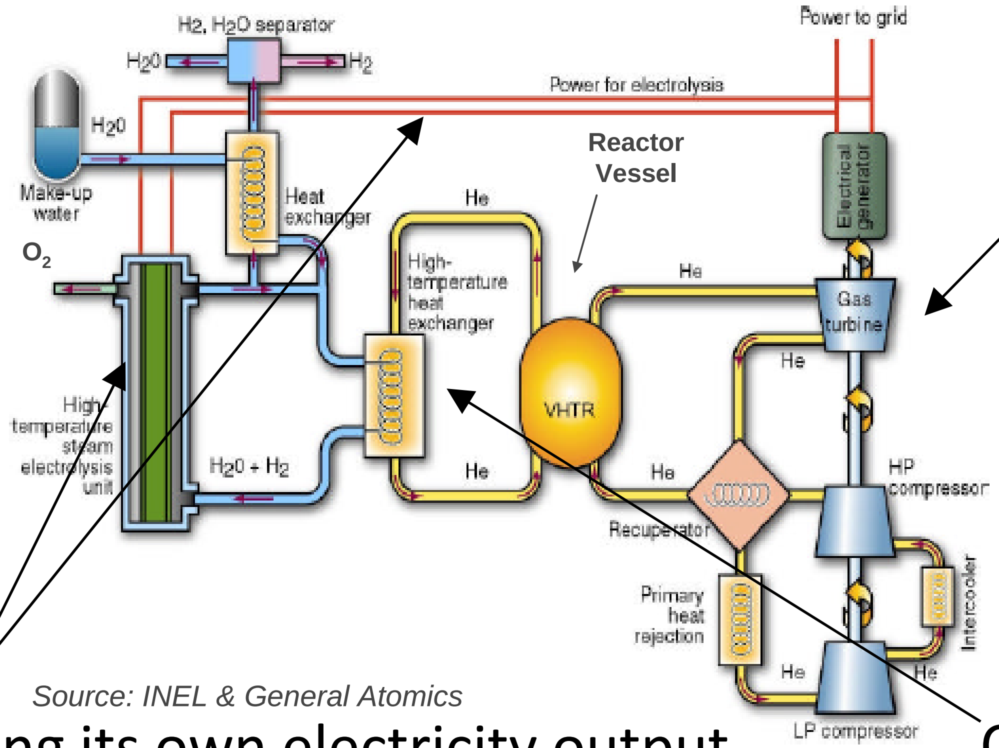
- Carbonless
  - No CO_2
- Non-Eco-Invasive
  - Minimal land/ecology impact
- Off-the-table
  - Large scale renewables (wind, solar, bio)
  - Sequestration

Technology Menu

- Generation
  - HTGCR Nuclear (80%)
    - electrons
    - protons
  - PV Solar Roofs (20%)
- Transmission
  - Hydricity SuperCable
- Storage
  - Hydrogen + Hydricity Fuel Cell
- End Use Power
  - Electricity
  - Hydrogen

Implementation Technology I

HTGCR Nuclear Power



Source: INEL & General Atomics

- Gen IV High Temperature Gas-Cooled Reactors can make <u>electricity</u> the old fashioned way by spinning turbines

- The same reactor can make <u>hydrogen</u> from water in *two* ways…

Using its own electricity output to perform electrolysis…

$2H_2O \rightarrow 2H_2 + O_2$

Or with heat drawn from the reactor…

$2H_2O \rightarrow 2H_2 + O_2$

900 °C

Implementation Technology II

The Hydricity Economy

Hydrogen for:

- Personal Transportation
- Storage of Electricity
- Industrial Thermal/Chemical Processing
- Residential/Commercial Heating

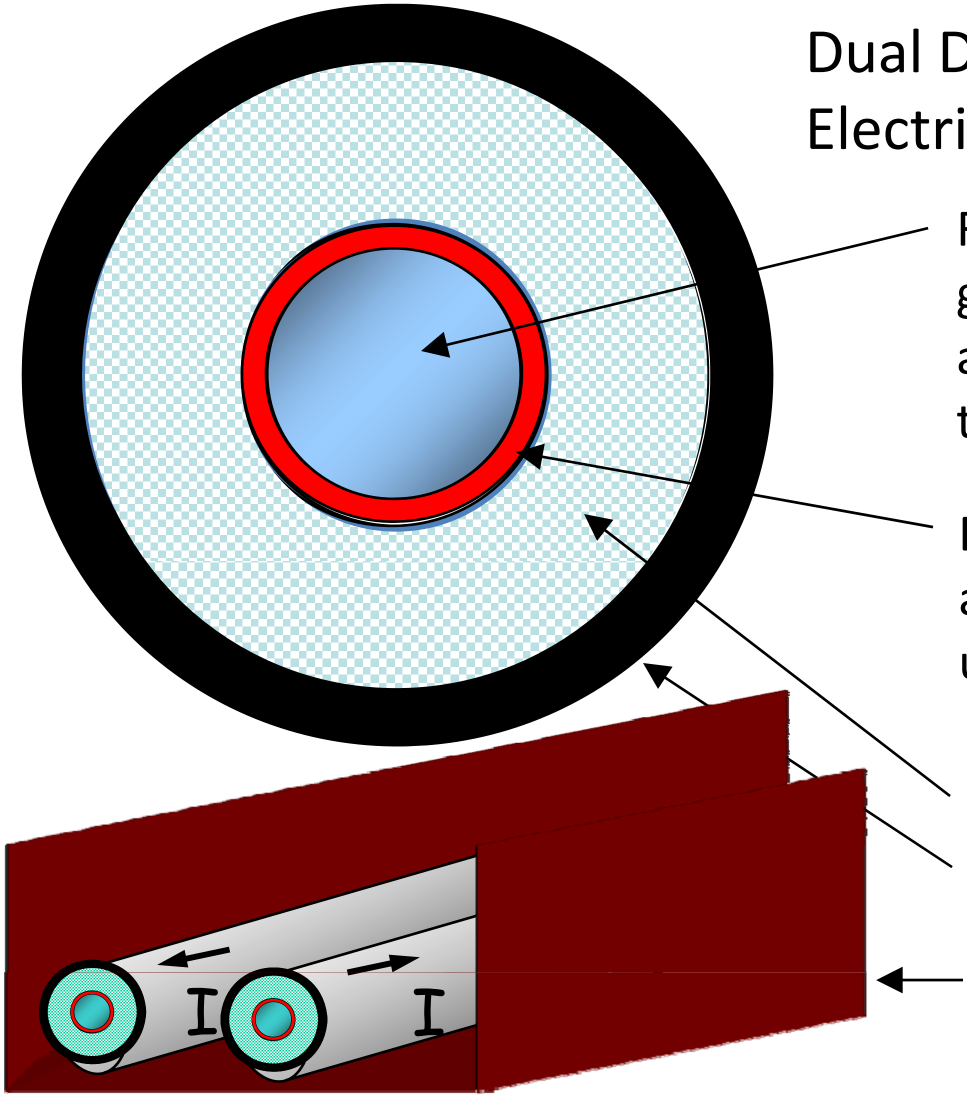
Electricity for:

-Just about everything else!

(maybe even space heating, as well)

Implementation Technology III

The Hydricity SuperCable



Dual Delivery of Hydrogen and Electric Power

Flowing liquid hydrogen or cold H_2 gas under pressure delivers power and also serves as the refrigerant to …

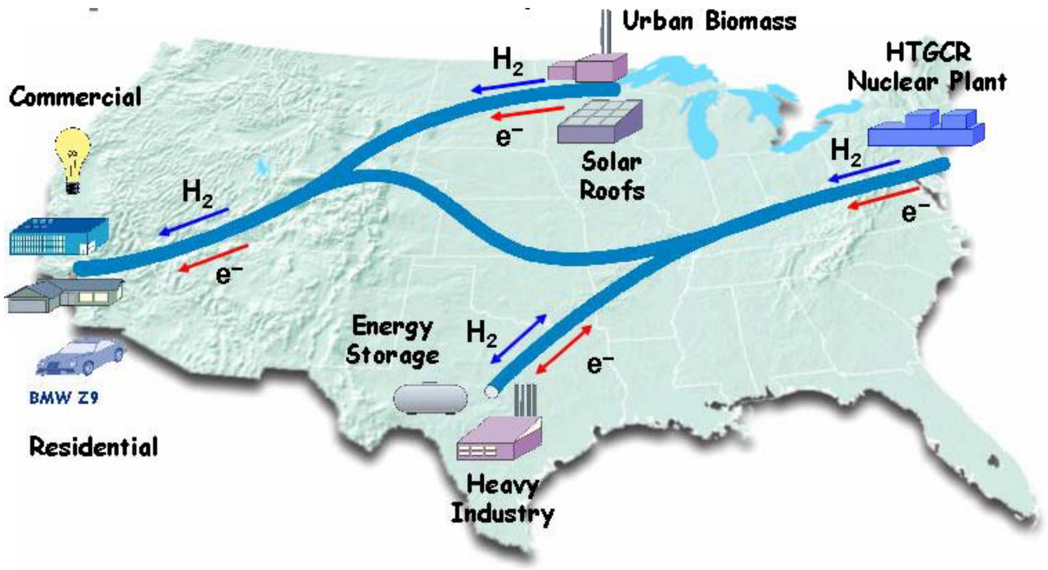
Enable the transmission of large amounts of electric power losslessly using superconductors

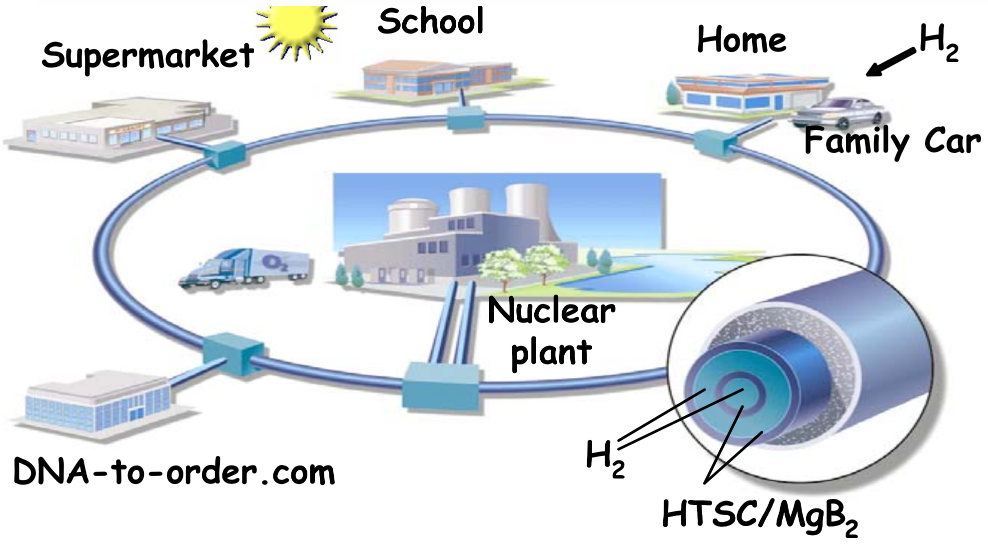
Thermal Insulation

Electrical Insulation

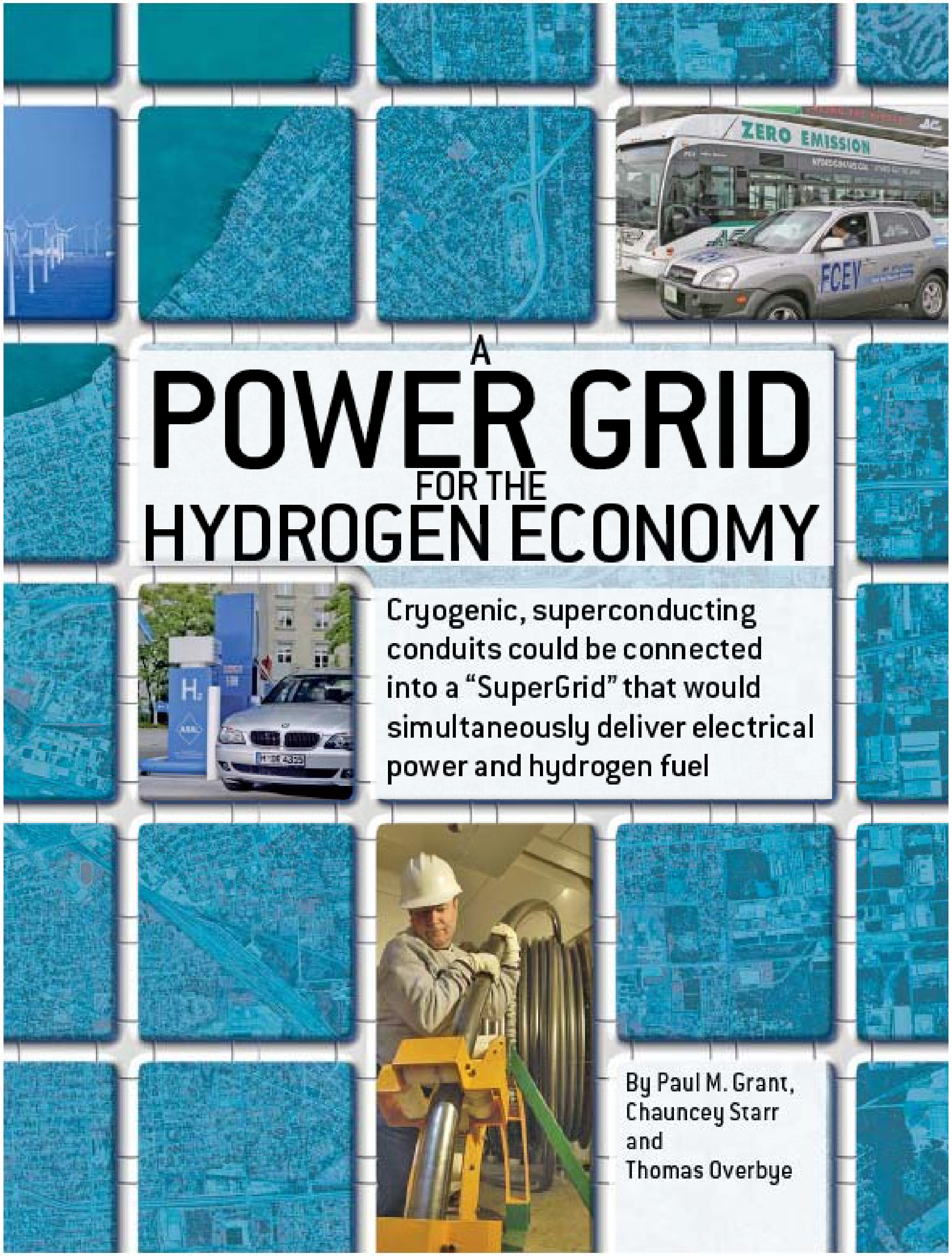
Enclosed in underground tunnel or trench

SuperCities & SuperGrids





- Nuclear Power can generate both electricity and hydrogen – “Hydricity”
- Hydricity can be distributed in underground pipelines like natural gas
- The infrastructure can take the form of a **SuperGrid**
- …or a **SuperCity**



A POWER GRID FOR THE HYDROGEN ECONOMY

Cryogenic, superconducting conduits could be connected into a "SuperGrid" that would simultaneously deliver electrical power and hydrogen fuel

By Paul M. Grant,
Chauncey Starr
and
Thomas Overbye

On the afternoon of August 14, 2003, electricity failed to arrive in New York City, plunging the 10 million inhabitants of the Big Apple—along with 40 million other people throughout the northeastern U.S. and Ontario—into a tense night of darkness. After one power plant in

Published in

SCIENTIFIC AMERICAN

July, 2006

"System Crash"

Omni Productions,
Vancouver, BC
CBC Broadcast October, 2008

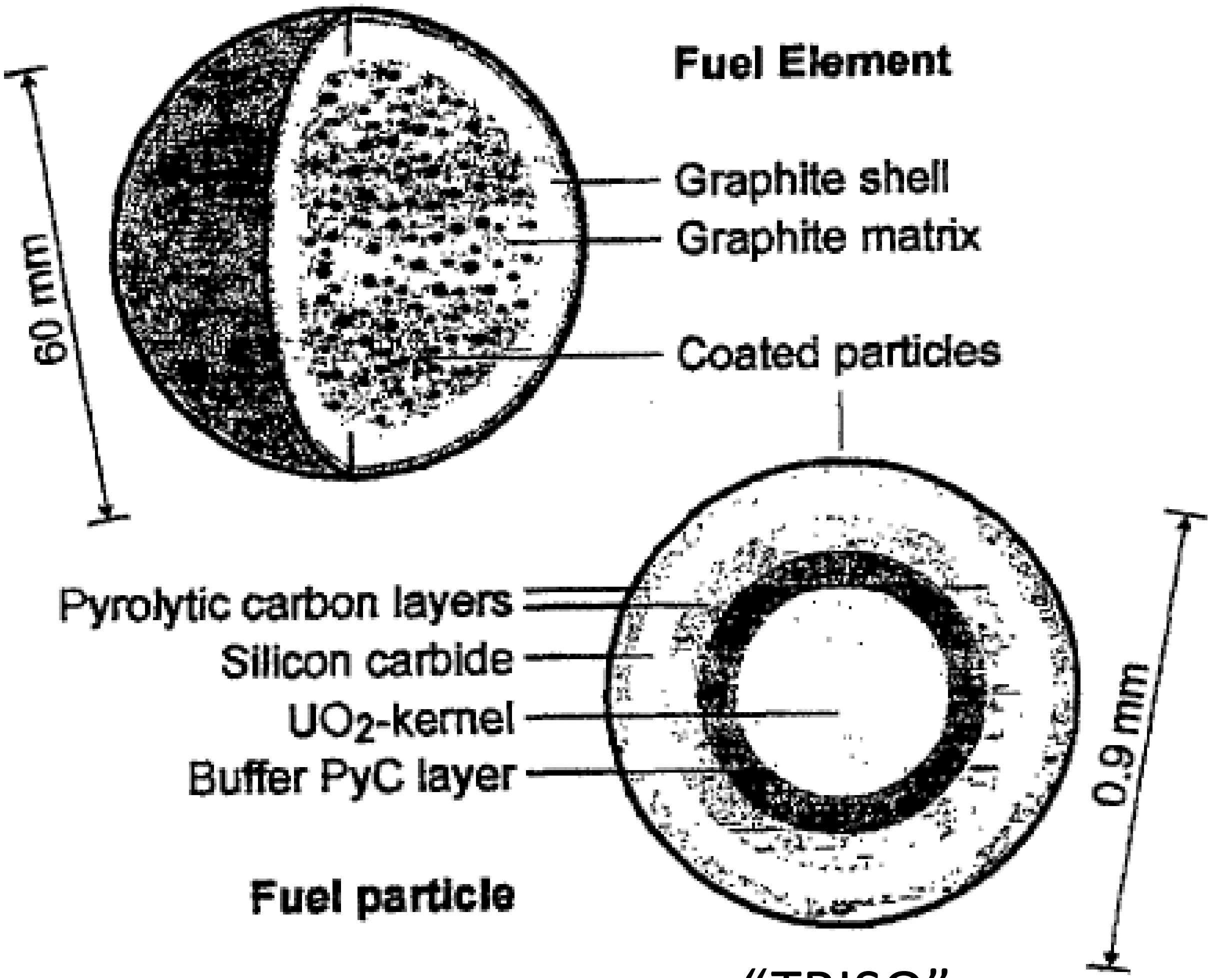
Nuclear

Oklo “Natural” Reactor

- Pu was created 2 billion years ago!
- Reactor produced 100 kW of power for 500,000 years!
- “Waste” has moved less than one meter.

