SuperCities and SuperGrids:

Teratechnology Energy Societies for an Exajoule World

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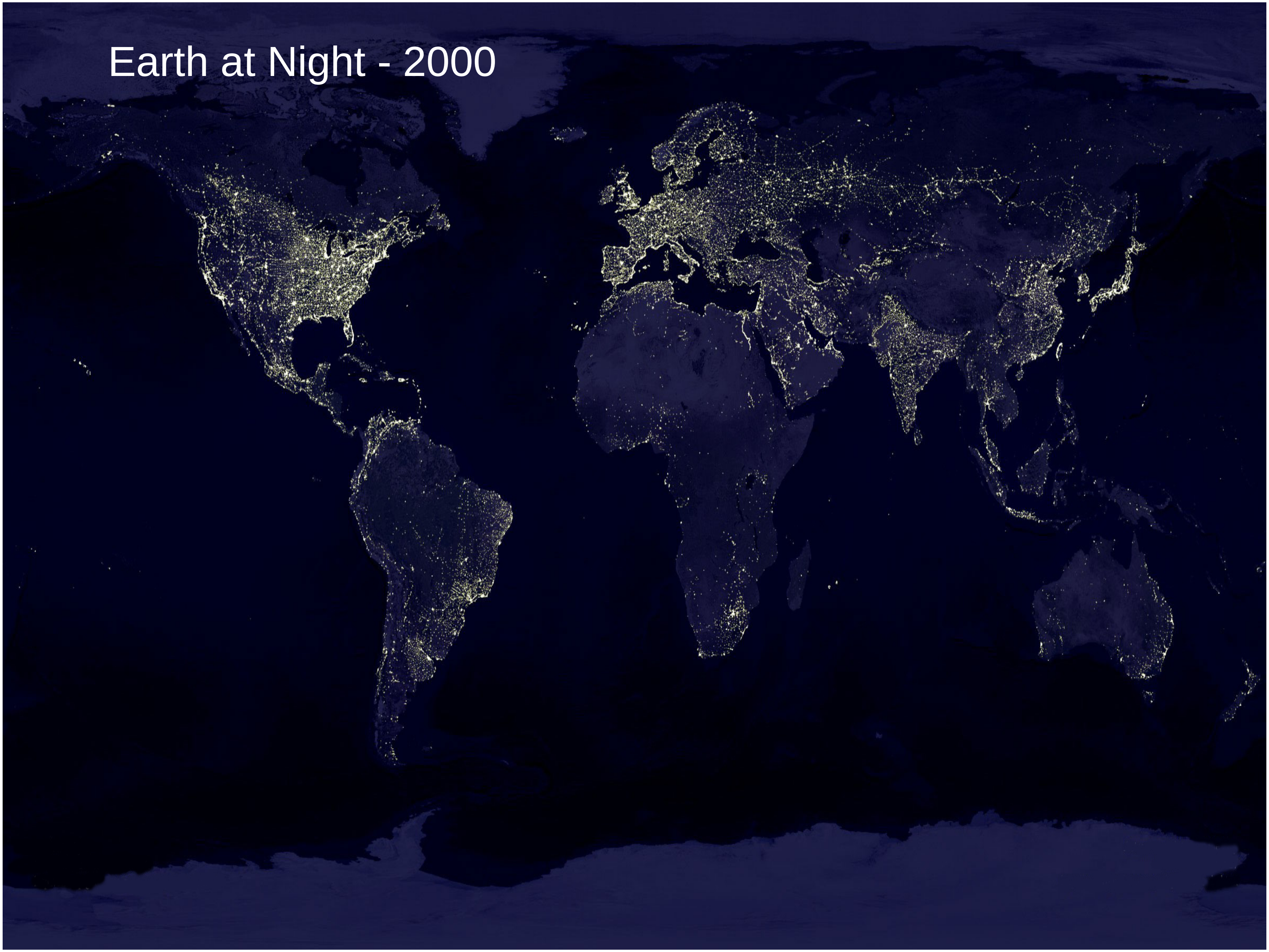
Brown Bag Science Seminar
7 April 2006
Ohlone Community College
Fremont, CA