Particle/Pebble Nuclear Fuel

“Pebble”



“TRISO”

Eskom Pebble Bed Modular Reactor

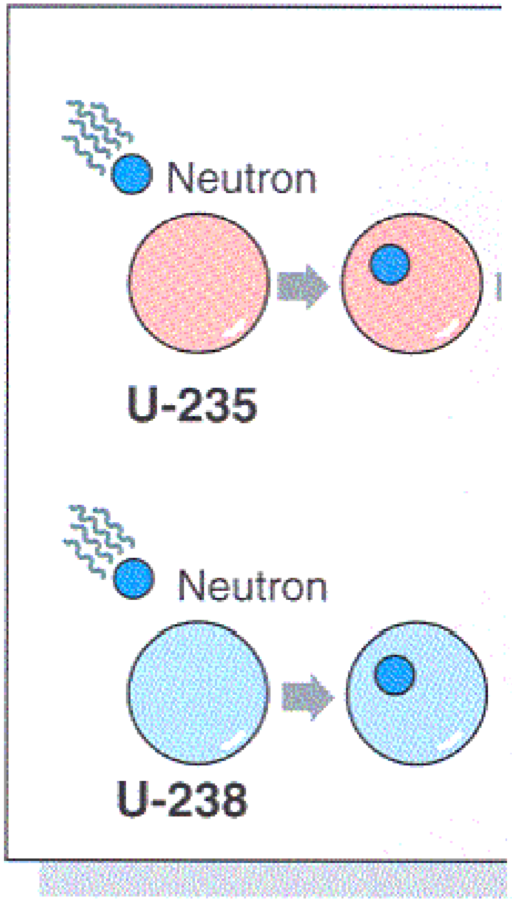
- Helium gas cooled (Brayton Cycle)
  - Won’t melt down
  - Direct turbine drive
- “Baseball” packaged fuel
  - Continuous fuel replenishment and removal
  - Theoretical 100% availability
- Modular Design
  - Scalable: 100 – 500 MW units
  - High safety and security factor
- Economical
  - 1.2 cents/kWh … cheaper than coal

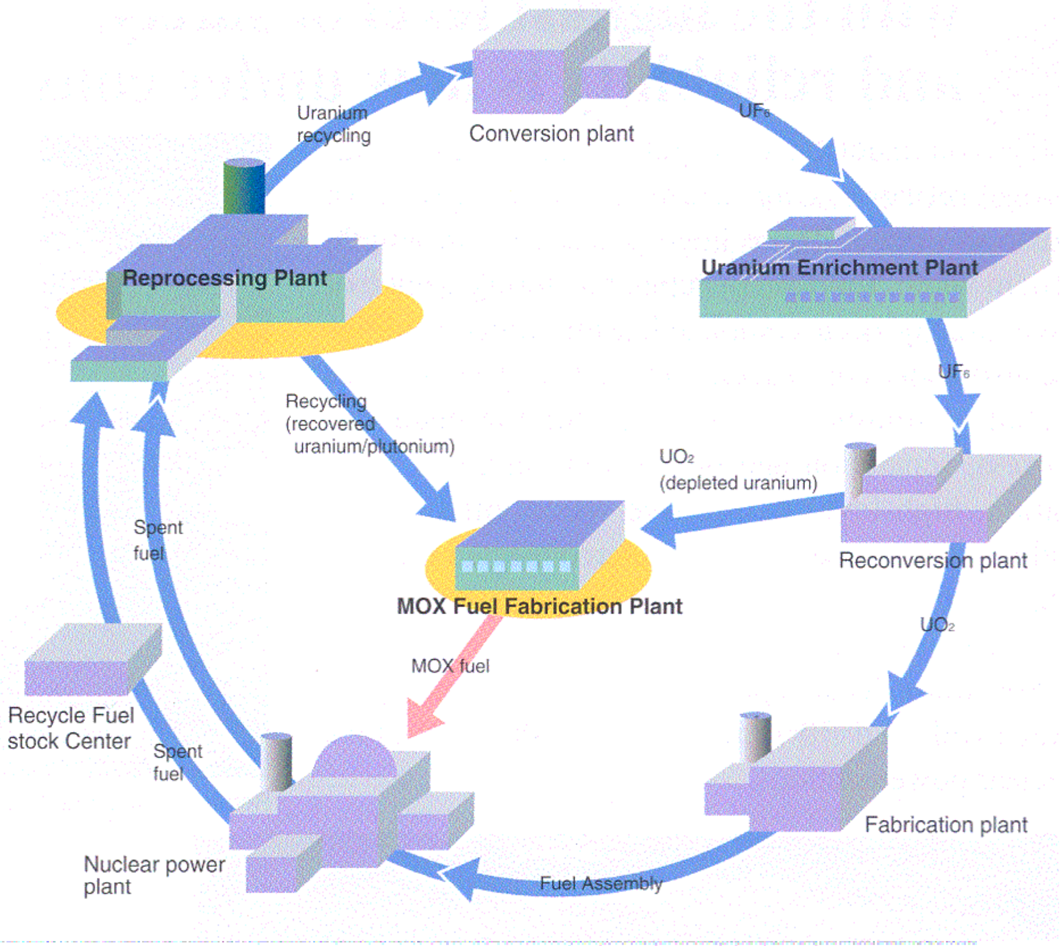
http://www.eskom.co.za/nuclear_energy/pebble_bed/pebble_bed.html

Yucca Mountain

Created by Emma Hill, 2002

Reprocessing “Spent” Fuel



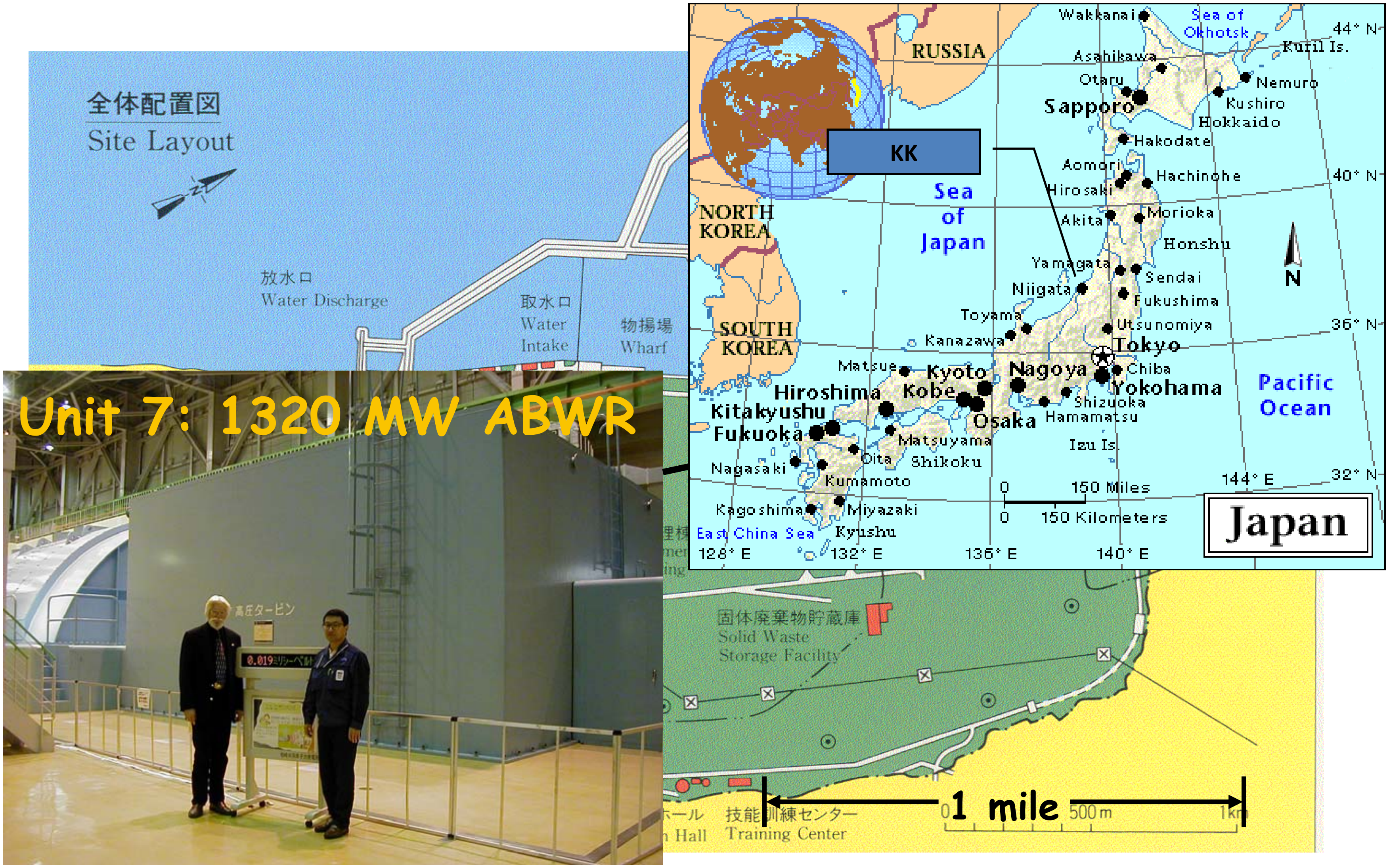


JNFL Rokkasho Reprocessing Plant

- $20 B, 5 Year Project
- 800 mt U/yr
- 1 mt U -> 50 kg HLW

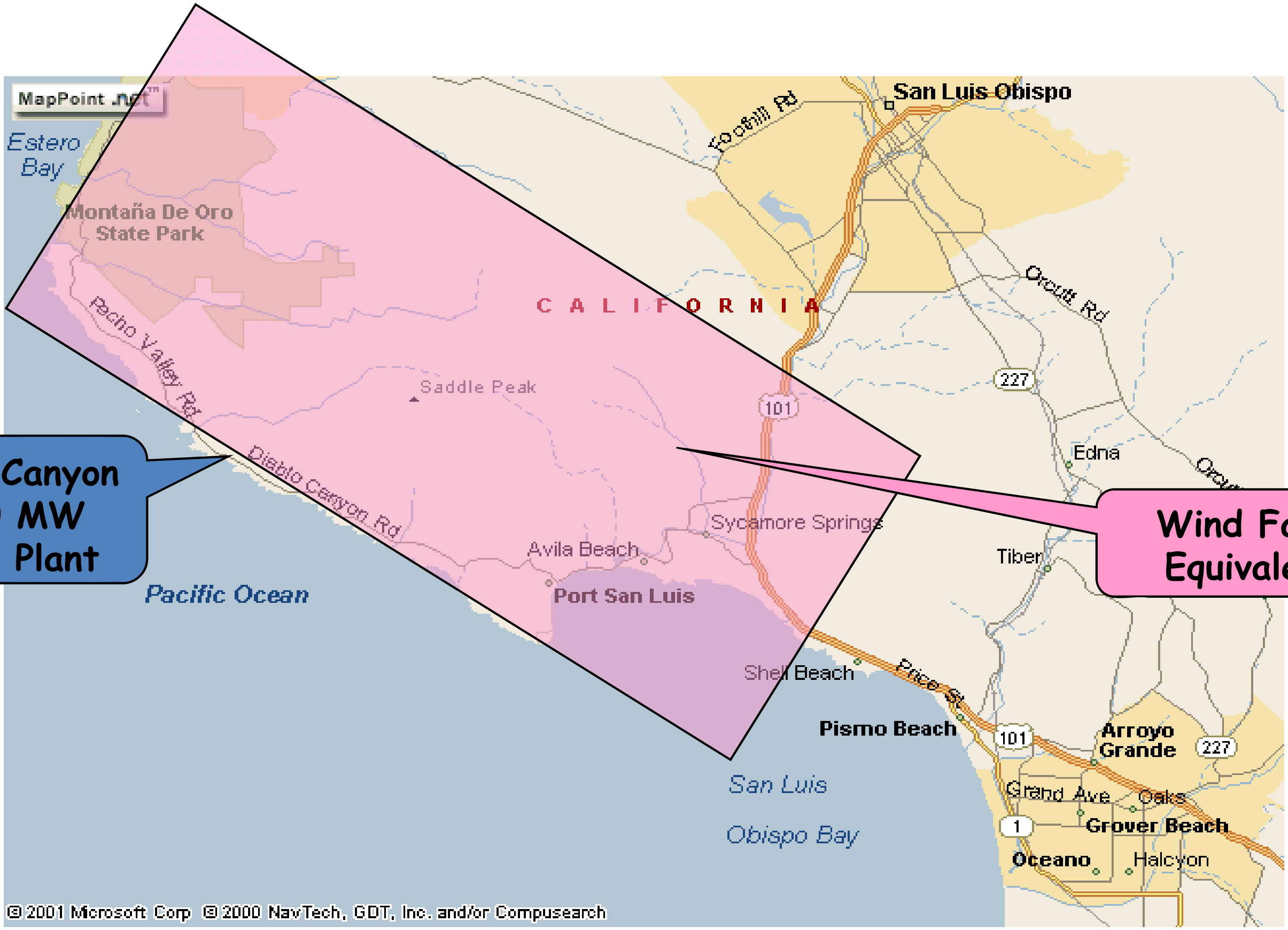
http://www.jnfl.co.jp/english/contact/visitor-center.html

Kashiwazaki Kariwa: 8000 MW



Diablo Canyon

California Coast Power



Diablo Canyon
2200 MW
Power Plant

Wind Farm
Equivalent

Hydrogen

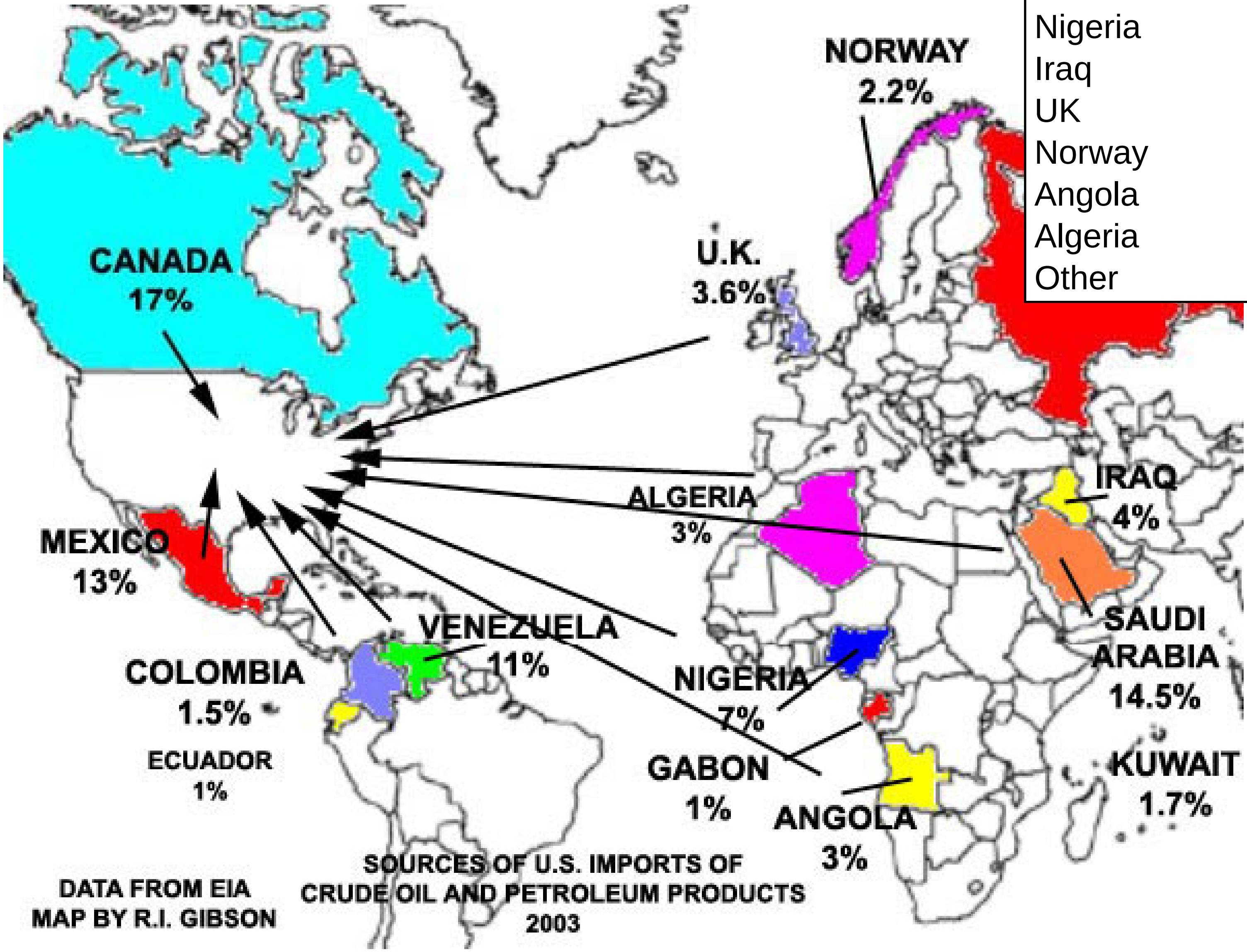
Overview of a Hydrogen Economy

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

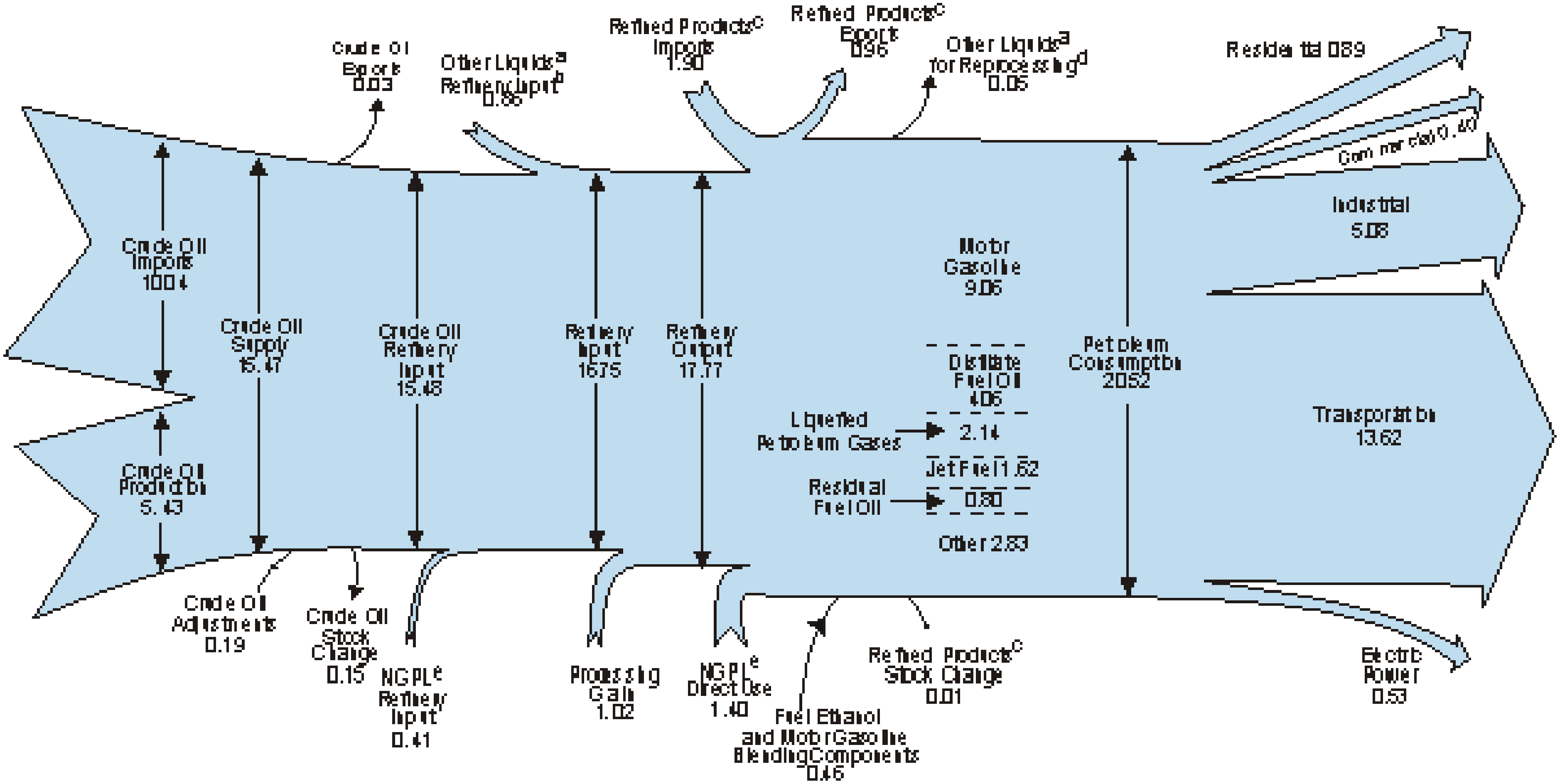
- How much oil do we produce and import?
- Can we replace the portion used for domestic surface transportation with hydrogen?
  - You're going to have to make a lot of hydrogen!
  - How will we make it?
  - Obviously from water, but from how much water?
  - Any side effects?

US Oil Imports (2003)

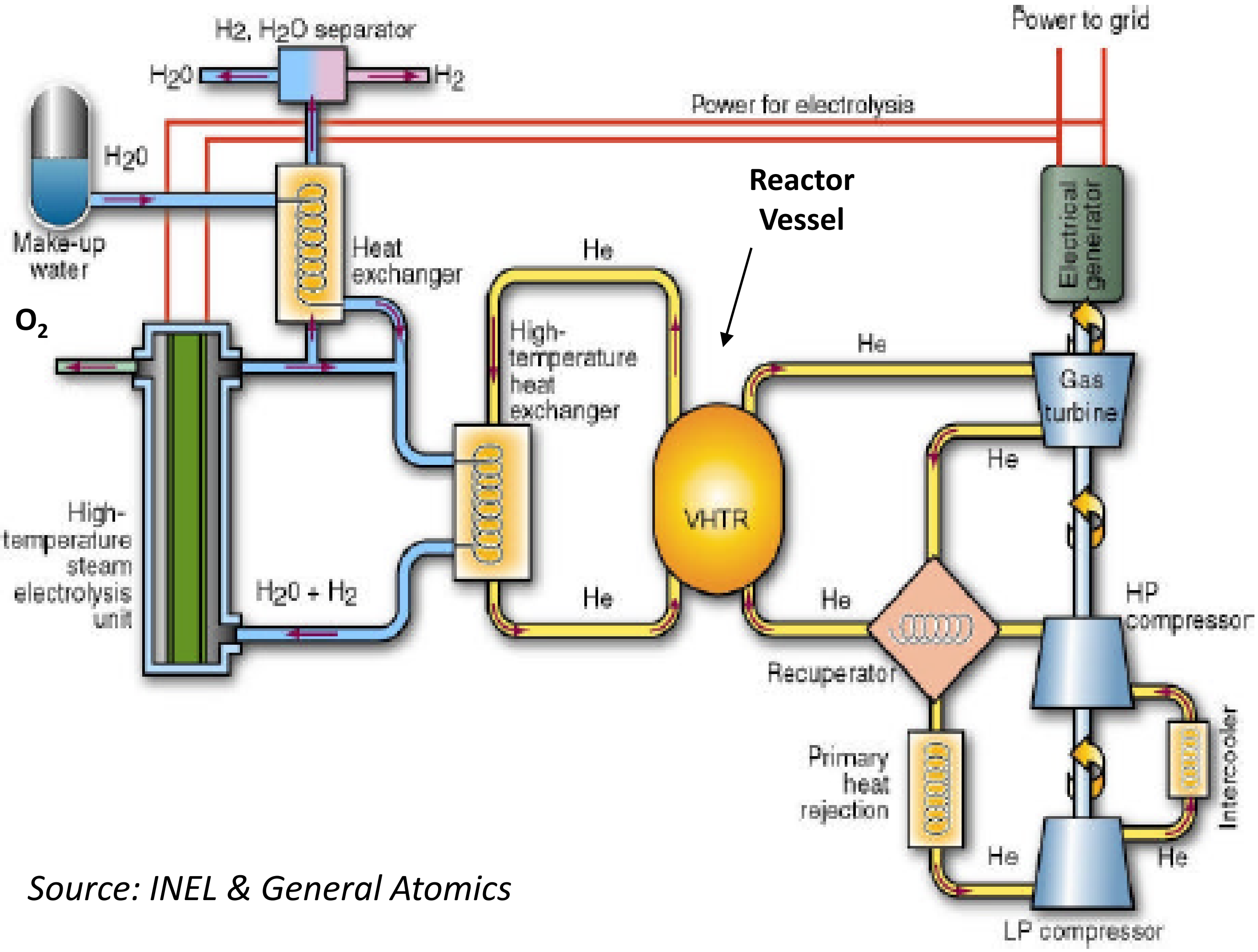
US	39%
Canada	13%
Saudi Arabia	10%
Mexico	10%
Venezuela	9%
Nigeria	4%
Iraq	4%
UK	3%
Norway	3%
Angola	2%
Algeria	2%
Other	2%



Oil: Source to End Use (2005)



Co-Production of Hydrogen and Electricity



Reactor Vessel

O_2

Source: INEL & General Atomics

Hydrogen for US Surface Transportation
“You have to make a lot of it”

The "25% 80-80-80 400 GW" Scenario

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

Factoids & Assumptions

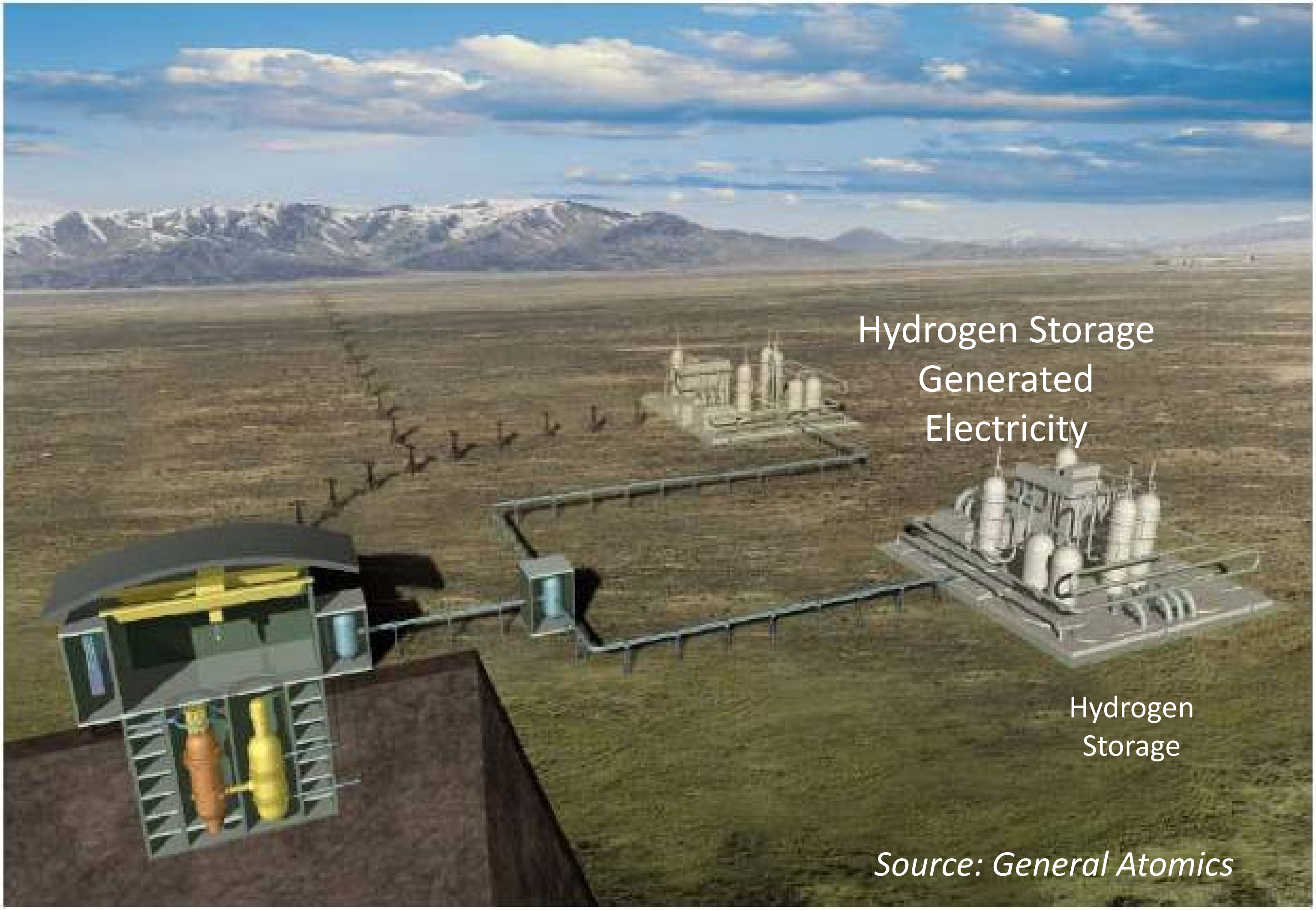
Daily consumption of gasoline and diesel by US cars & Trucks	8.6 Billion barrels/day
Effective Otto Cycle Efficiency (Useful conversion to drive chain)	25 %
Water Electrolysis Efficiency (Source Electricity-to-Hydrogen)	80 % (aggressive)
Fuel Cell Efficiency (Onboard Hydrogen-to-Electricity)	80 % (very aggressive)
Conversion/drive chain Efficiency	80 % (nominal)
Additional Electric Generation Plant Capacity for Hydrogen Vehicles	**400 GW**

Hydrogen for US Surface Transportation: Generation by Renewable Electricity

The "25% 80-80-80 400 GW" Scenario

Land Area Required to Supply by Renewables		
Technology	Area (km^2)	Equivalent
Wind	130,000	New York State
Solar	20,000	50% Denmark Death Valley + Mojave
Biomass	271,915	3% USA State of Nevada

Nuclear "Hydricity" Production Farm



Source: General Atomics

Hydrogen for US Surface Transportation: Water Requirements

The "25% 80-80-80 400 GW" Scenario

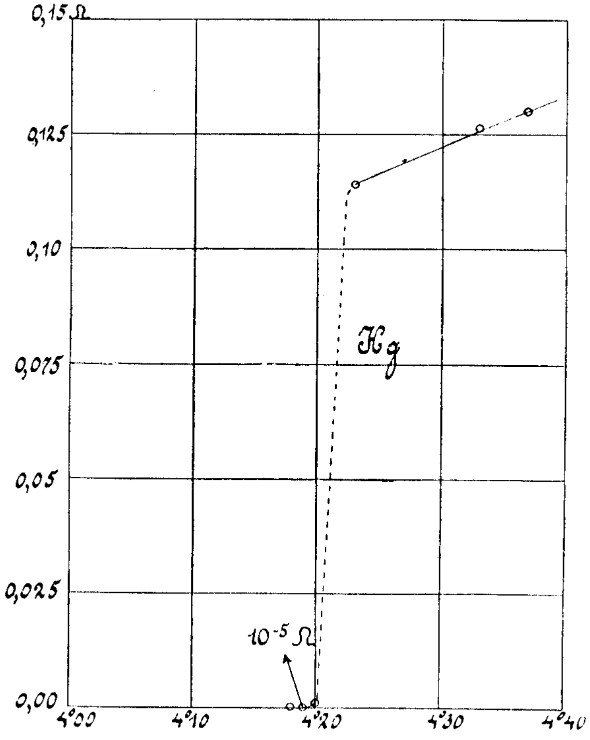
Hydrogen per	
Tonnes	Shuttles
230,000	2,225

Water per D	
Tonnes	Surface
2,055,383	


22 x 12 Miles
40 Trillion Gallons

Super Conductors

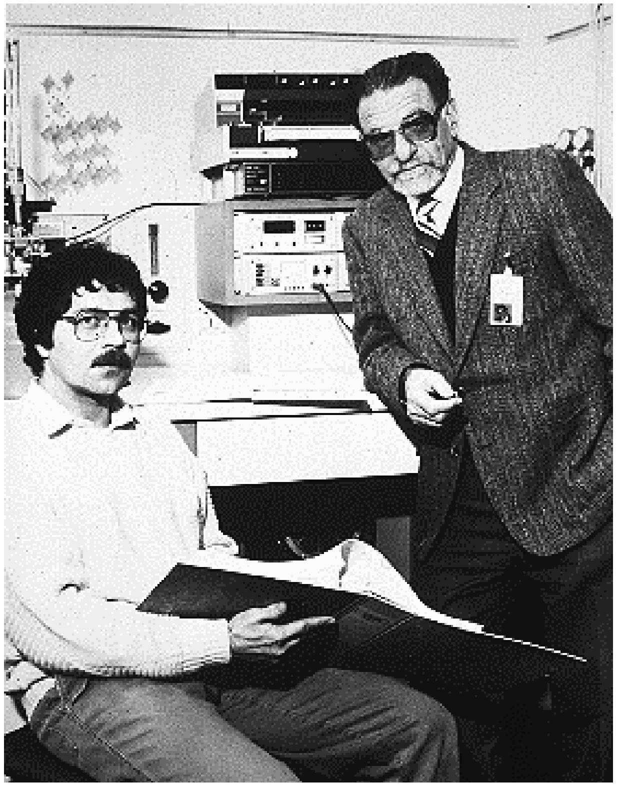
1911: A Big Surprise!



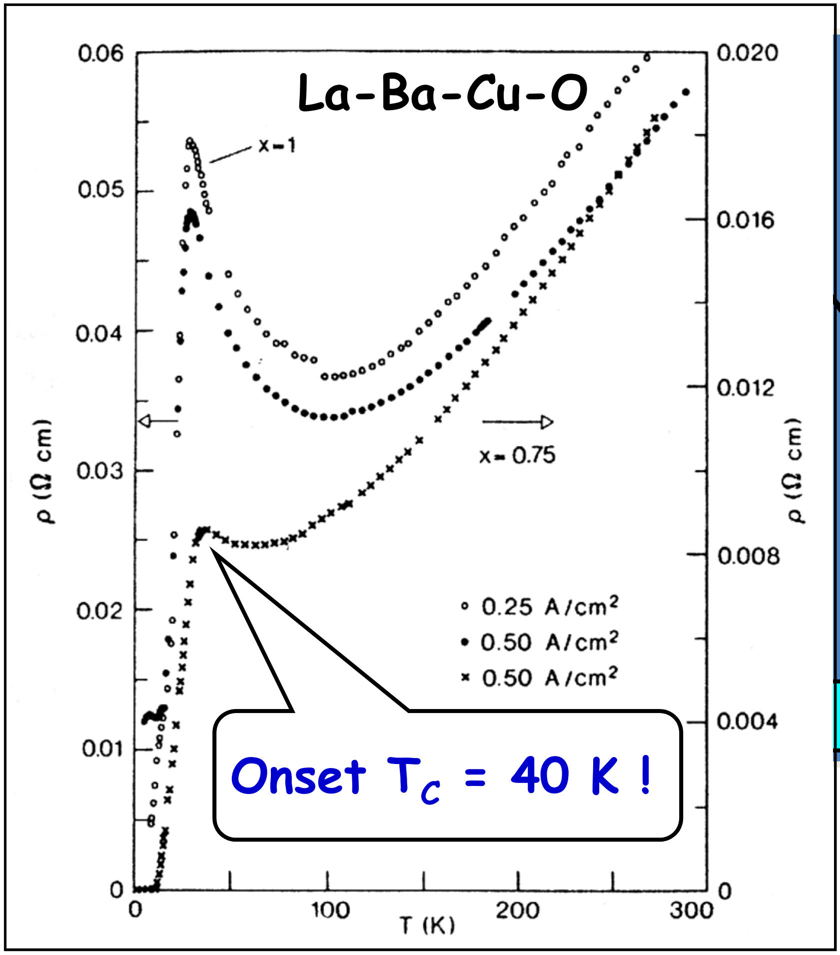
Thus the mercury at 4.2 K has entered a new state, which, owing to its particular electrical properties, can be called the state of *superconductivity*

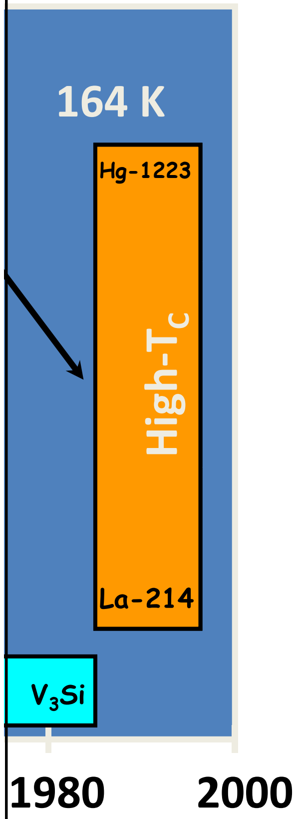
H. Kamerlingh-Onnes (1911)

1986: Another Big Surprise!



Bednorz and Mueller
IBM Zuerich, 1986





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

Woodstock of Physics
NYC, 1987

Physicists' Night Out!

WHAT IS MORE EXCITING THAN

High Tc — Physics Art!

PAM DAVIS
STEVE KIVELSON
DAN ROKHSAR and
SHAHAB ETEMAD
invite you to

LIMELIGHT
[illegible]

FOR DANCING
AT NEW YORK'S MOST FASHIONABLE NIGHTCLUB
● ● ● ● ● THURSDAY, MARCH 19, 1987 ● ● ●
DOORS OPEN 10:00 PM SHARP
DANCING ALL NIGHT

COMPLIMENTARY ADMISSION FOR YOU AND A GUEST WITH THIS INVITATION
[illegible]

THIS INVITATION CANNOT BE SOLD OR TRANSFERRED

commentary

Woodstock of physics revisited

Ten years have passed since the now famous American Physical Society meeting that heard the first breathless accounts of high-temperature superconductivity. Now, in calmer times, practical applications are emerging.

Paul M. Grant

Snap quiz: who can tell me the winner of the 1987 Super Bowl? Not most physicists, I suspect, for whom it was certainly eclipsed by two events of far greater consequence that shared the early months of that year. One, the discovery of Supernova 1987A, perhaps portended the other: the announcement of superconductivity above liquid-nitrogen temperature on planet Earth — a dream fulfilled for many condensed-matter physicists like myself, whose careers had orbited around this elusive star.

The successful sighting[1] fell to W. K. Wu and C. W. (Paul) Chu and their teams of students and postdocs at the Universities of Alabama and Houston, following only five months after the publication in autumn 1986 by Georg Bednorz and Alex Müller[2] at IBM Zürich of their discovery of superconductivity in a previously unexplored class of compounds, the layered copper-oxide perovskites.

Rising stars: Müller and Chu with Shoji Tanaka (right), whose Tokyo laboratory provided one of the first confirmations of Bednorz and Müller's discovery.

The 'inside' story of the hectic interval between the first week in January 1987 — when an announcement of the confirmation of Bednorz and Müller's discovery first brought 'high-temperature superconductivity' to wide public attention — and the week of the American Physical Society's March meeting, remains to be told. Suffice it to say that this period, and the last three months of 1986, were replete with incredulity, credulity, excitement, secrecy and a sense of immediacy in competition with one's peers, all of which resulted in, frankly, a substantial amount of intrigue and suspicion. All who participated surely came to understand, if they had not done so before, that physics is not only a science but, perhaps more significantly, an intensely human pursuit — something they do not teach you in graduate school.

The programme of the March meeting, held each year in a different US city, is 'cast in concrete' early the preceding December; thereafter, an absolute policy of no alterations prevails. By the deadline of 5 December 1986, for the 1987 meeting at the Hilton hotel in New York City, only one abstract had been accepted on the new materials: "Specific heat of Ba–La–Cu–O superconductors" by Rick Greene and his collaborators at IBM Yorktown. But the explosion of results that appeared in the new year prompted the meeting's organizers to take an unprecedented step. Brian Maple of the University of California, San Diego, was asked to put together a special post-deadline evening session devoted entirely to the discovery.