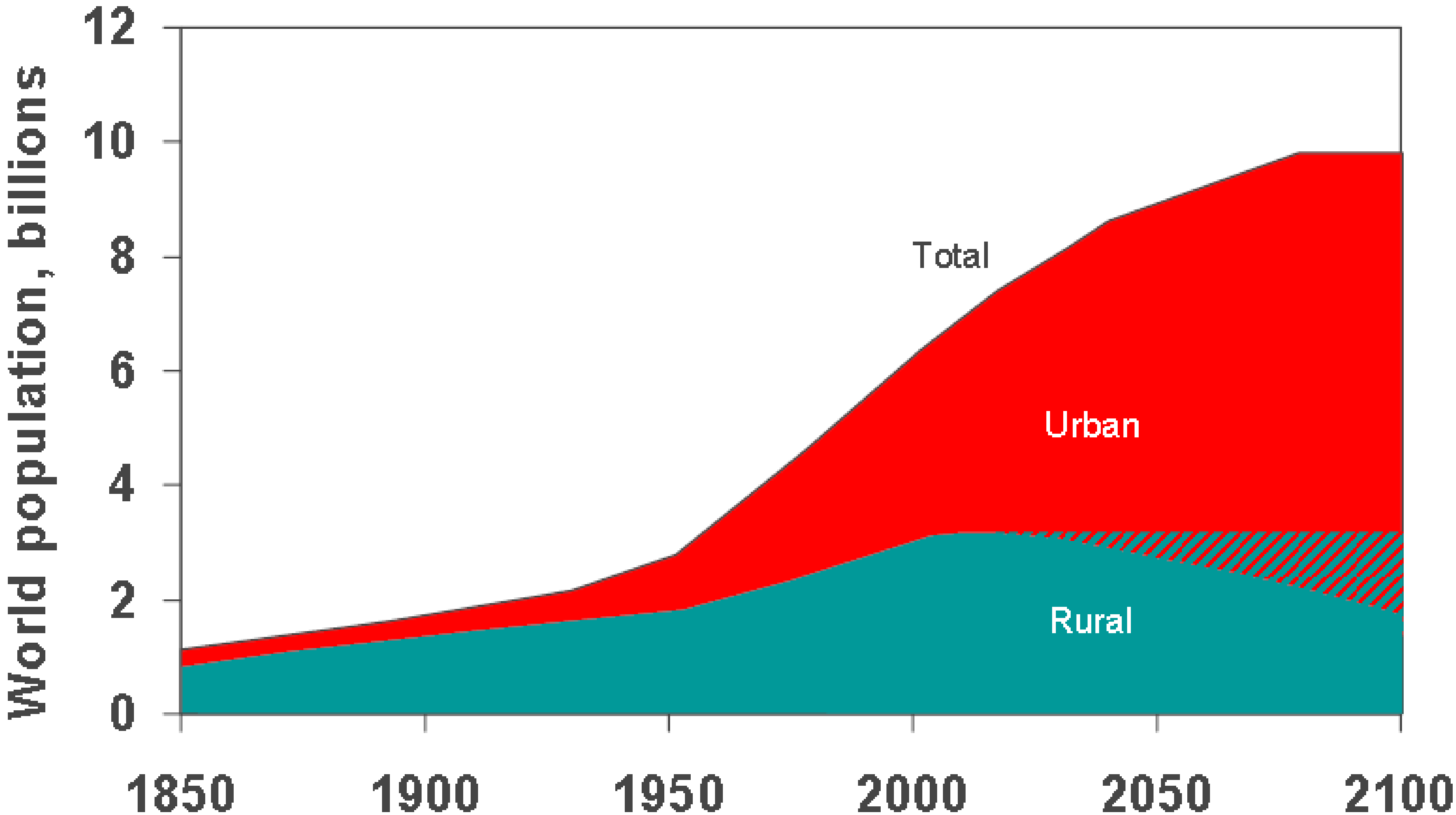
http://www.w2agz.com/ohlonebbss.htm

(Includes Ballads in Celebration of Irish Freedom !)

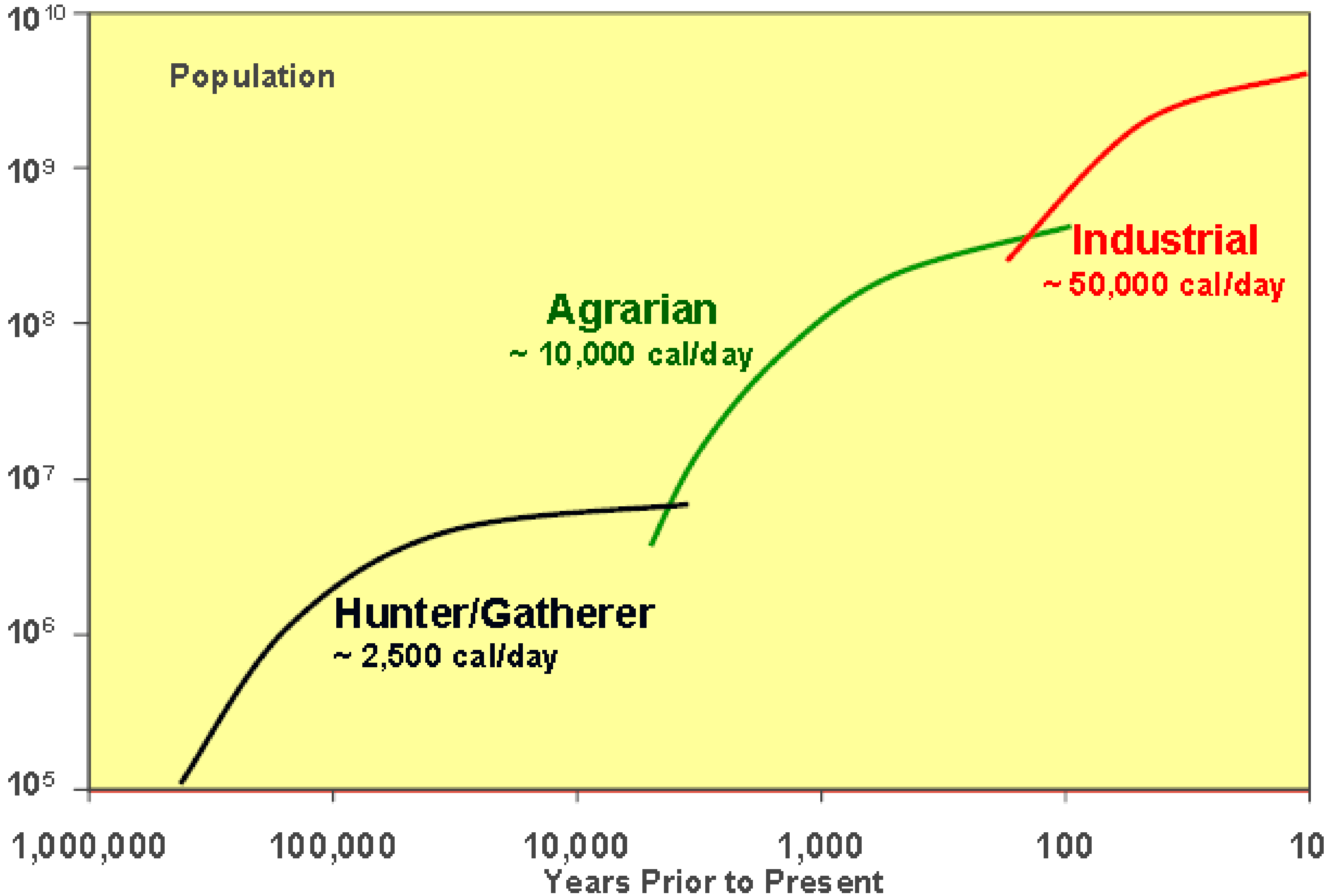
Chauncey Starr


Earth at Night - 2000

World Population: 1850 - 2100

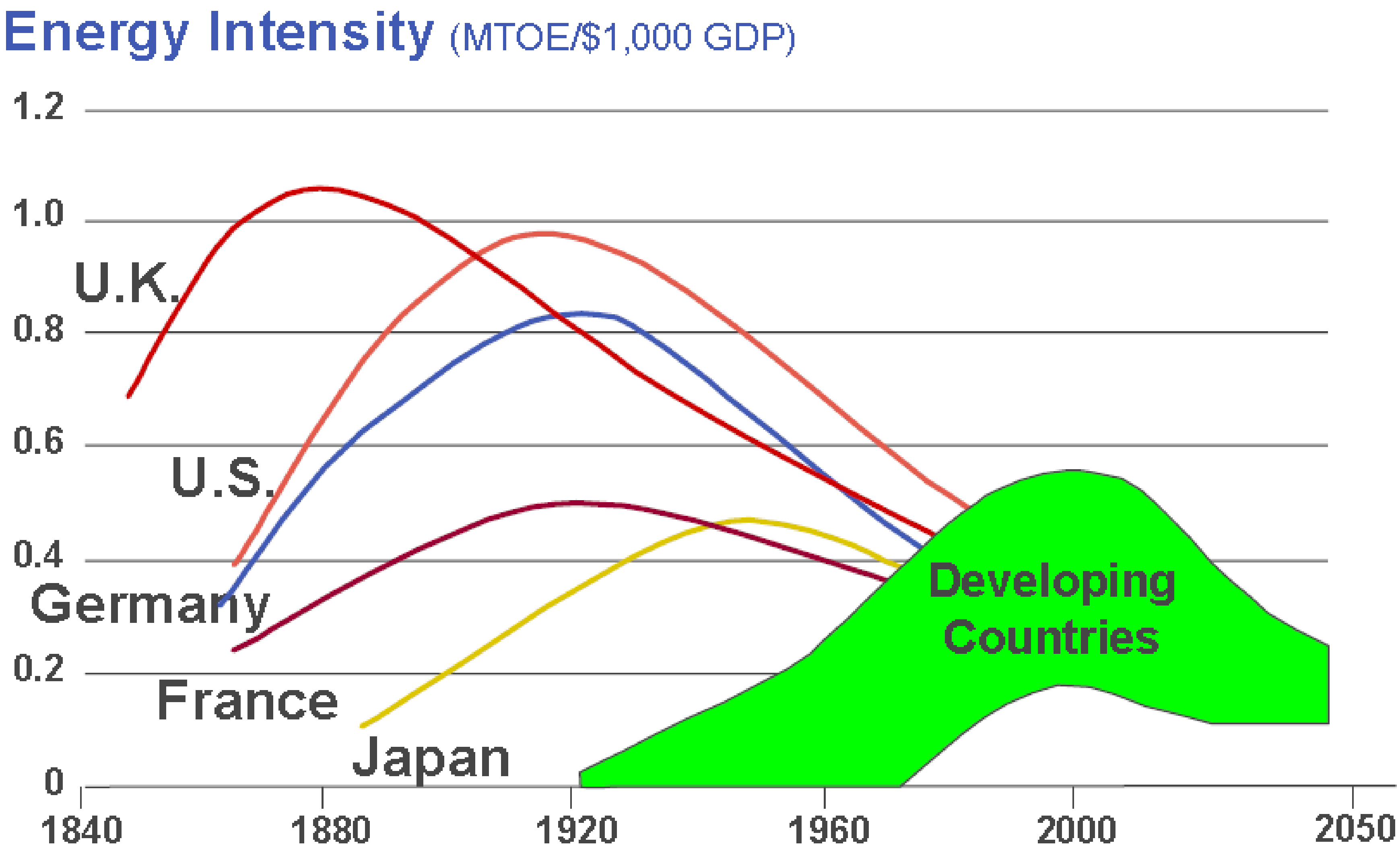


Energy/Demographics Timeline

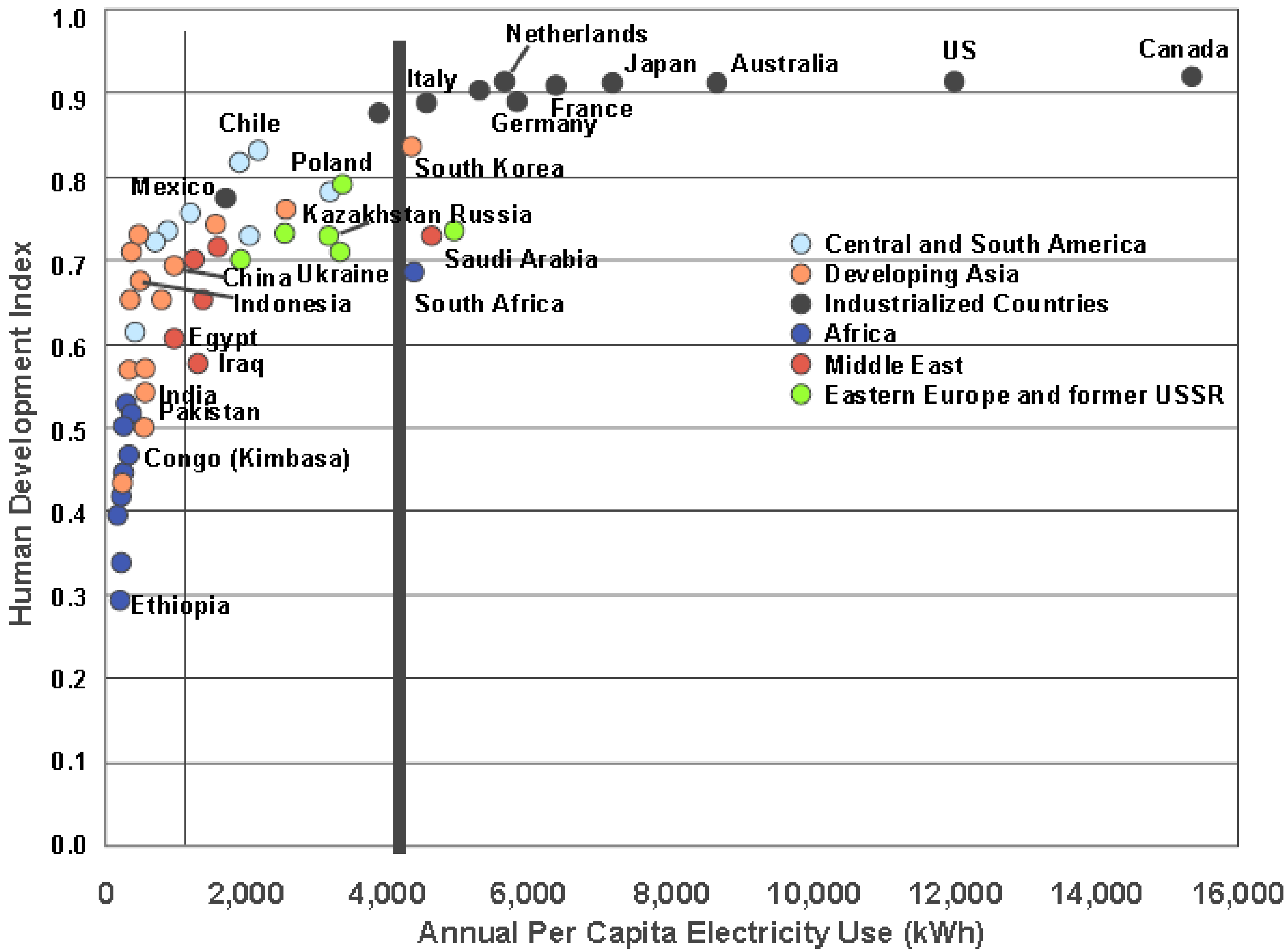