All those wishing to report results would be granted five minutes each, in order of the arrival of their request to take part — and did the requests rain in, reaching a downpour in the two weeks before the meeting, as confirmations of the Wu–Chu measurements were made. All in all, 51 presentations were to be given throughout the evening and early morning of Wednesday and Thursday, 18 and 19 March. That memorable and riotous session was to become our "Woodstock of physics", so named in honour of the village only 50 miles north where, in an obscure farmer's muddy field in 1969, the rock concert occurred that defined a generation of youth the world over.

Opening act

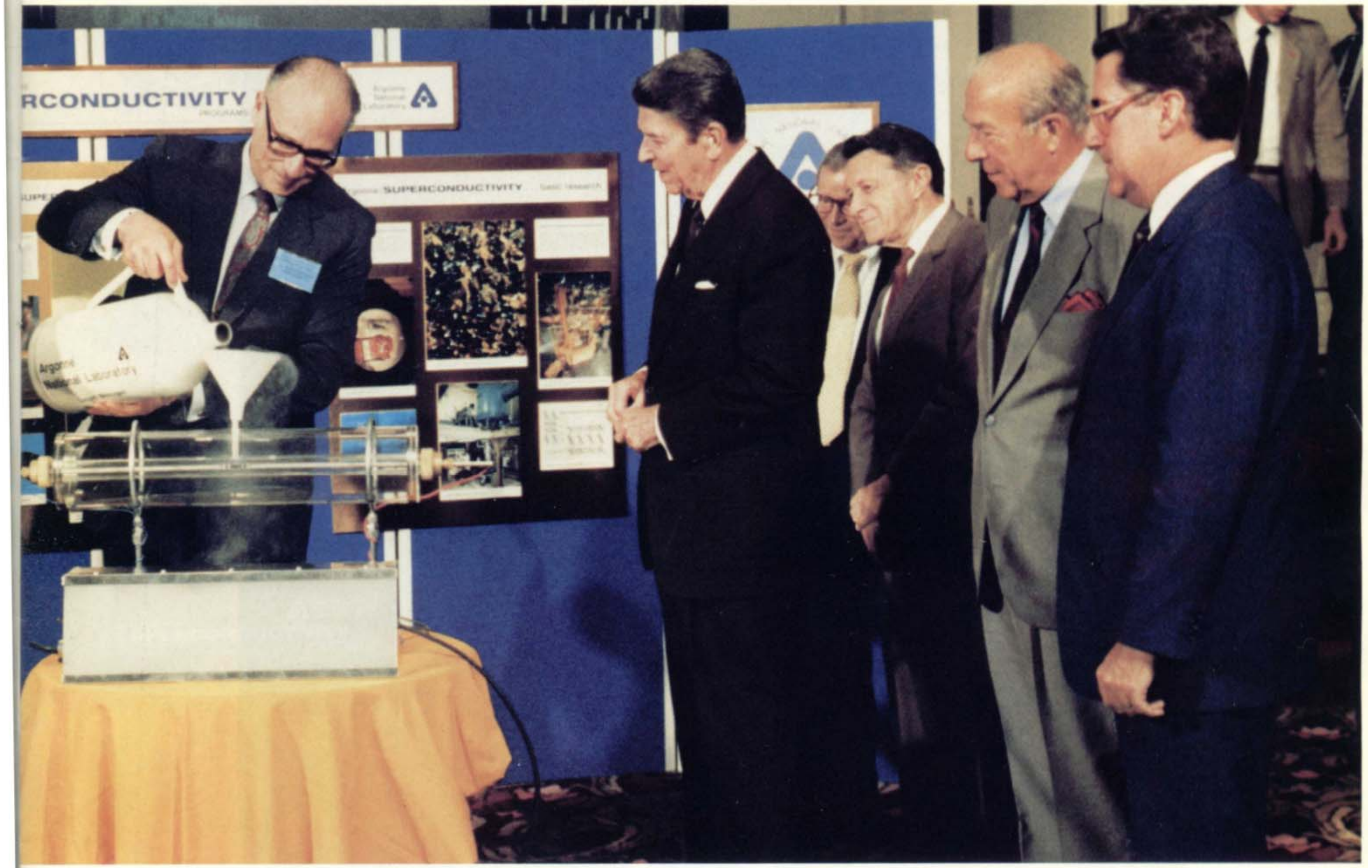
A few personal observations and anecdotes may help to convey the colour of that week in midtown Manhattan. Excitement was running high even before Wednesday night. On Monday, the opening day, the press were already beginning to catch some of us to be interviewed. That noon my colleague Ed Engler and I went to lunch at a nearby Brew 'n' Burger and found Alex Müller sitting by himself in a corner booth, attempting to escape the turmoil at the Hilton. At the time he was not yet widely recognizable to those attending the meeting or to the press — a situation that would soon change.

Fever pitch: the room filled to overflowing with physicists eager for news of superconductivity.

NATURE | VOL 386 | 13 MARCH 1997

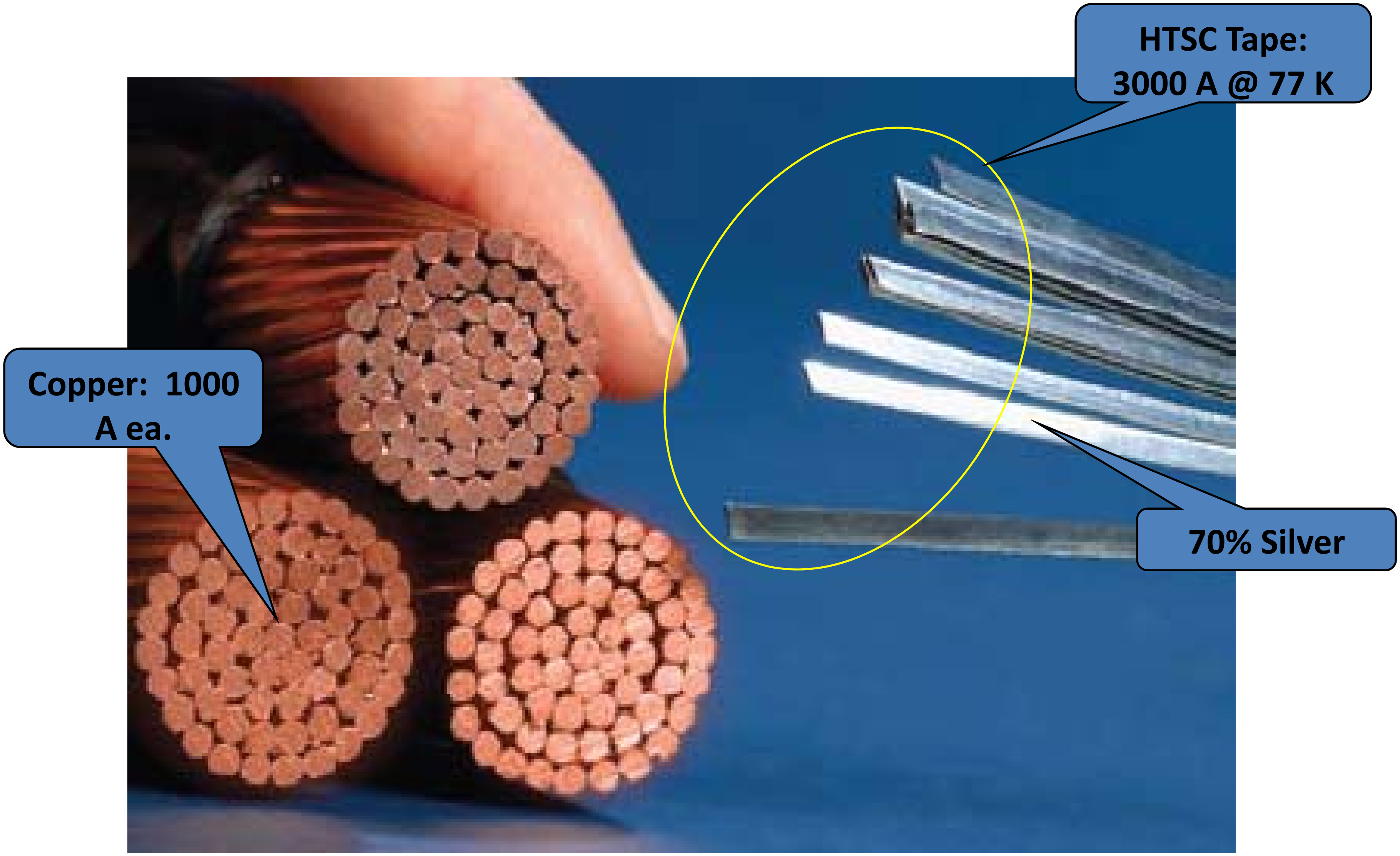
115

"The Great Communicator"

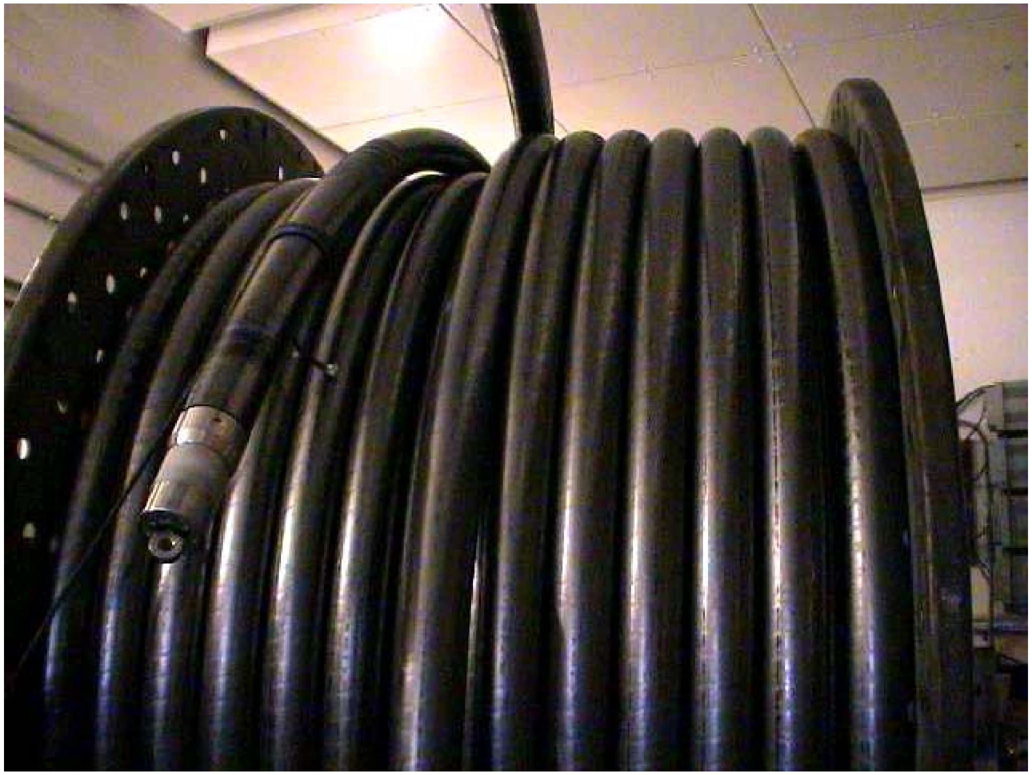


Alan Schriesheim, Director of Argonne National Laboratory, demonstrates superconductivity to the President, Chief of Staff Howard Baker, Secretary of Defense Caspar Weinberger, Secretary of State George Shultz and Secretary Herrington.

HTSC Tape (AMSC)



Finished Cable



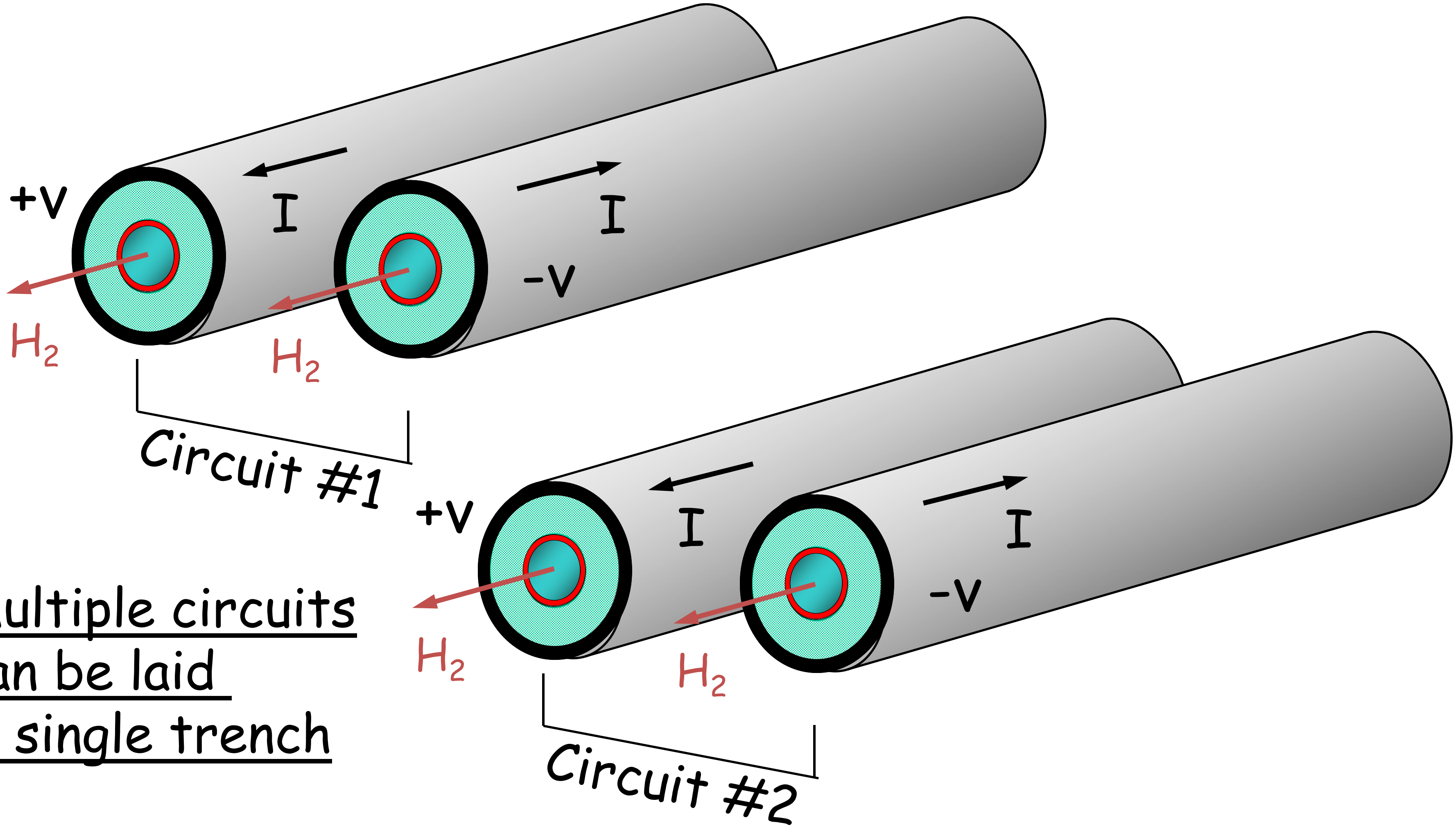
Puji Substation (Kunming City)

Recuirs Jes' Minmal Skil Levil

- Harvard PhD…OK
- But…
- Ya gotta pass the IBEW apprentice exam too!

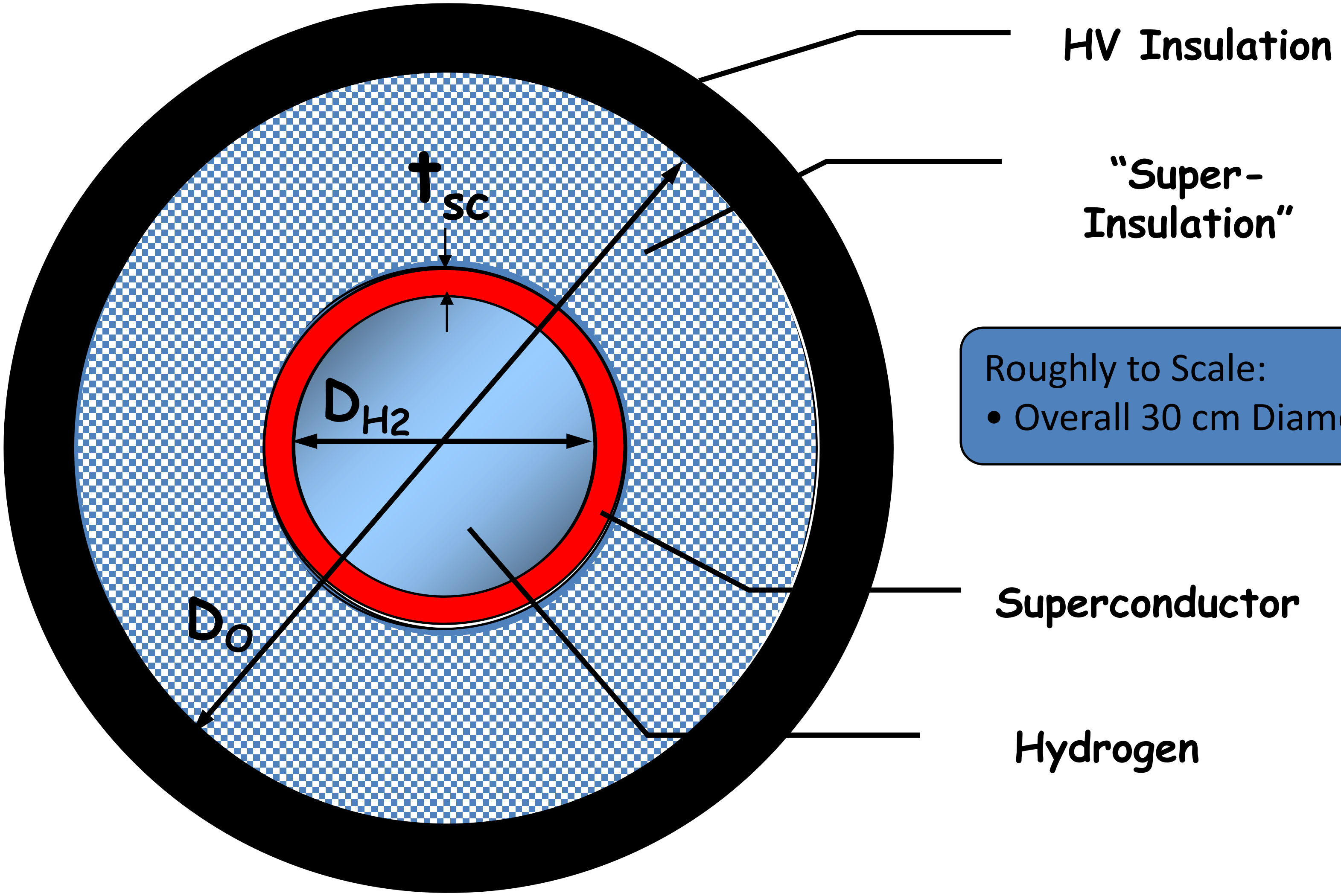
Hydricity
SuperCables

"Hydricity" SuperCables:
"Proton/Electron Power (PEP) to the People"



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

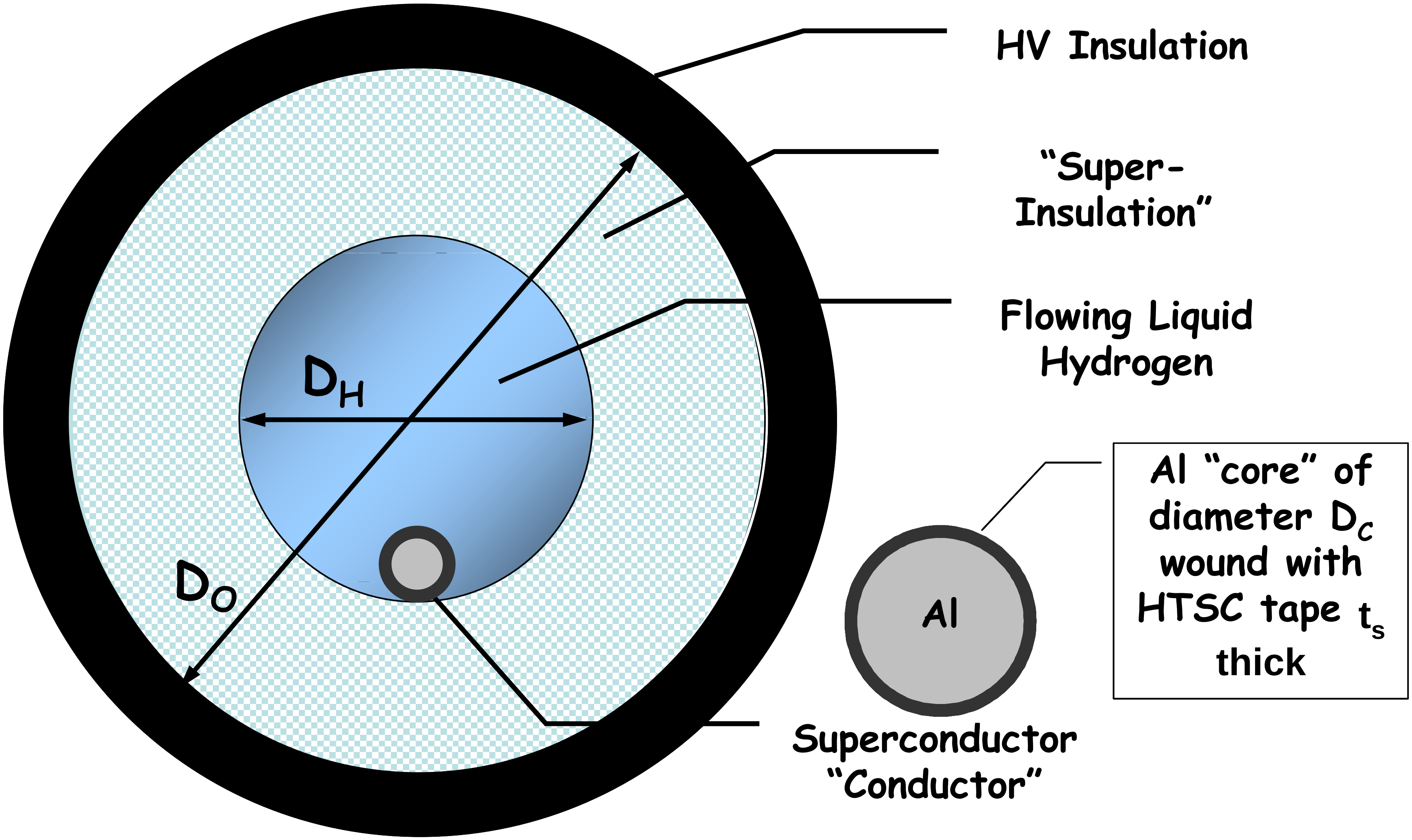
LH_2 SuperCable



Roughly to Scale:

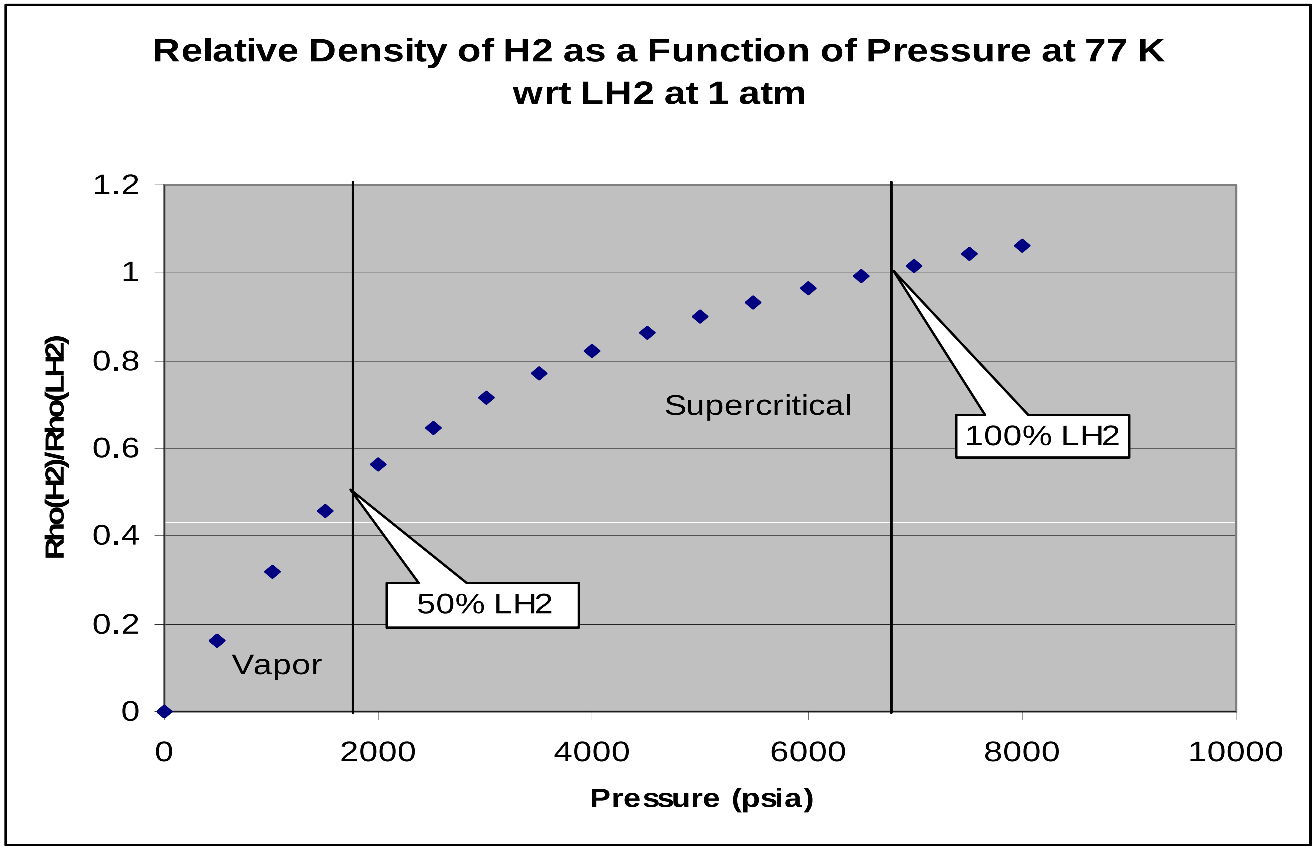
- Overall 30 cm Diameter

SuperCable Monopole (Alternative)



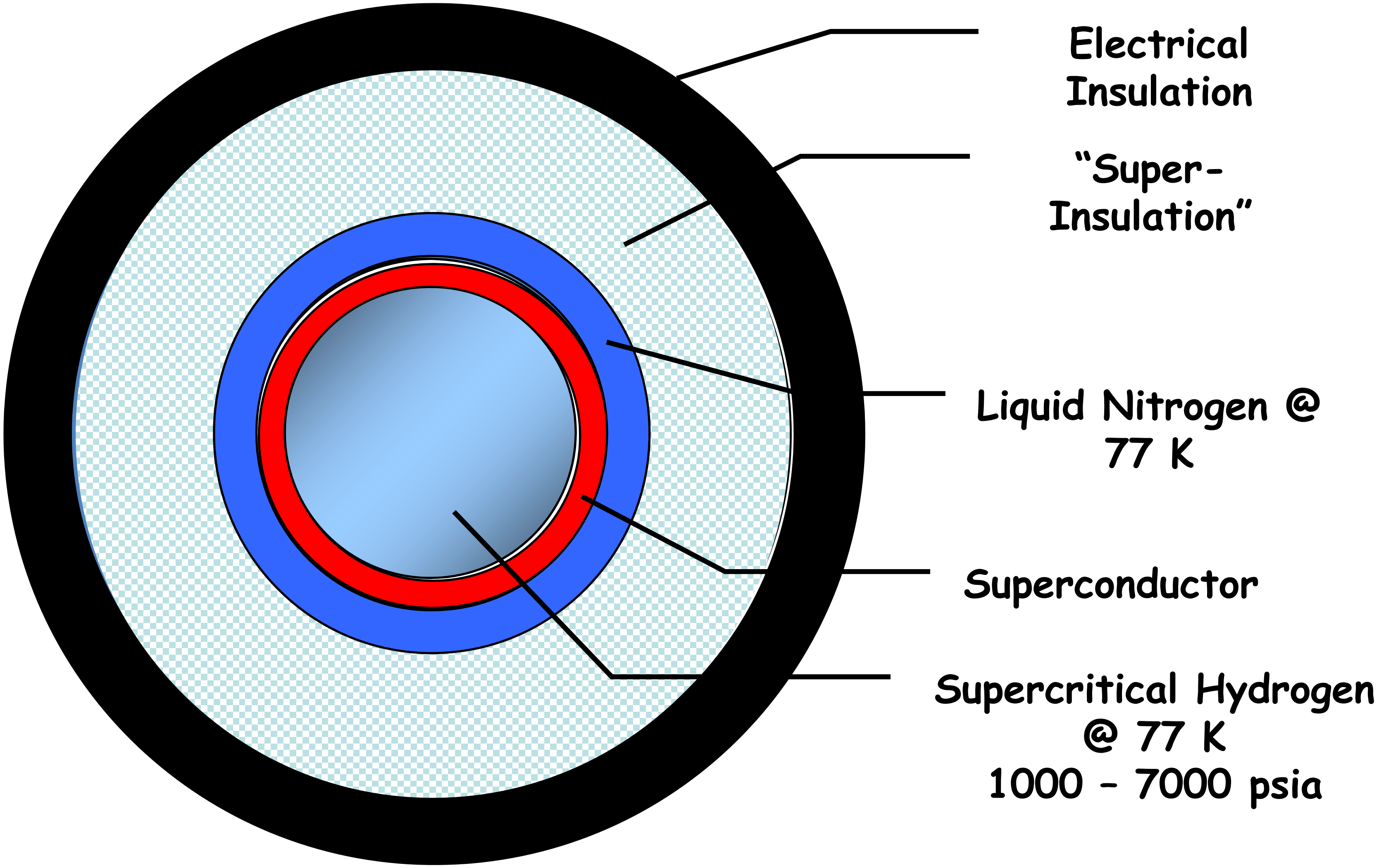
Al "core" of diameter D_C wound with HTSC tape t_s thick

Hydrogen Mass-Density Energy Content

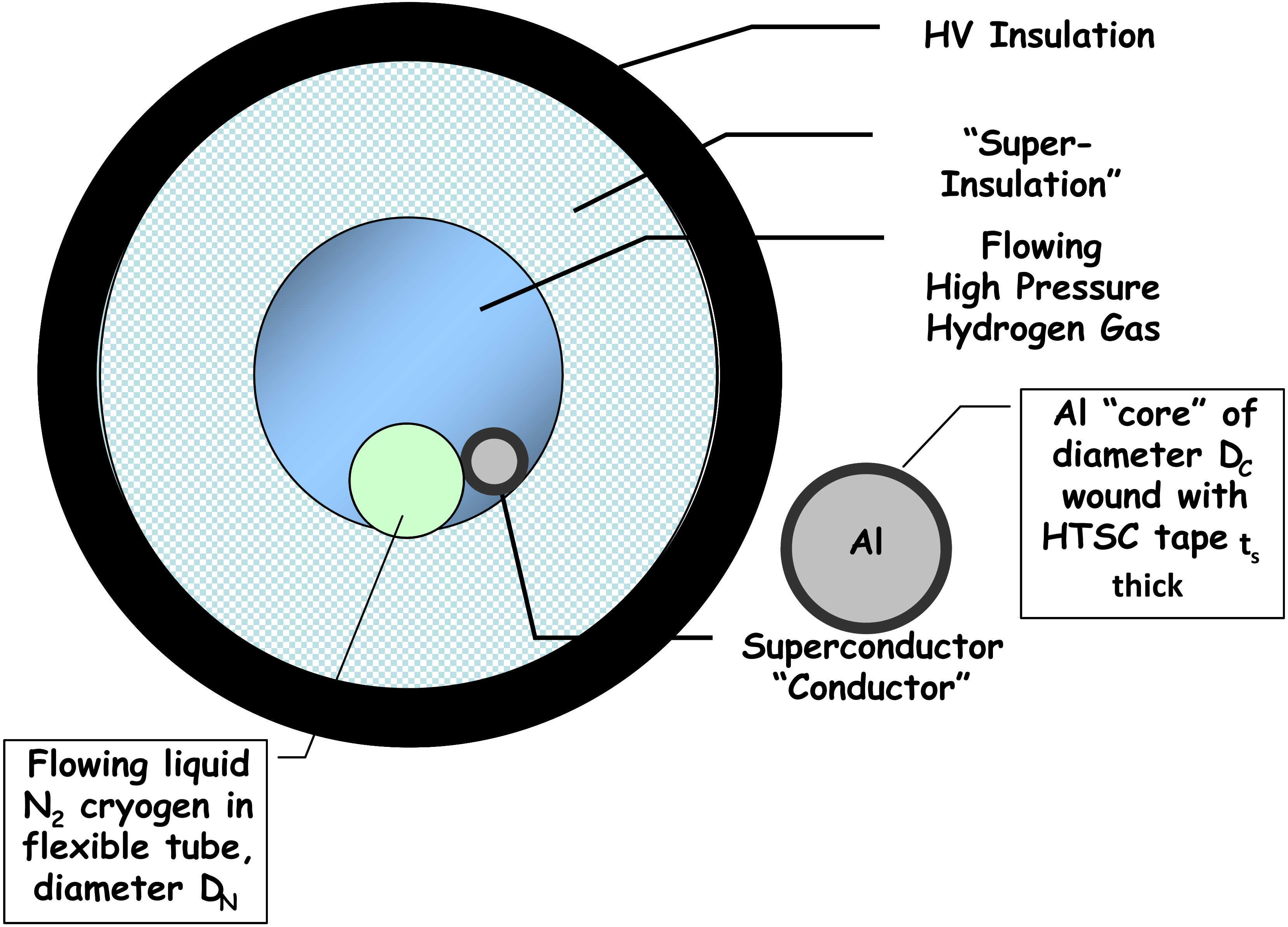


H_2 Gas at 77 K and 1850 psia has 50% of the energy content of liquid H_2 and 100% at 6800 psia

Supercritical H_2 SuperCable



Supercritical H_2 SuperCable (Alternative)



HV Insulation

"Super-Insulation"

Flowing High Pressure Hydrogen Gas

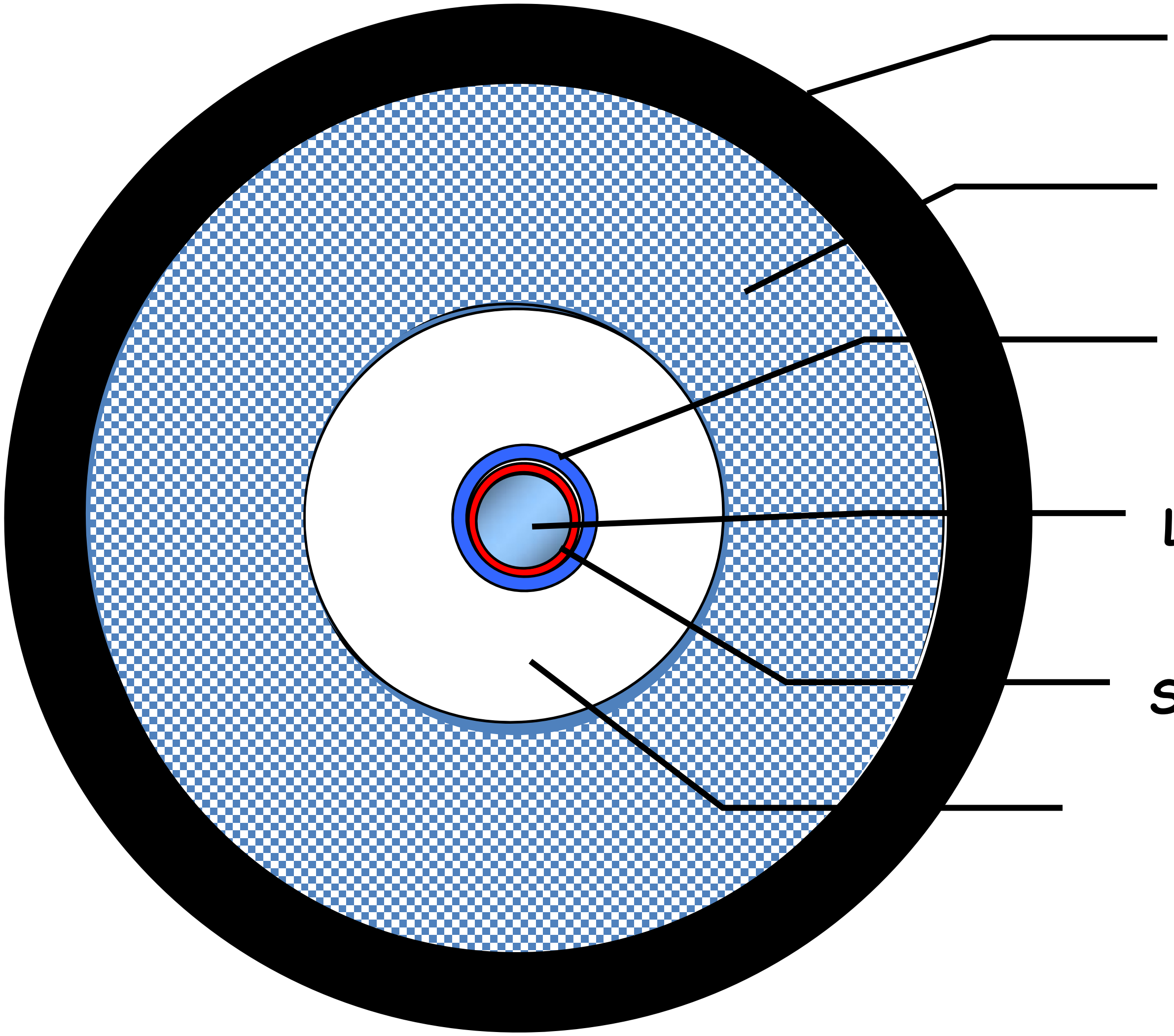
Al "core" of diameter D_C wound with HTSC tape t_s thick

Superconductor "Conductor"

Flowing liquid N_2 cryogen in flexible tube, diameter D_N

Design for eventual conversion to high pressure cold or liquid H_2

LNG SuperCable



Electrical Insulation

"Super-Insulation"

Thermal Barrier to LNG

Liquid Nitrogen @ 77 K

Superconductor

LNG @ 105 K
1 atm (14.7 psia)

Relative Power Flows

$P_{SC} = 2|V|JA_{SC}$, **where** **Electricity**

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

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

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:

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

"Energy Density"

"Pressure"

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/cm²K⁴
$T_{amb} = 300$ 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
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

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

T **°K**	**P** **psia**	**ρ** **kg/m³**	**μ** **μPa×s**	**μ²/ρ** **ndyne**	**V** **m/s**	**Re** **10⁶**
20	14.7	70.8	13.6	261	4	2.08
77	1850	35.4	5.6	87	8	5.06