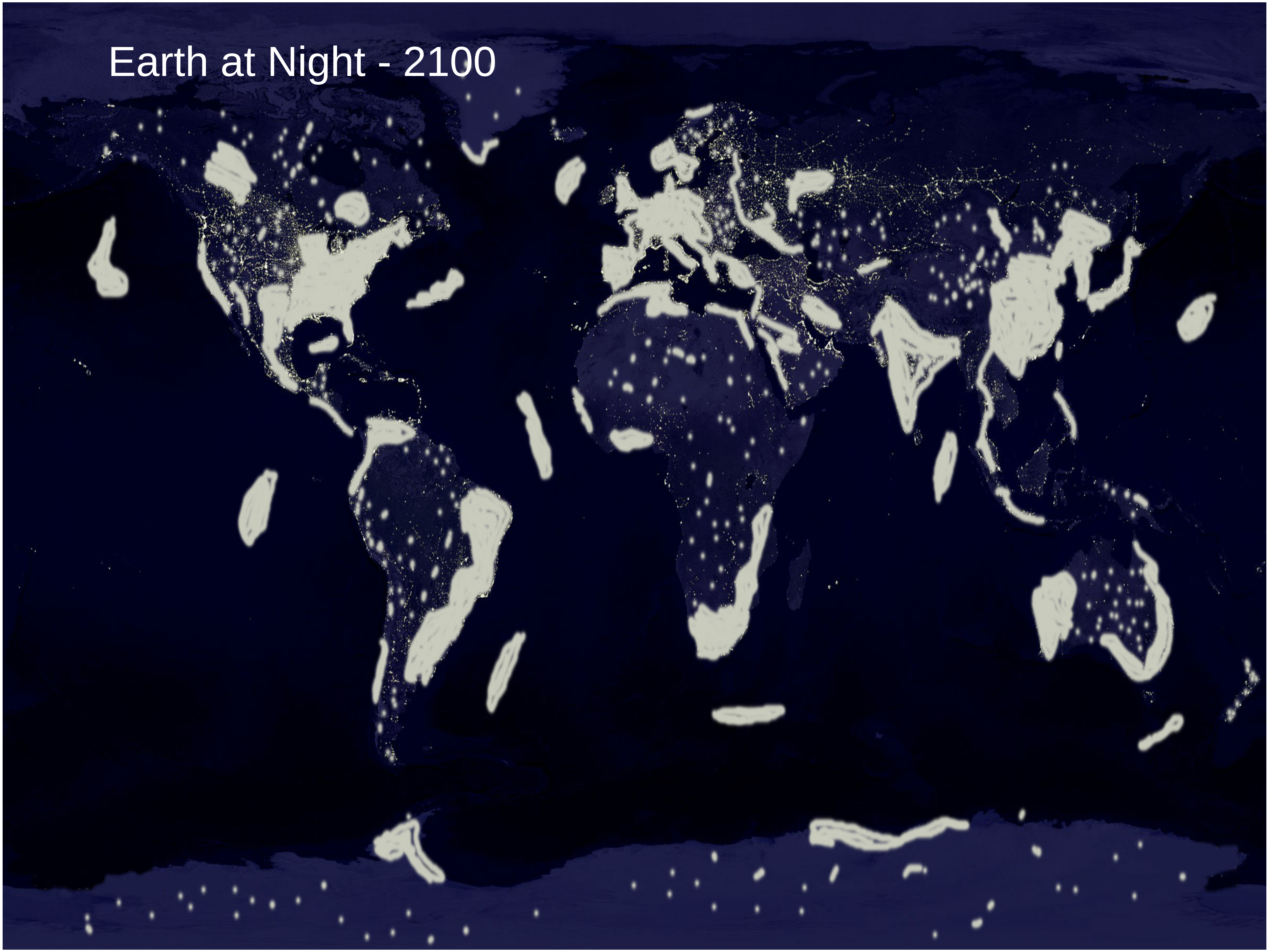
Enfranchisement of Women

Industrialization Helps Bring Energy Efficiency



HDI vs per capita Electricity

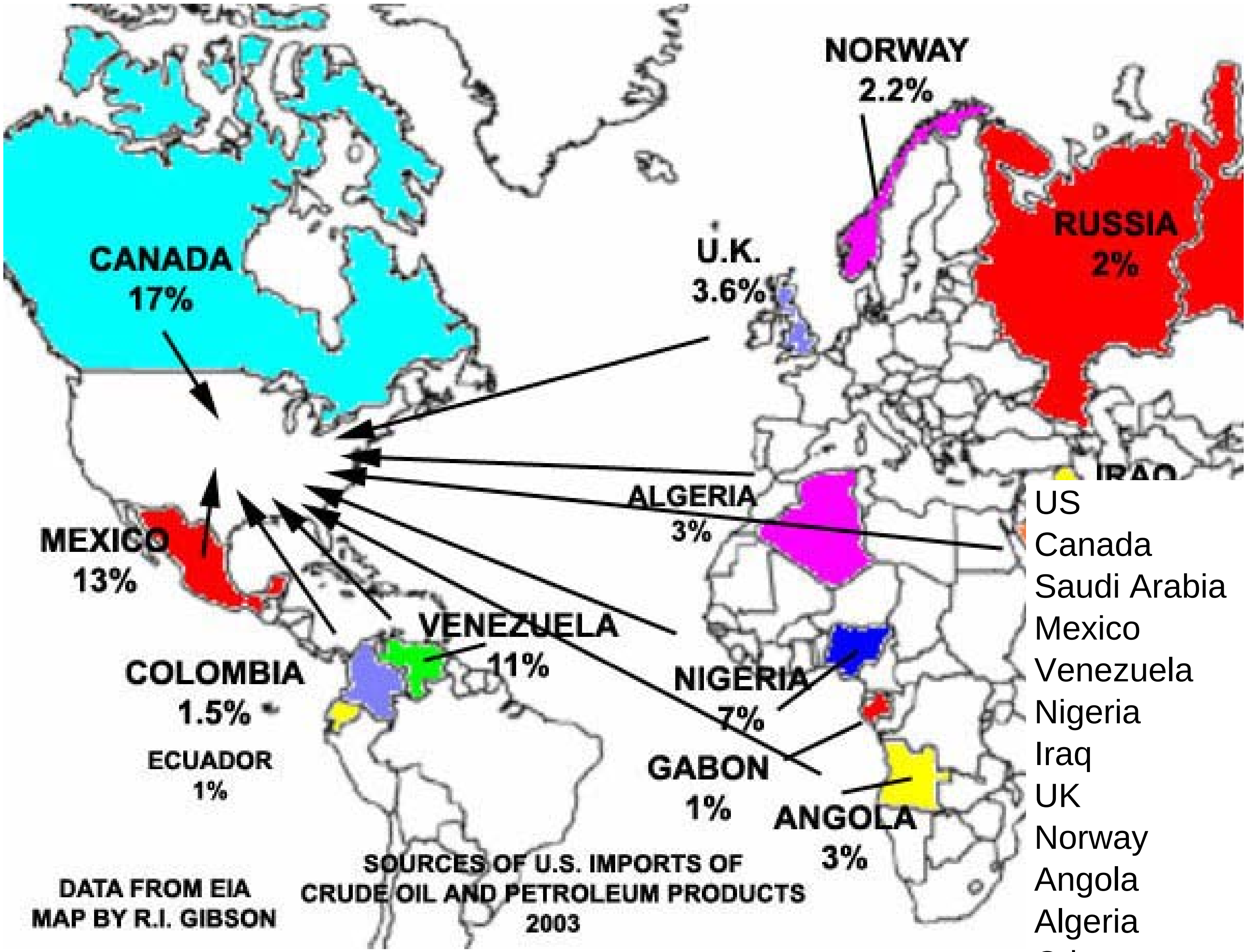



Earth at Night - 2100

US Energy Consumption (2001)

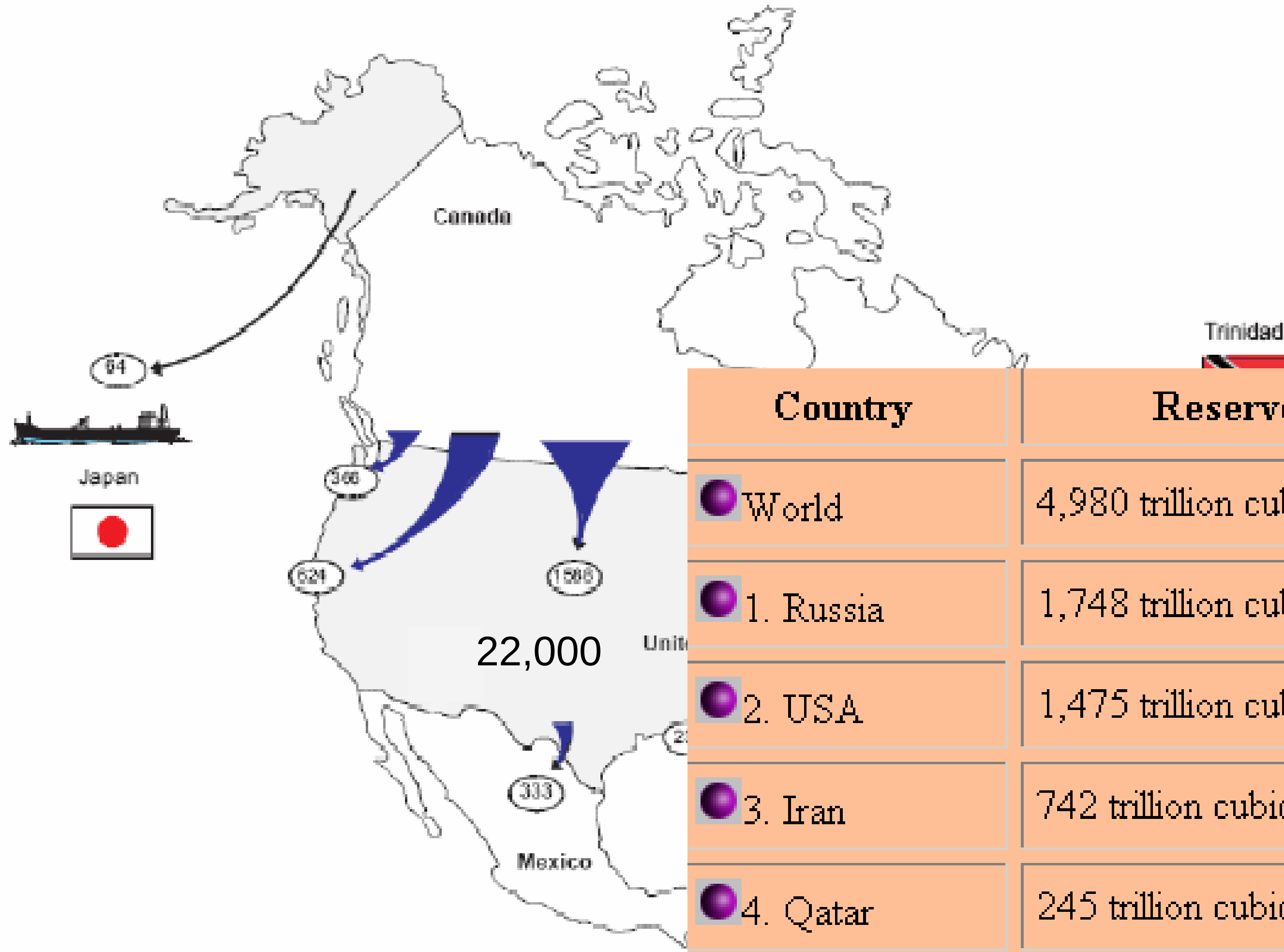
Energy Source	Percentage of total
Petroleum	42%
Coal	24%
Natural Gas	20%
Nuclear	8%
Hydro power	2%
Solar, Wind, etc.	2%

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%

US Natural Gas Imports (BCF, 2003)



Country	Reserve estimate
World	4,980 trillion cubic feet
1. Russia	1,748 trillion cubic feet
2. USA	1,475 trillion cubic feet
3. Iran	742 trillion cubic feet
4. Qatar	245 trillion cubic feet
5. Abu Dhabi	188 trillion cubic feet