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

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

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

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

Colebrook's Equation

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

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

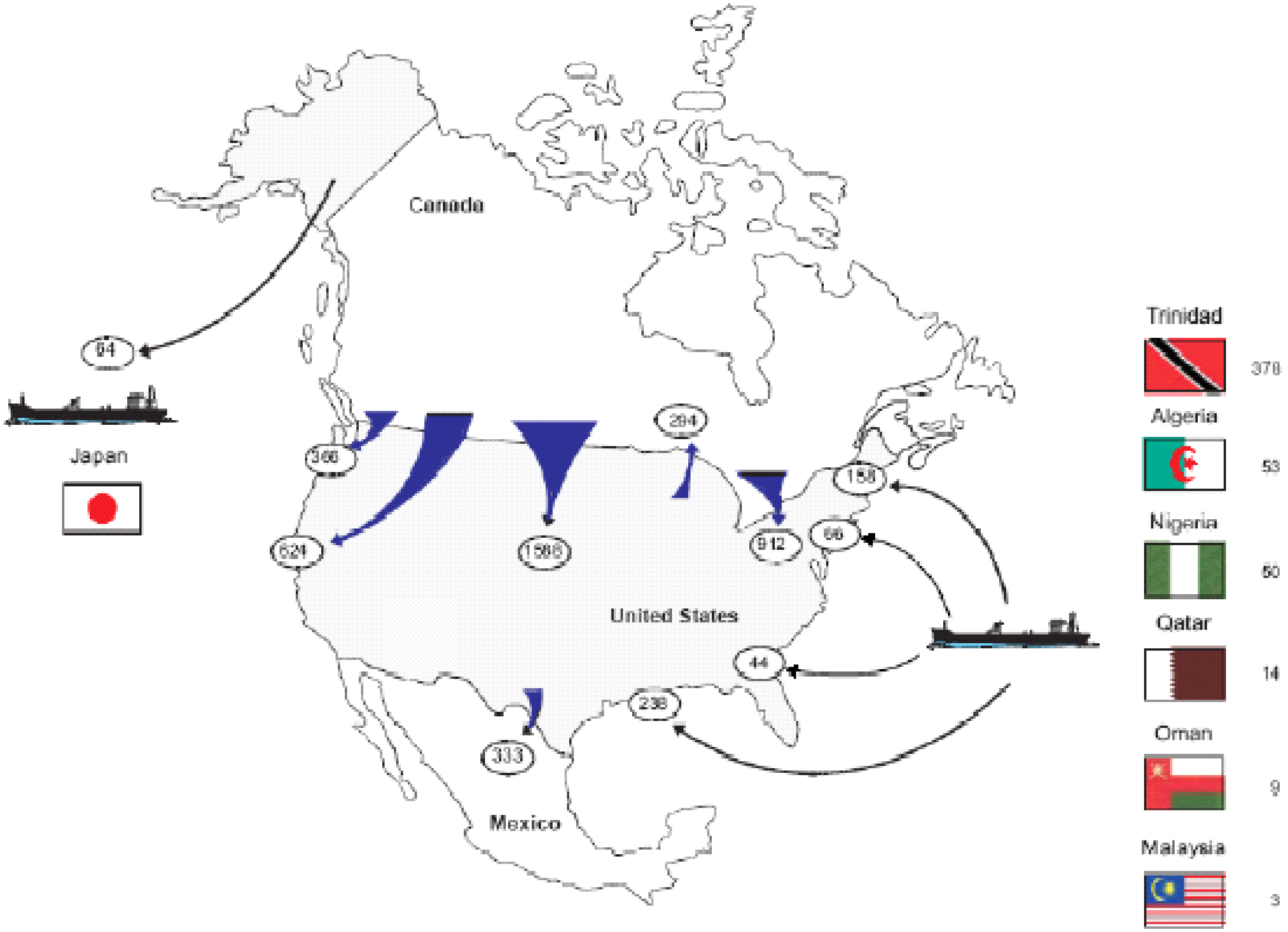
One Raccoon Mountain = 13,800 cubic meters of LH2

LH_2 in 10 cm diameter, 250 mile bipolar SuperCable

= Raccoon Mountain

Super Grids

US Natural Gas Imports (BCF – 2003)



A Canadian's View of the World

The Mackenzie Valley Pipeline

http://www.mackenziegasproject.com

1220 km
18 GW-thermal
2006 - 2010

MVP Specs

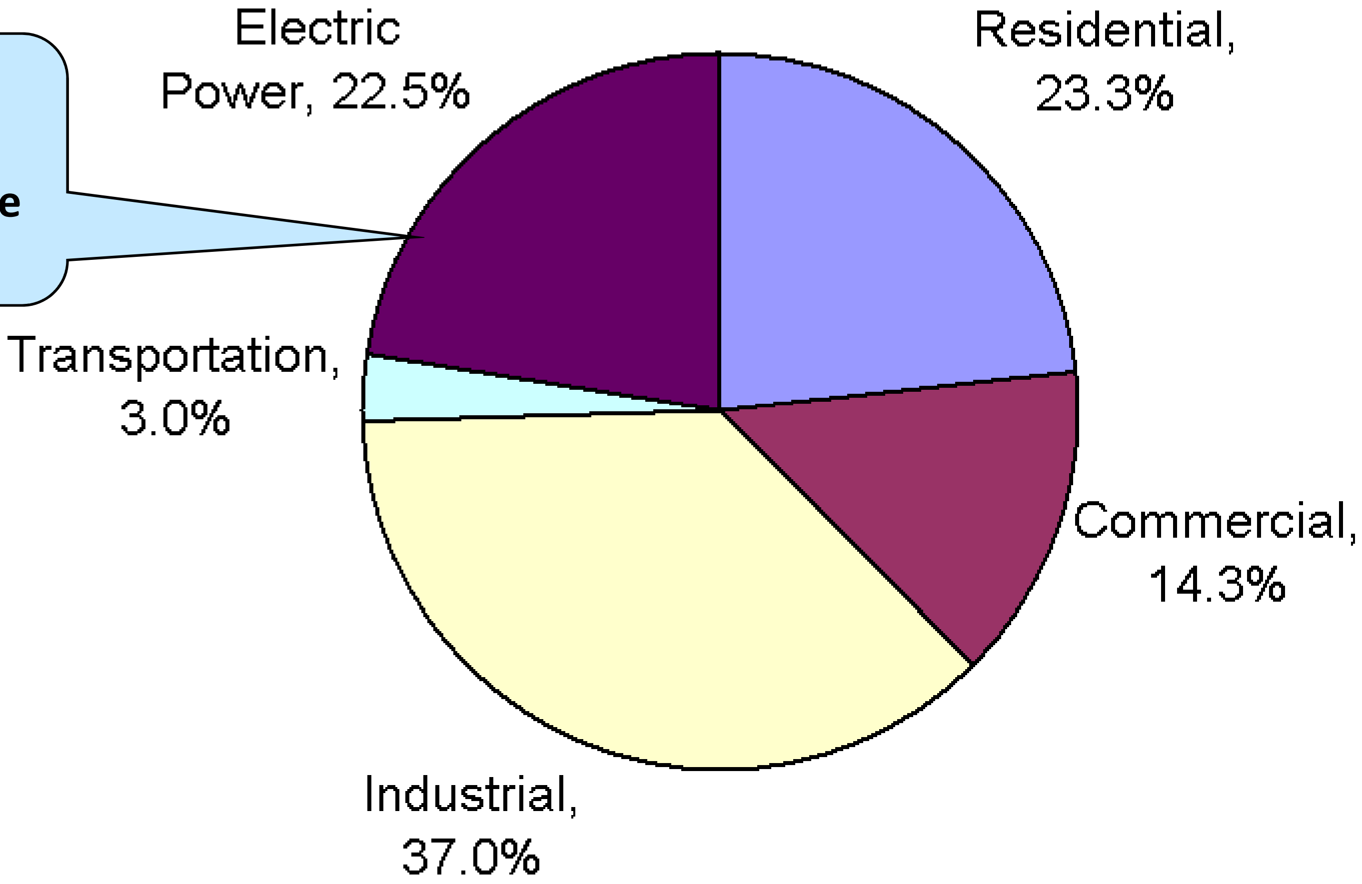
Pipeline Length	1220 km (760 mi)
Diameter	30 in (76 cm)
Gas Pressure	177 atm (2600 psia)
Pressurization Stations	~250 km apart
Flow Velocity	5.3 m/s (12 mph)
Mass Flow	345 kg/s
Volume Flow	1.6 Bcf/d (525 m^3/s)
Power Flow	18 GW (HHV Thermal)
Construction Schedule	2006 - 2010
Employment	25,000
Partners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

Constructing Gas Pipelines

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?



Wellhead LNG + Electricity

MVP Scenario

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!*
- We have built the LNG SuperCable years before
- Put HTCGR Nukes on the now empty gas fields to make hydrogen and electricity (some of the electricity infrastructure, e.g., I/C stations, already in place)
- Enable the pre-engineered hydrogen capabilities of the LNG SuperCable to now transport protons and electrons.

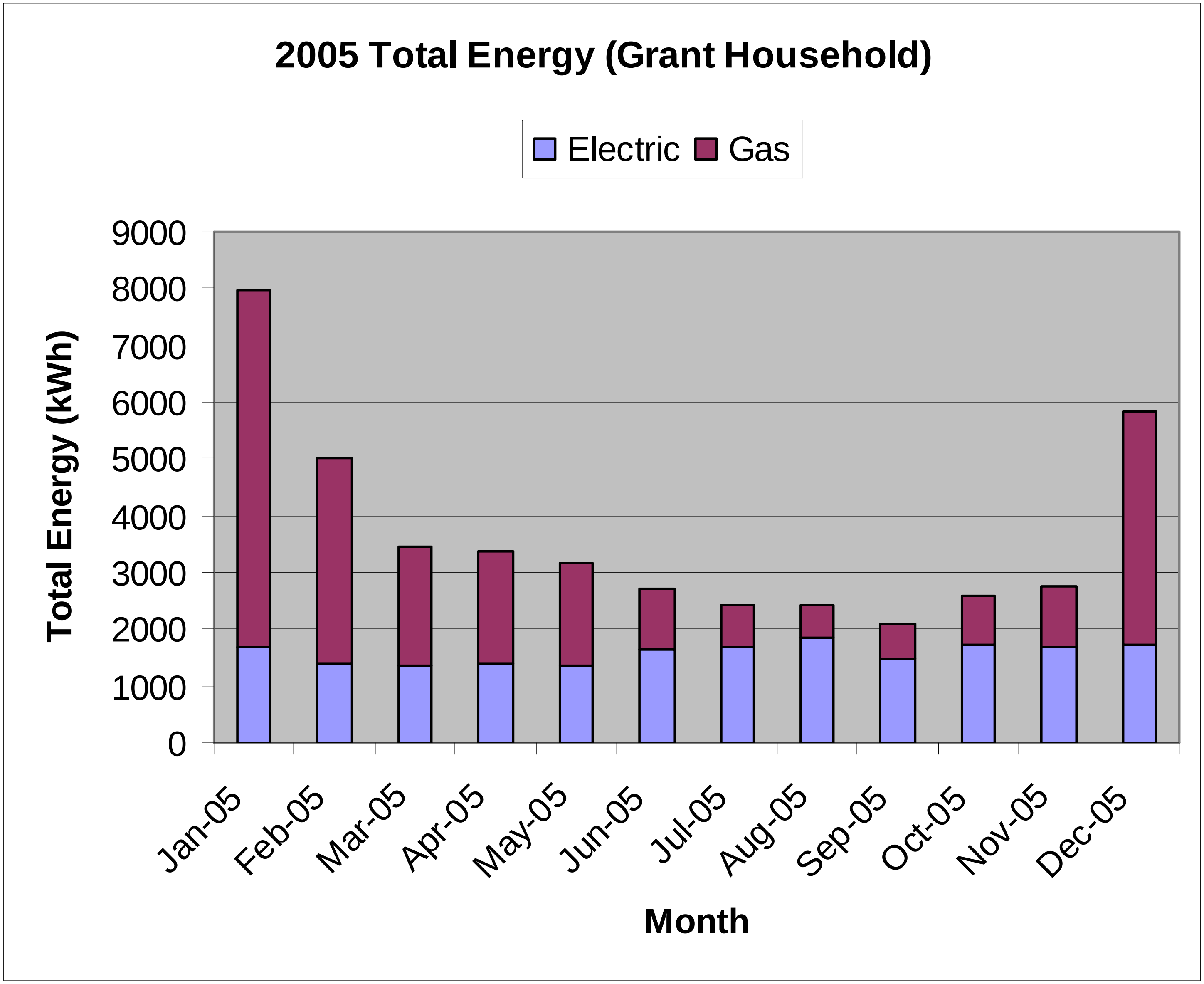
SuperCities (SuperSuburbs)

ICEC-ICMC, Seoul, 2008

SuperSuburb Parameters

- Electricity for residential appliances, lighting, space conditioning and cooking
- Hydrogen for storage of electricity and personal transportation
- Off the Agenda:
  - Commercial business; shopping centers
  - Electric rail/rapid transport
  - Street lighting

California Living!



Baseline Electric Power and Energy Storage Requirements per GHE in SuperSuburb

Baseline Power (kW)	Energy Stored (kWh)	Hydrogen Mass Equivalent (kg)	Volume as Liquid (21 K, 14.7 psia) (cube edge in meters)	Volume as Gas (300 K, 2000 psia) (cube edge in meters)
5.99	6129	187	1.38	2.63

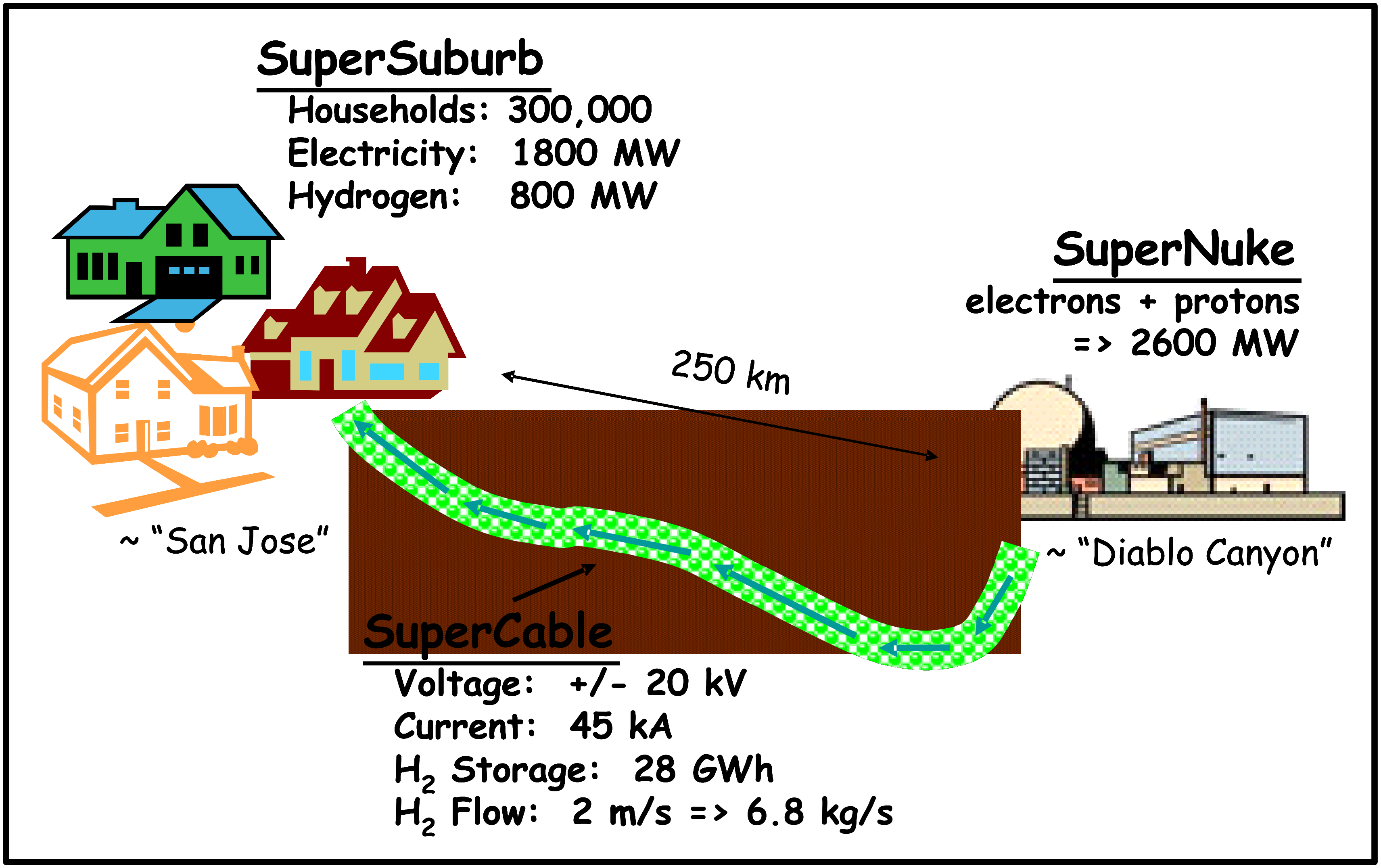
GHE Transportation Energy Consumed

Miles/Year	DOE H_2 Mileage (kWh/mile)	H_2 Daily Mass Consumption (kg)	SuperCable H_2 Delivery Power (kW)
30,000	0.76	1.91	2.61

Baseline Electric and Hydrogen Power Needs of a “San Jose” SuperSuburb of GHEs

GHE Households	Base Electric Power (MW)	Electricity to be Stored as H_2 (tonnes)	Base H_2 Power (MW)	H_2 Stations
300,000	1798	56,104	782	748

The Cryogenic Neighborhood



SuperSuburb

Households: 300,000
Electricity: 1800 MW
Hydrogen: 800 MW

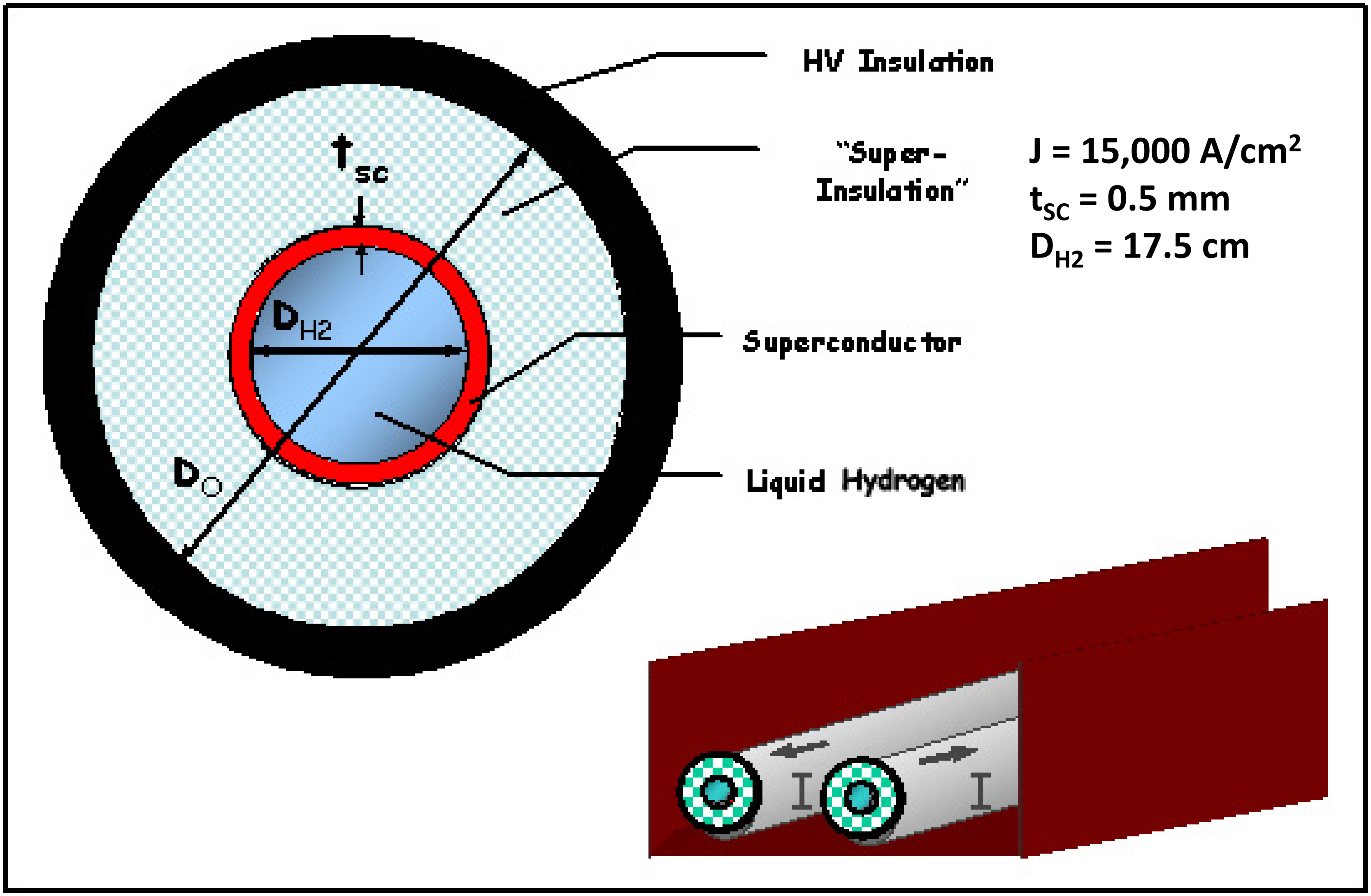
SuperNuke

electrons + protons
=> 2600 MW

SuperCable

Voltage: +/- 20 kV
Current: 45 kA
H_2 Storage: 28 GWh
H_2 Flow: 2 m/s => 6.8 kg/s