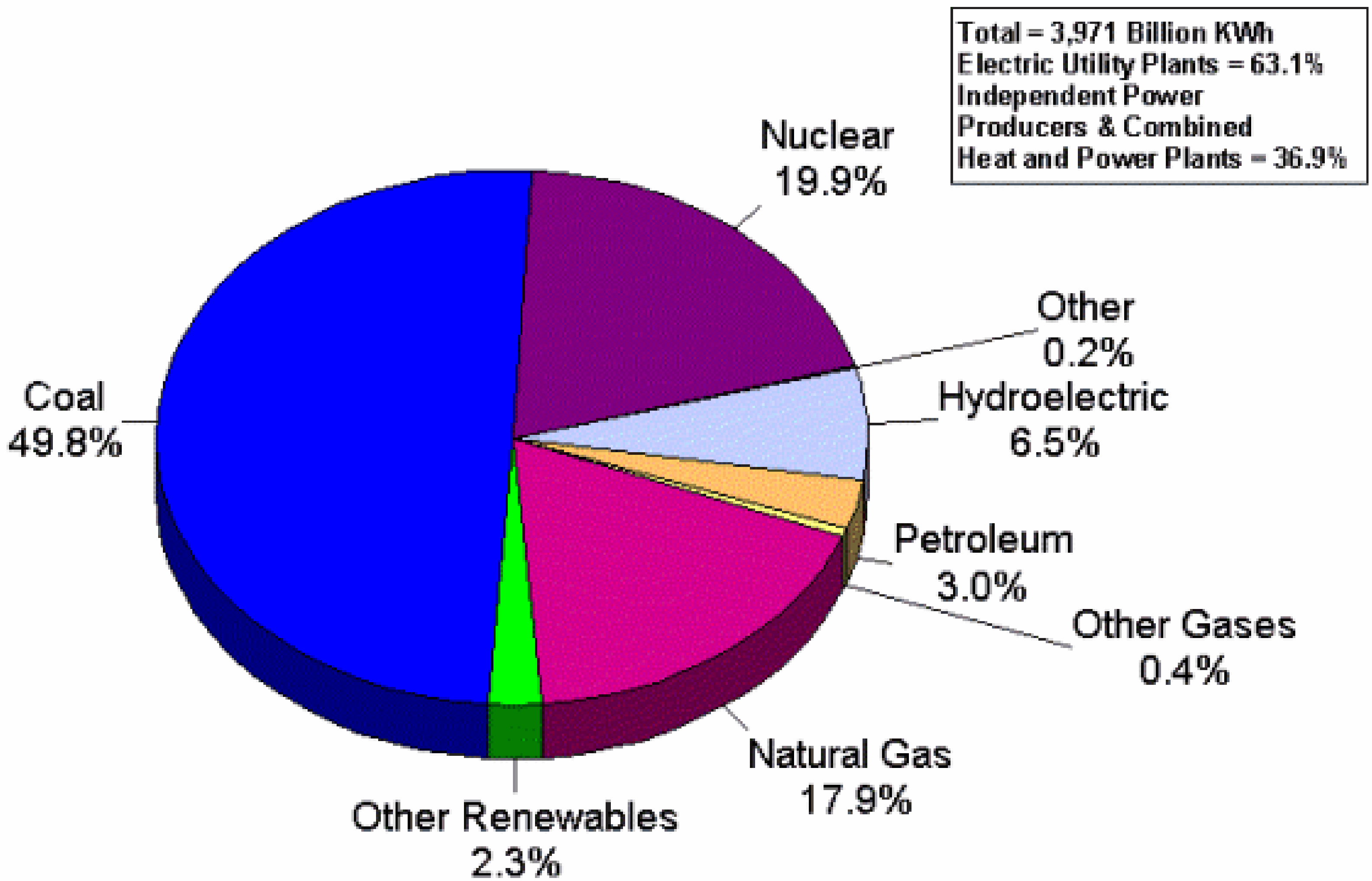
China-USA Recoverable Coal Reserves (2002)

	Million Short Tons	Years Left*
China	126,215	273
USA (NA)	280,464	309

• One Short Ton = 6150 kWh

Efficiency Conversion – 40%

US Electricity Generation - 2005



Note: Conventional hydroelectric power and hydroelectric pumped storage facility production minus energy used for pumping.

China-USA Electricity Statistics (2001)

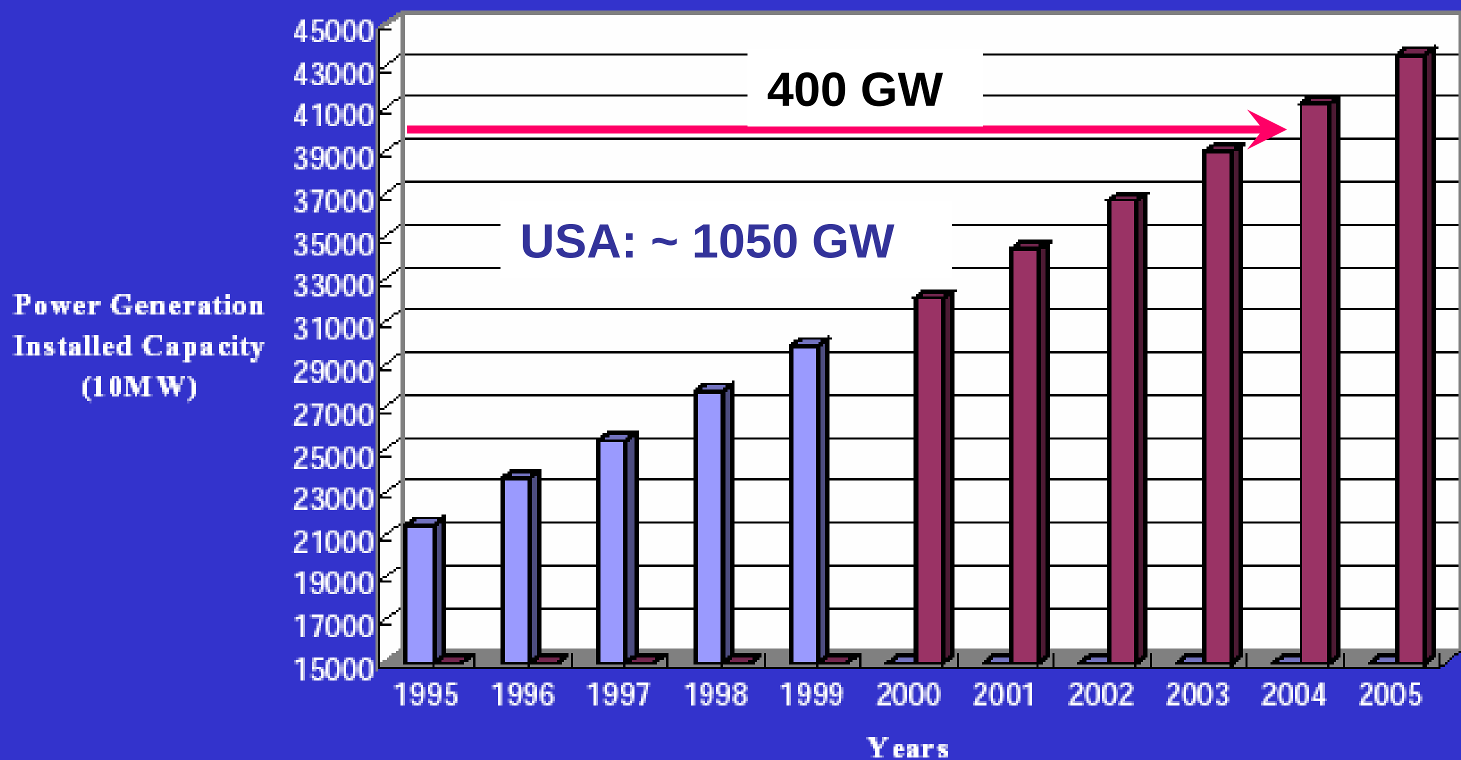
Source (CIA & EIA)

Production Source (%)	China	USA (NA)
Fossil	80.2	71.4 (15% NG)
Hydro	18.5	5.6
Other	0.1	2.3
Nuclear	1.2	20.0
Annual Producton (TkWh)	1.42	3.72

China – Installed Generation Capacity

7%/year increasing (now > 380 GW)

根据预测，2010年将达到6.5亿千瓦左右，2020年达到9.5亿千瓦左右。



电荒，2004年中国仲夏夜之恶梦

Electrical power shortage (30GW), the midsummer nightmare of 2004 .