The CryoNet



$J = 15{,}000\ A/cm^2$

$t_{SC} = 0.5$ mm

$D_{H2} = 17.5$ cm

SuperCable Physical Parameters

Operating Current Density, J (A/cm^2)	t_{SC} (cm)	Hydrogen Flow Rate (m/s)	D_{H2} (cm)	Maximum Magnetic Field (T)
15, 000	0.05	2	17.5	0.10

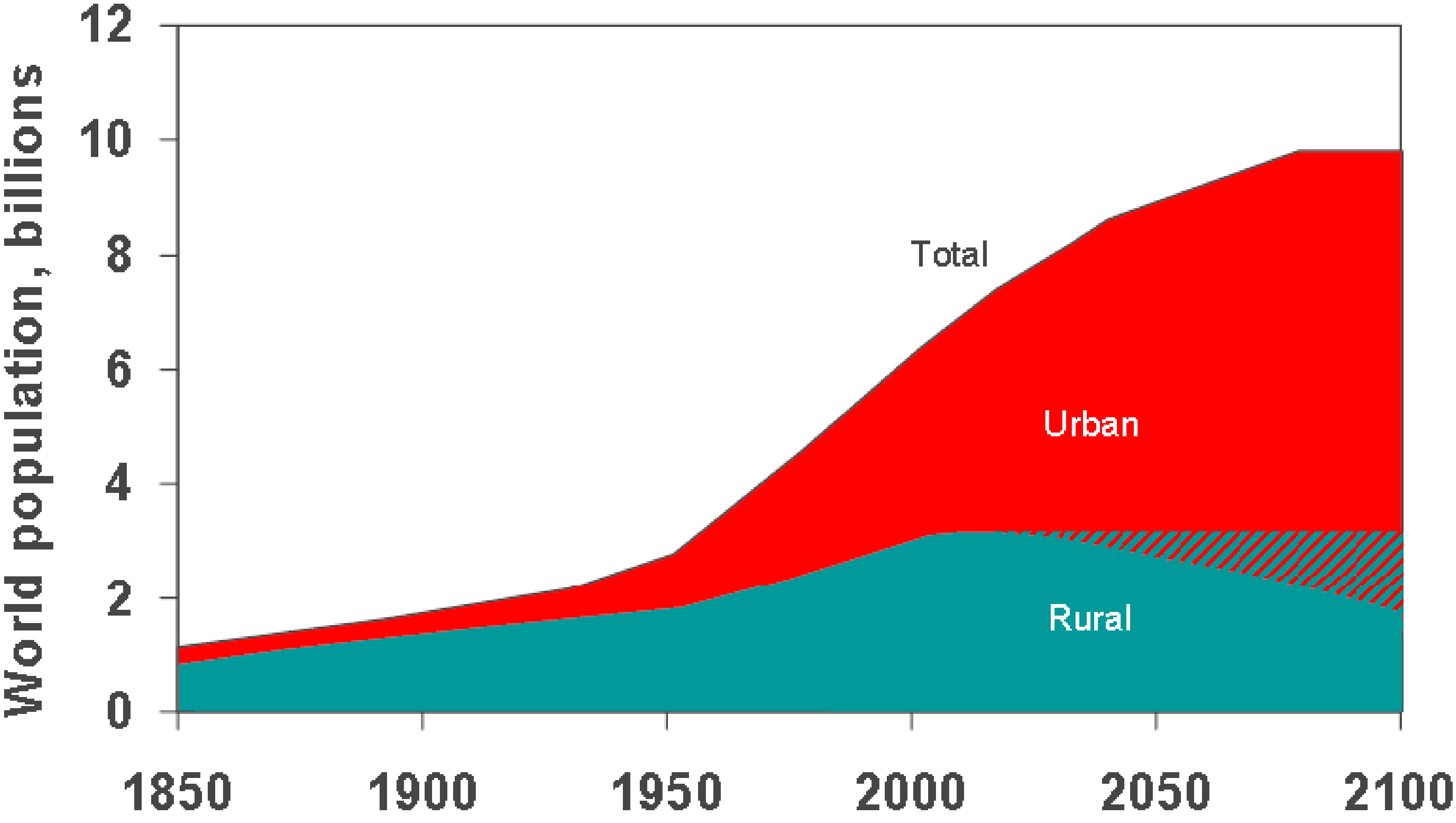
Bottom Line

SuperSuburb SuperCable Economic Factors.

Cost of Electricity ($/kWh)	Line Losses in Conventional Transmission (%)	Annual Value of Losses on 1800 MW Transmission Line (M$)	Additional Capital Costs for HTSC and Refrigeration (M$)	FRB Discount Rate (%)	Period for ROI (Years)
0.05	5 %	39.4	1185	5.5 %	18

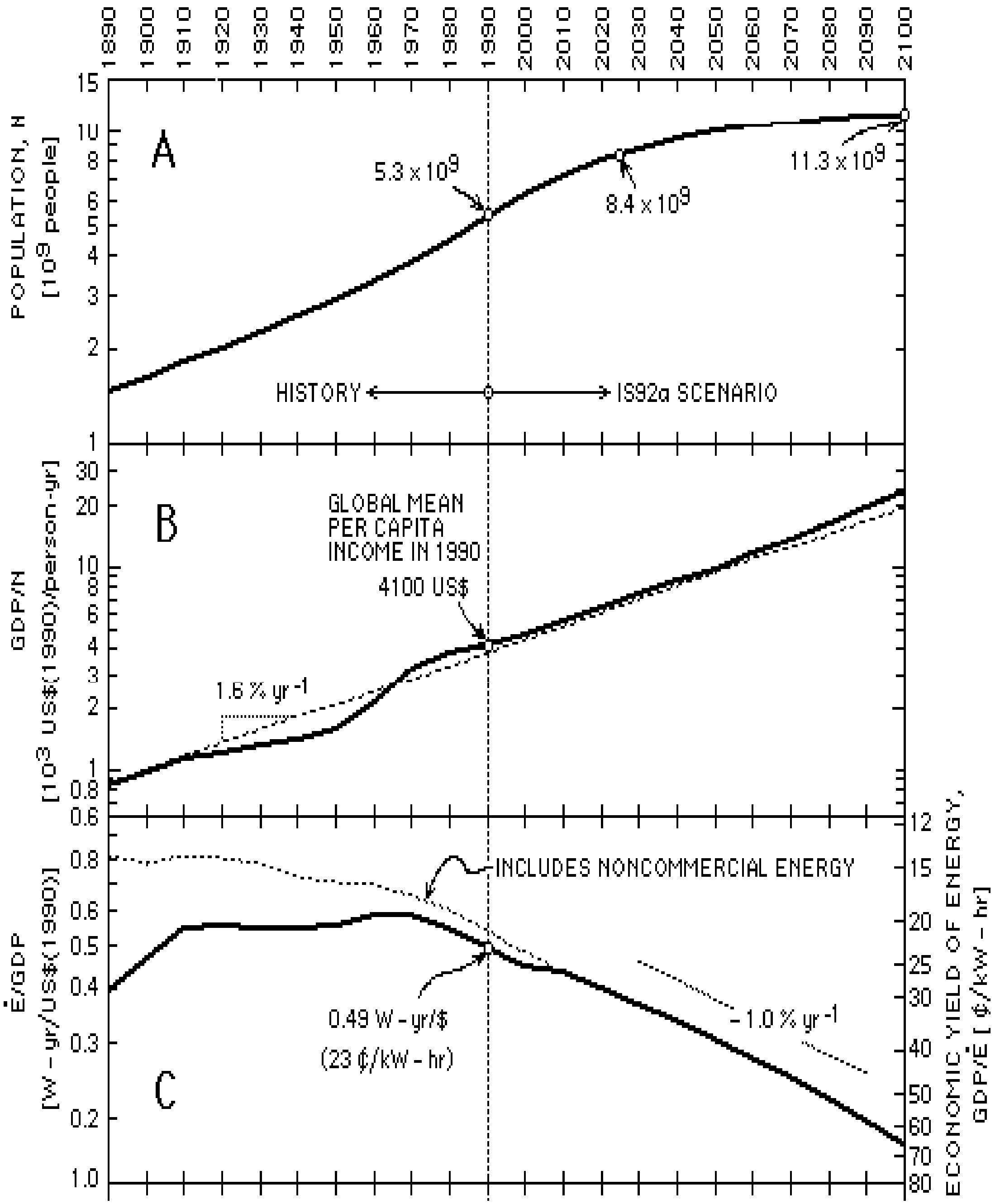
Finale

World Population: 1850 - 2100



From Global Energy
Perspective – 2007

Nate Lewis, Cal Tech

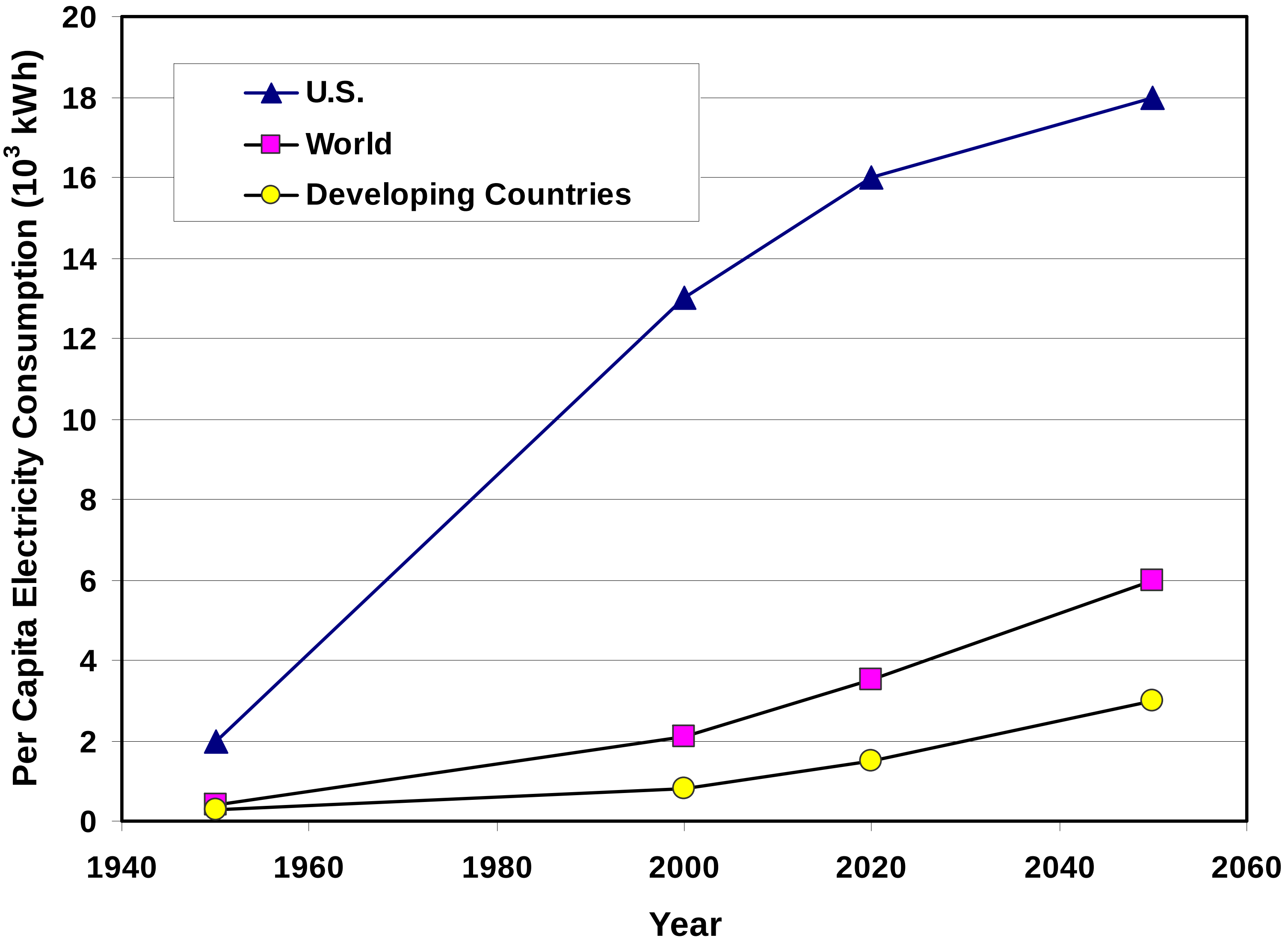


Population Growth to
10 - 11 Billion
People in 2050

Per Capita GDP Growth
at 1.6% yr^{-1}

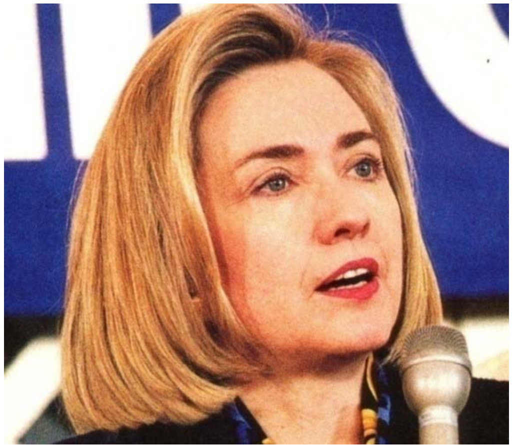
Energy consumption per
Unit of GDP declines
at 1.0% yr $^{-1}$

Trends in Per Capita Electricity Consumption



Enfranchisement of Women







…But There Are Always Exceptions!

Where there is no vision,
the people perish…

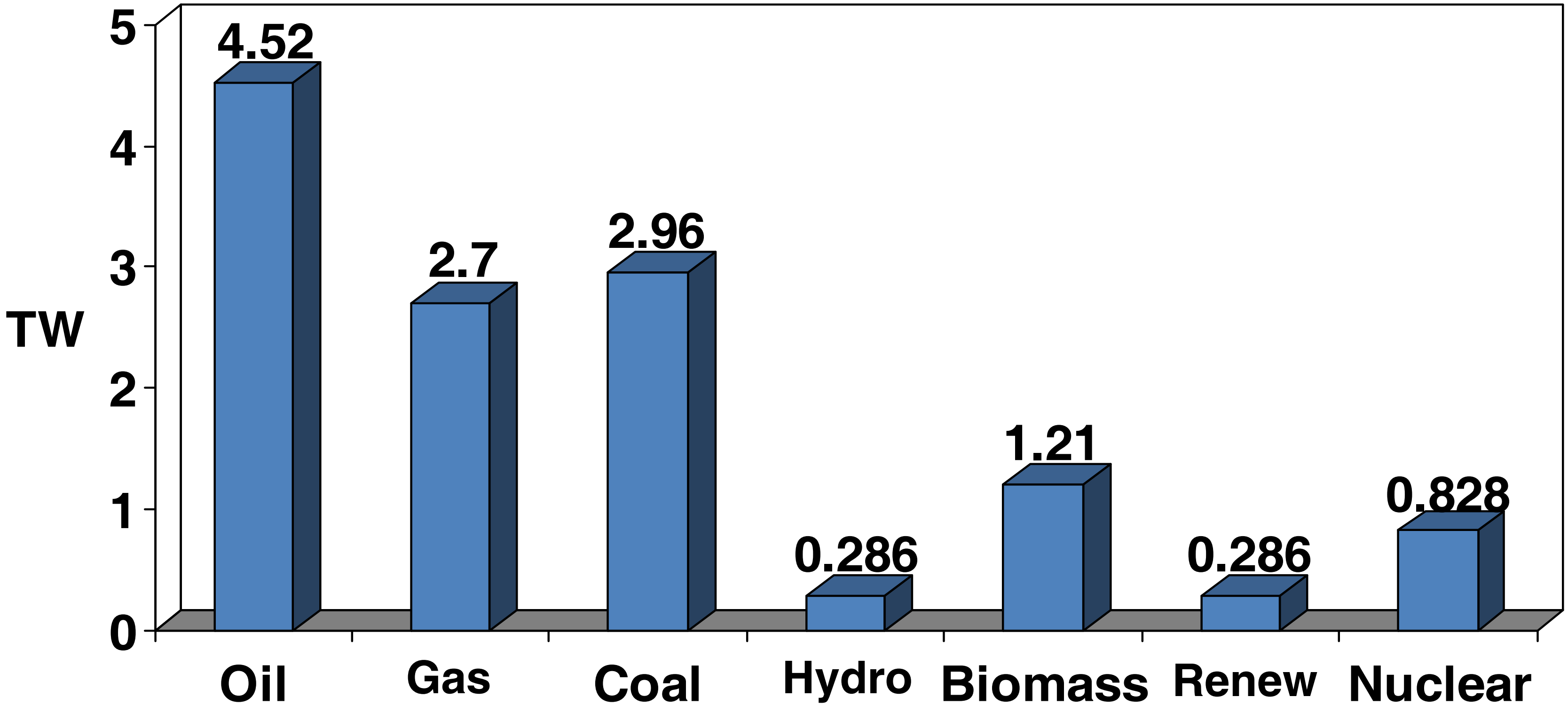
Proverbs 29:18

“You can’t always get what you want…”

“…you get what you need!”