2月全国发电量1581.77亿千瓦时（日均发电量54.54亿千瓦时），比上年同期增长31.36%。

全国发电装机容量已达３．８５亿千瓦，在建电力项目１．３亿千瓦。

Capacity 385GW,

Shortage 30GW,

线损率 line losses 7% (Three Gorges Project: 18 GW)

130GW under construction

It is said that 2006 could be better

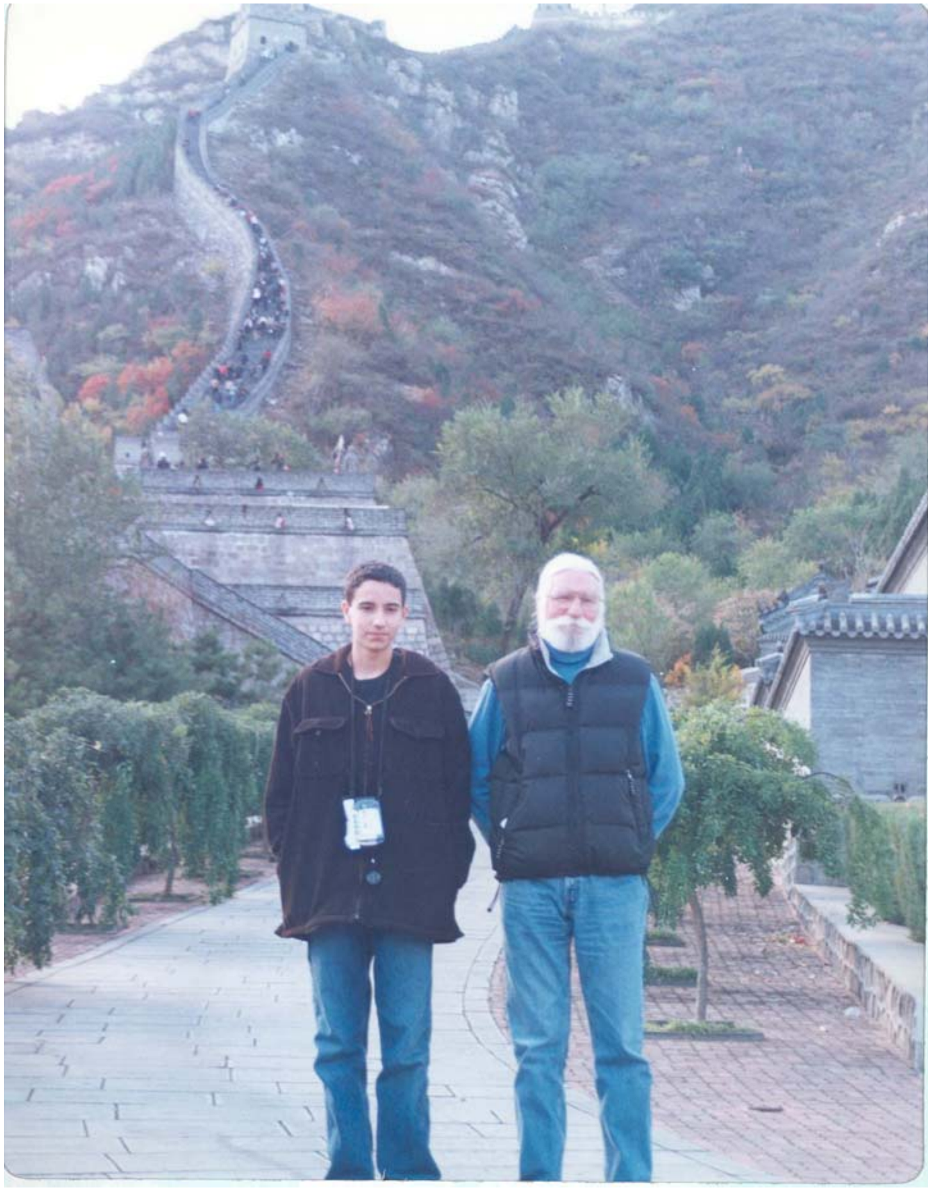
Could be worse

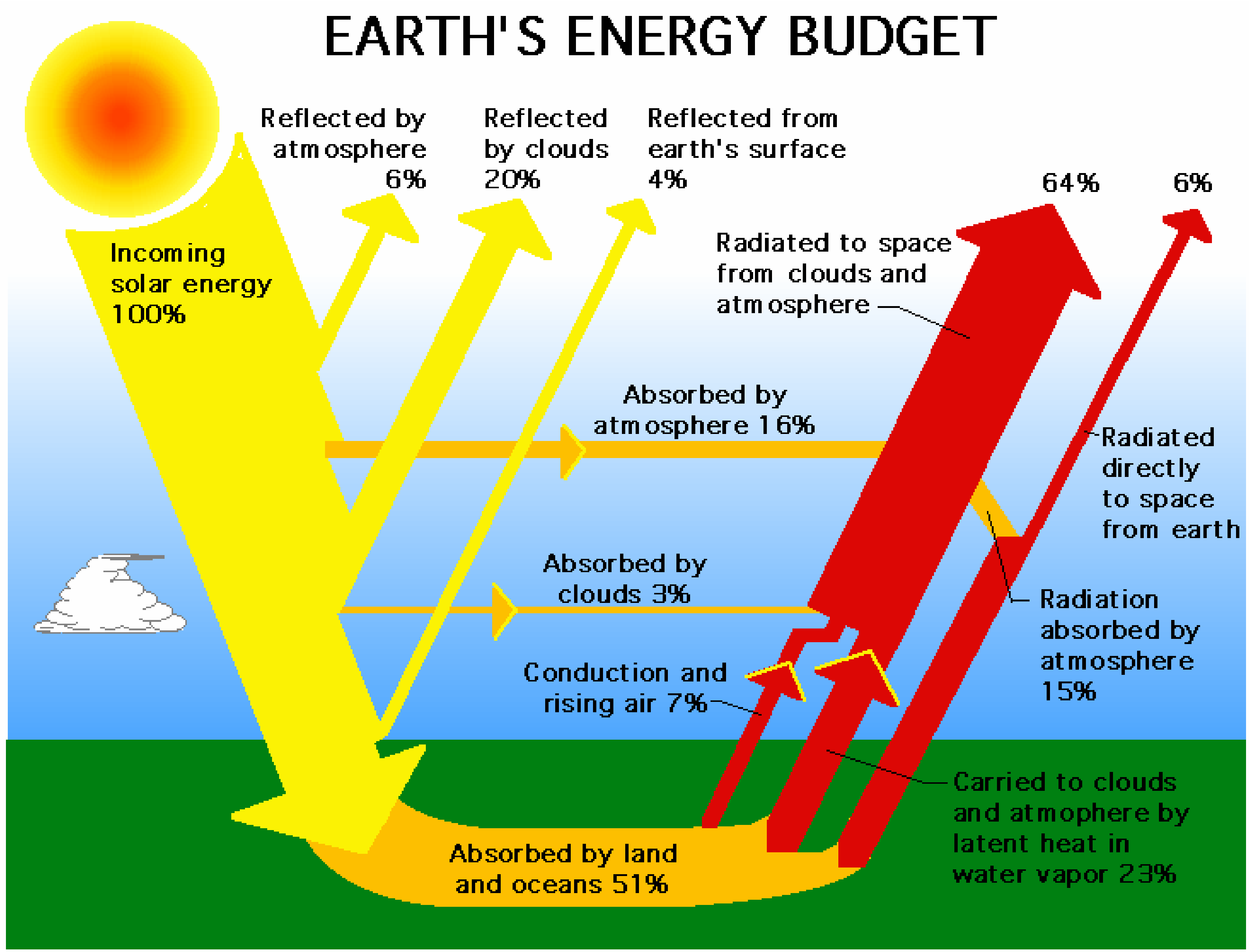
China “Factoid”