Extras

Mean Global Energy Consumption 1998

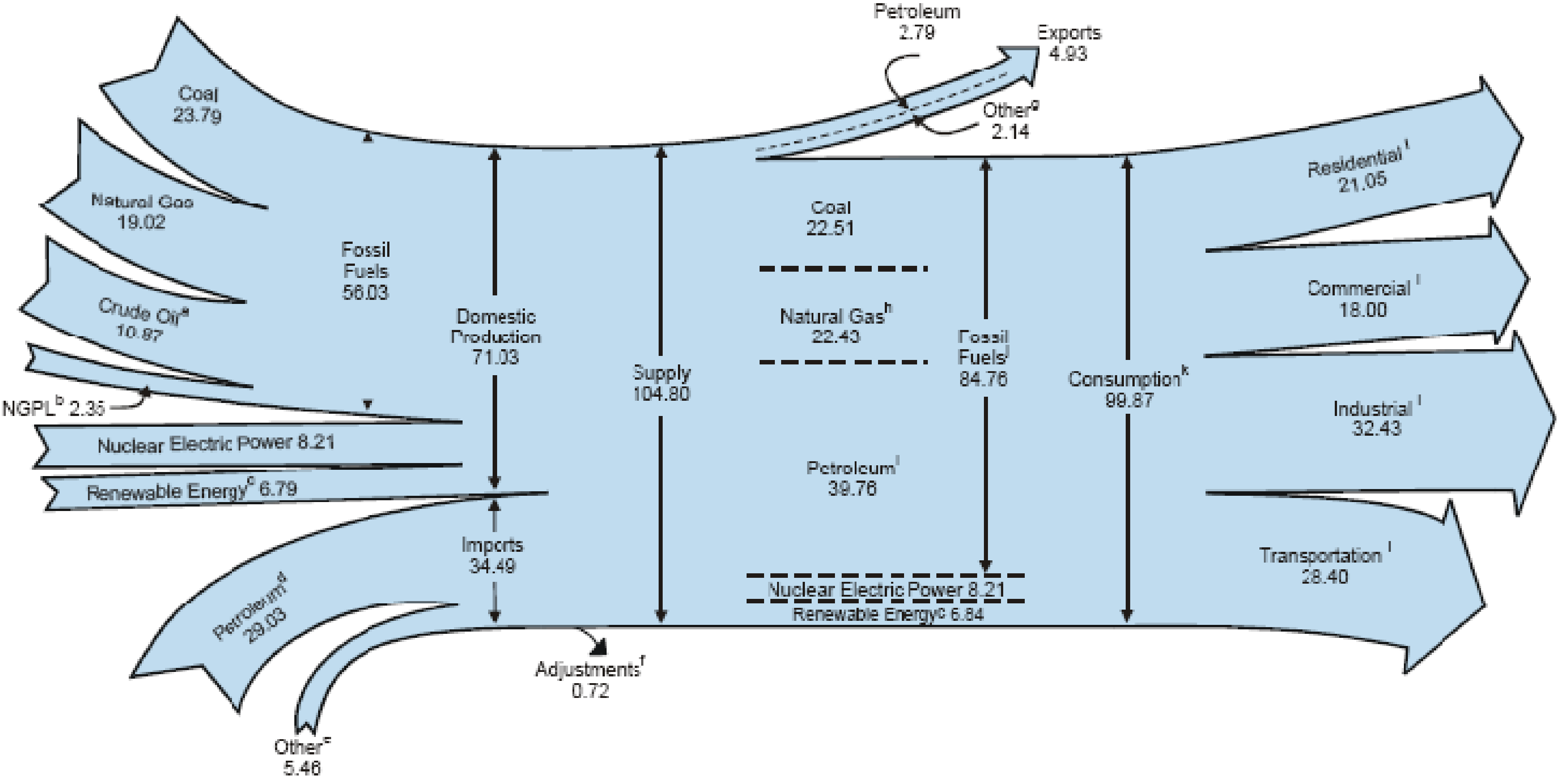


Global Total: 12.8 TW

US: 3.3 TW (99 Quads)

(1 TW Electricity)

Diagram 1. Energy Flow, 2006
(Quadrillion Btu)



The Trioka Challenge of GCC

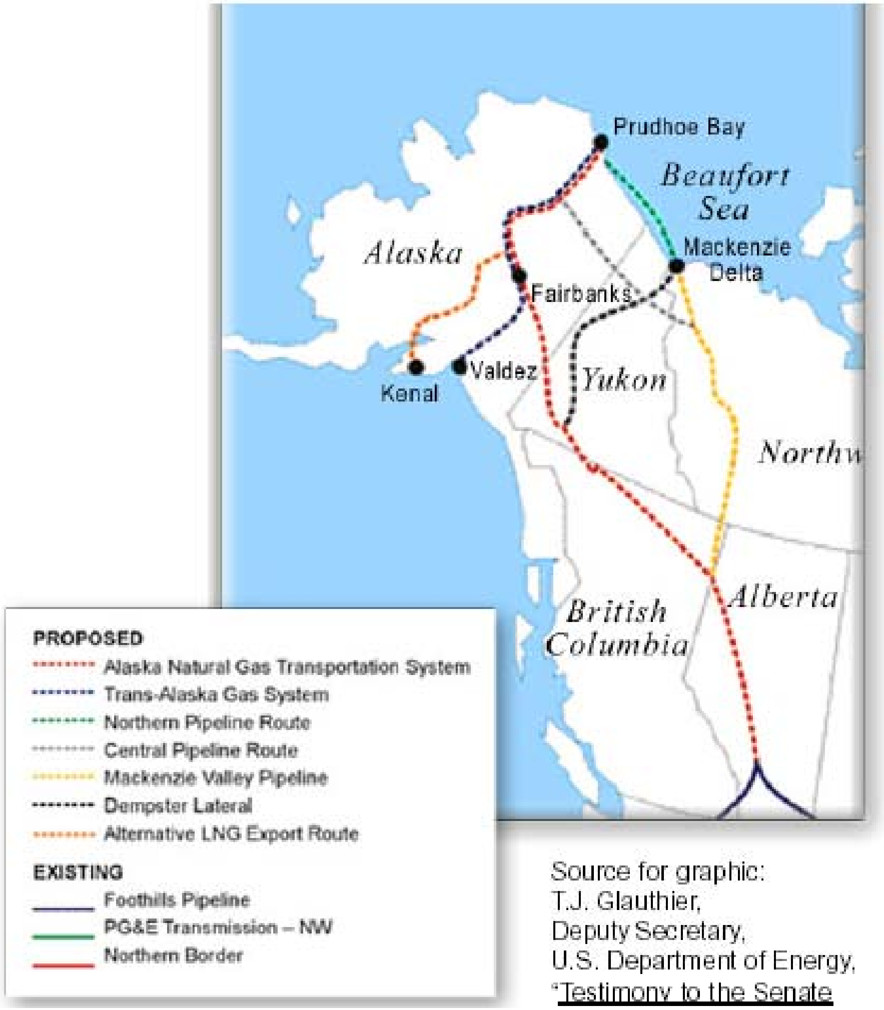
- Mitigation
  - If GCC is principally CO_2 emissions-driven:
    - How do we stop or stabilize them?
    - Can we stop or stabilize them?
    - *Does superconductivity have a role?*
- Impact
  - In any event, heat already stored in the oceans will continue to warm the planet?
  - What impact will this have on the human condition?
    - Massive redistribution of land and water resources?
- Adaptation
  - Since continuing warming is inevitable, what technologies need to be developed to ameliorate its impact?
    - *Does superconductivity have a role?*

Mitigation

- SuperGrid
  - Nuclear
  - Hydrogen
  - Superconductivity (efficiency!)
- DOE PR 1997
  - Transmission savings
  - Rotating machinery
  - Transformers

A North American Pipedream?

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).

2005 GHE Energy Consumption Statistics

Energy (kWh)	*Electricity*	*CH_4*	*Total*
Annual Total	18894	24882	43776
Monthly Average	1575	2073	3648
Standard Deviation	174	1747	1748
Skewness	-0.15	1.51	1.69
Kurtosis	-1.57	1.88	2.42

Monthly GHE Consumption

Power (kW)	*Electricity*	*Natural Gas*	*Total*
Monthly Mean	2.16	2.84	4.99
Standard Deviation	0.24	2.39	2.39
Mean + STD	2.39	5.23	7.39
Mean - STD	1.92	0.45	2.60

Number of GHEs per H_2 Station and Individual Station Capacity

US Households (2005)	Number of Stations (1998)	Households per Station	Turnover Rate (days)	H_2 Mass (kg)	Liquid “cube” (meter)	Gas “cube” (meters)
75,000,000	187,000	401	3	2298	3.2	6.1

SuperSuburb SuperCable Monopole Minutia and Costs)

HTSC Tape Parameters							
Width (mm)	Thickness (mm)	Length (m)	Total No. Tapes	Tape Req’d (km)	Approx. No. Splices	Tape C/P ($/kA×m)	HTSC Cost (M$)
4	0.25	800	~300	~80,000	~100,000	50	591

SuperSuburb SuperCable Thermal Loss Budget (W/m)

Radiation	Flow Friction	Addenda Loss	1.0 % Ripple	Total
0.70	0.49	0.20	0.09	1.48

SuperSuburb SuperCable Refrigeration Requirements

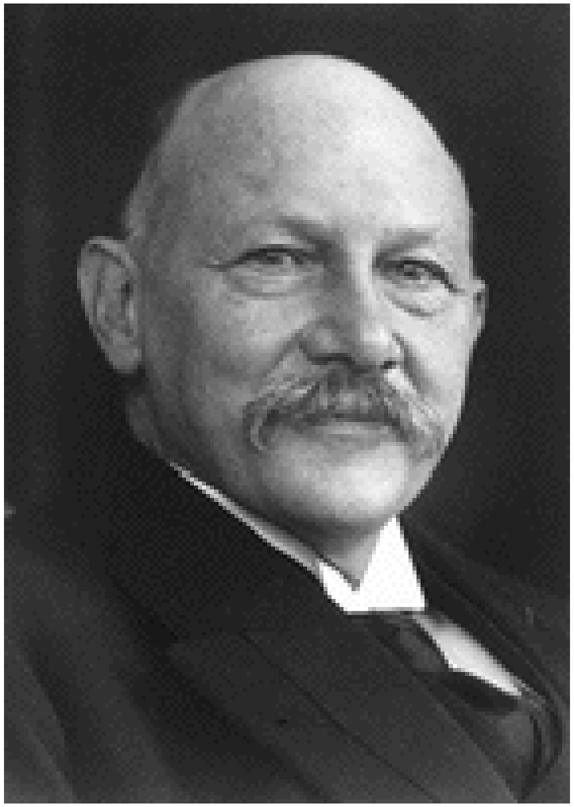
Temperature Rise (K/km)	Total Rise for 250 km SuperCable (K)	Permissible Rise Prior to Re-Cool (K)	Total Number of Cooling Stations Required
0.045	11	1	11

Station Spacing (km)	Cooling Power per Station (kW)	Cost of Heat Uplift ($/kW)	Per Station Cost (K$)	Total Station Cost (M$)
22.25	32.9	5	164	1.85

Fathers of Cryogenics

Dewar

CH_4	112 K
O	90
N_2	77
Ne	27
H_2	20
He	4.2



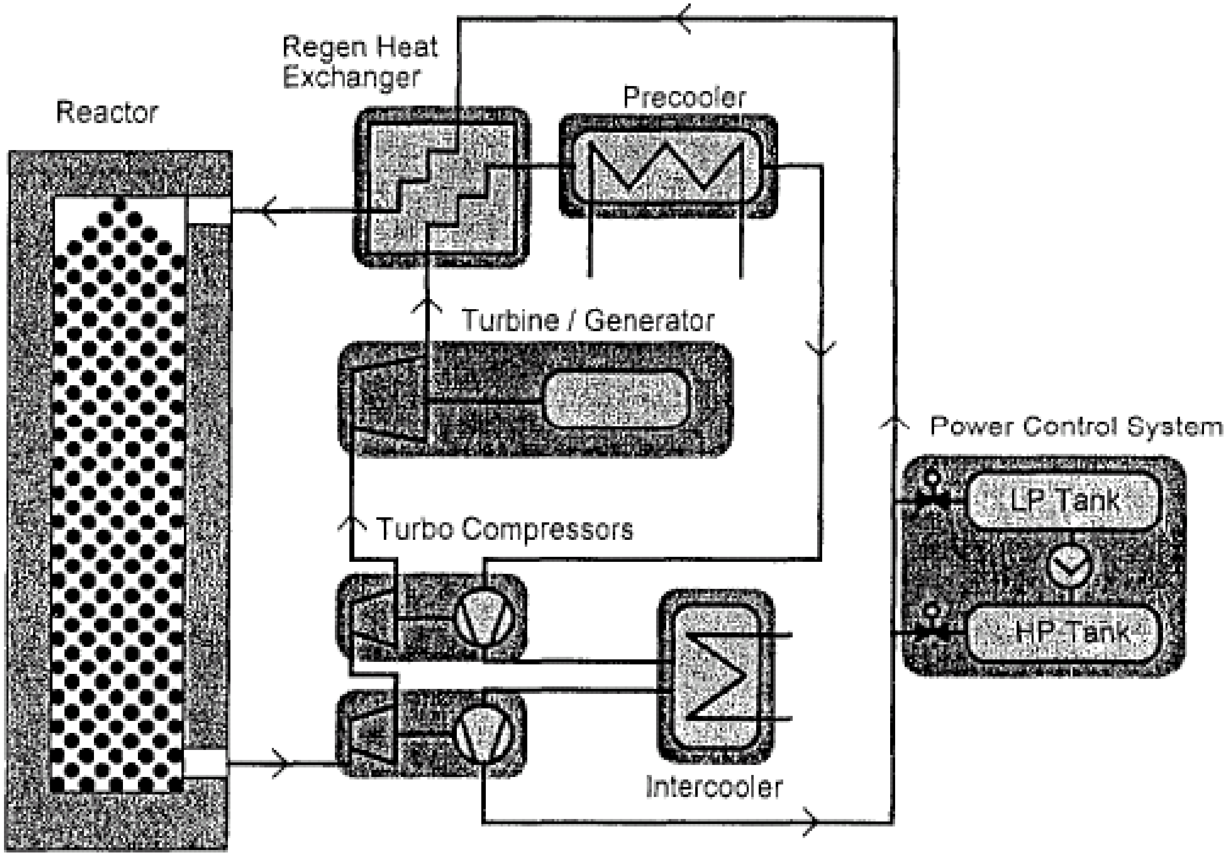
Kammerlingh-Onnes

Hydrogen
The Hydrogen Economy

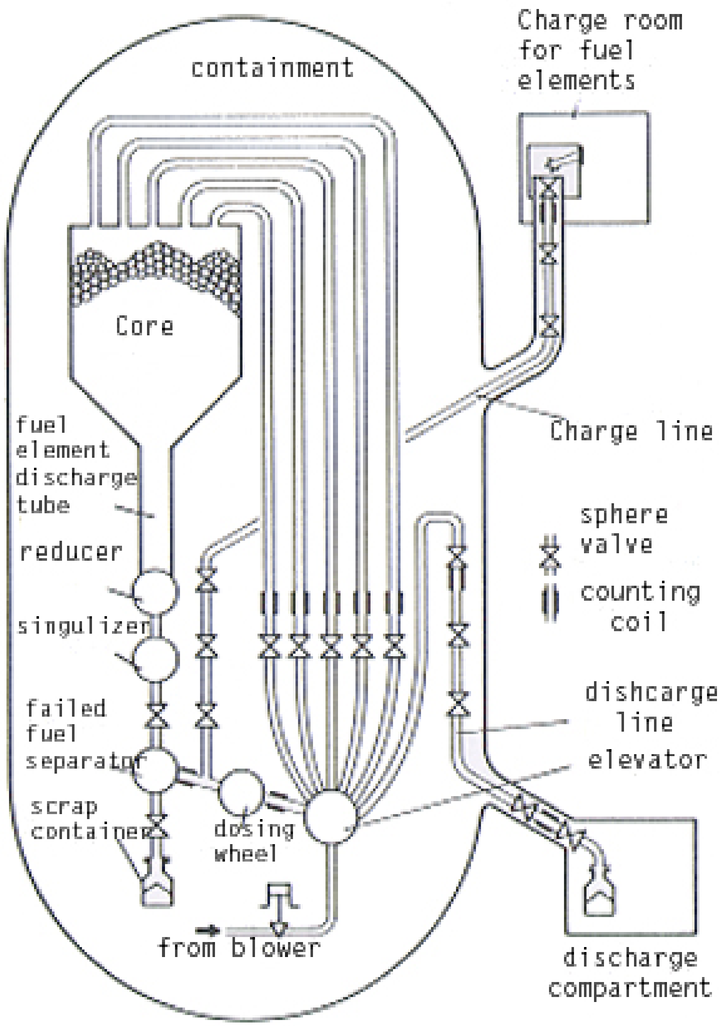
- You have to make it, just like electricity
- Electricity can make H_2, and H_2 can make electricity $(2H_2O \Leftrightarrow 2H_2 + O_2)$
- You have to make a lot of it
- You can make it cold, - 419 F (21 K)

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

High Temperature Gas Cooled Reactor



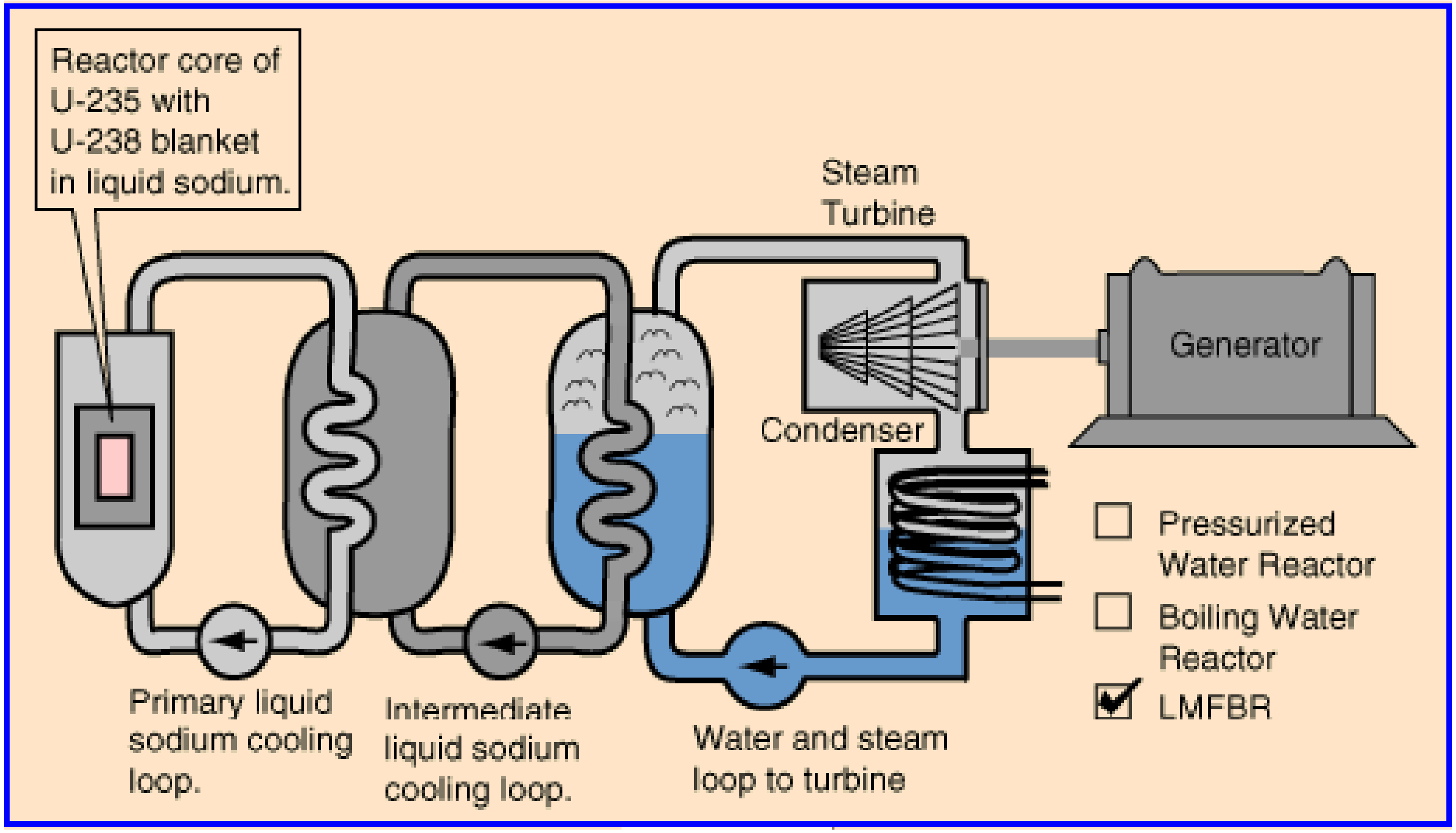
What is a Pebble Bed Reactor (MIT)?



- 360,000 pebbles in core
- about 3,000 pebbles handled in FHS every day
- about 350 pebbles discarded daily
- one pebble discharged every 30 seconds
- average pebble cycles through core 15 times
- fuel-handling most intensive part of plant

http://web.mit.edu/pebble-bed/

Fast Breeder Technologies



http://hyperphysics.phy-astr.gsu.edu/hbase/nucene/reactor.html#c5

Vision of a Sailing Railway

Mon

1828

George Stephenson - 1825

Source: Marshall, 1938