- Current Population: 1.3 Billion Souls
- All want to live like Americans
- Chinese Family Priorities:
  - (1) TV, (2) Washer, (3) Fridge…
  - Next an Air Conditioner (200 USD, 1 kW)
- Assume an average family size of three, then…

An extra 500 GW of generation capacity must be added just to keep them cool!

Diego & Dad at the Great Wall

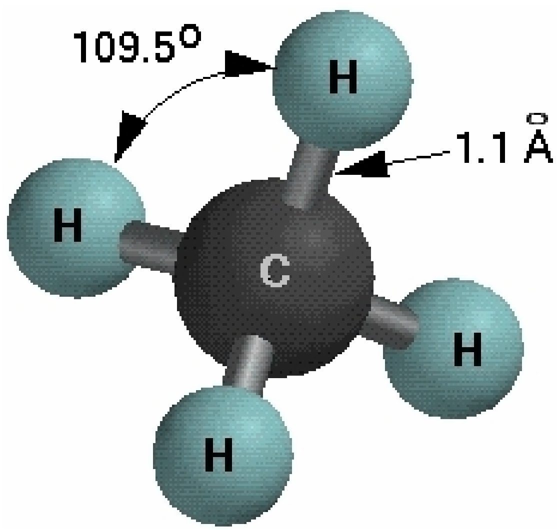


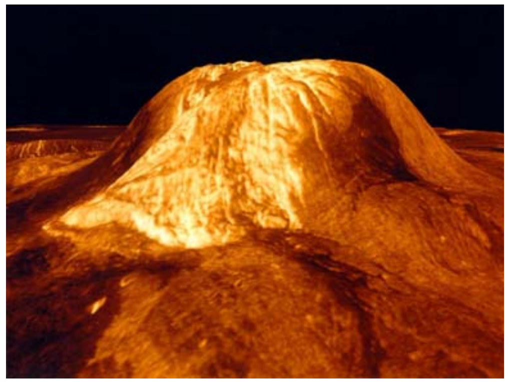


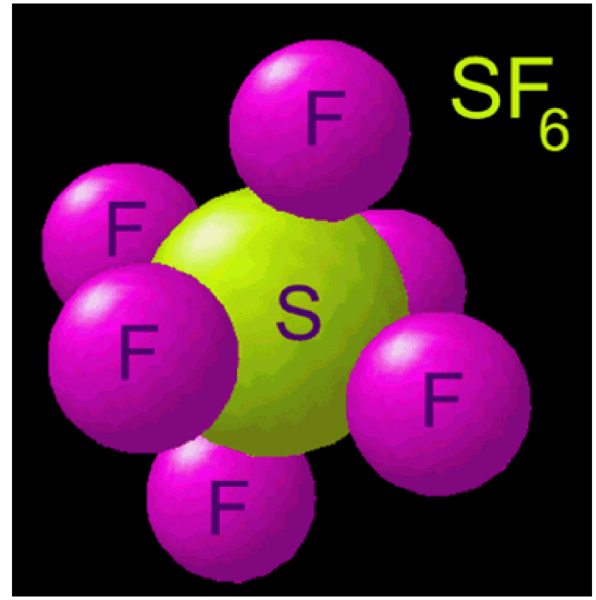
EARTH'S ENERGY BUDGET
Reflected by atmosphere 6%
Reflected by clouds 20%
Reflected from earth's surface 4%
64%
6%
Incoming solar energy 100%
Radiated to space from clouds and atmosphere
Absorbed by atmosphere 16%
Radiated directly to space from earth
Absorbed by clouds 3%
Radiation absorbed by atmosphere 15%
Conduction and rising air 7%
Carried to clouds and atmosphere by latent heat in water vapor 23%
Absorbed by land and oceans 51%

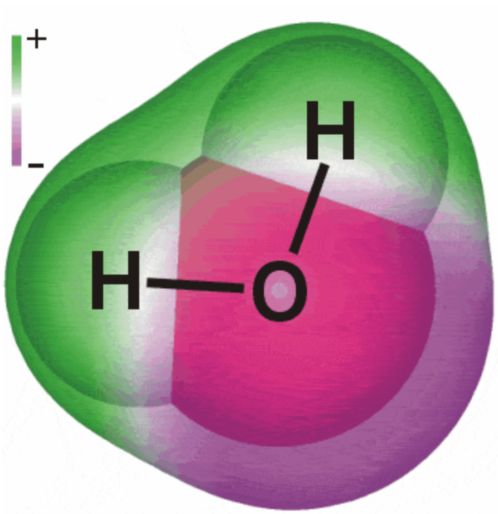
"Greenhouse Gases"

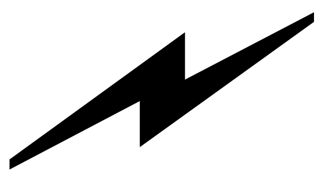
“More Greenhouse Gases”



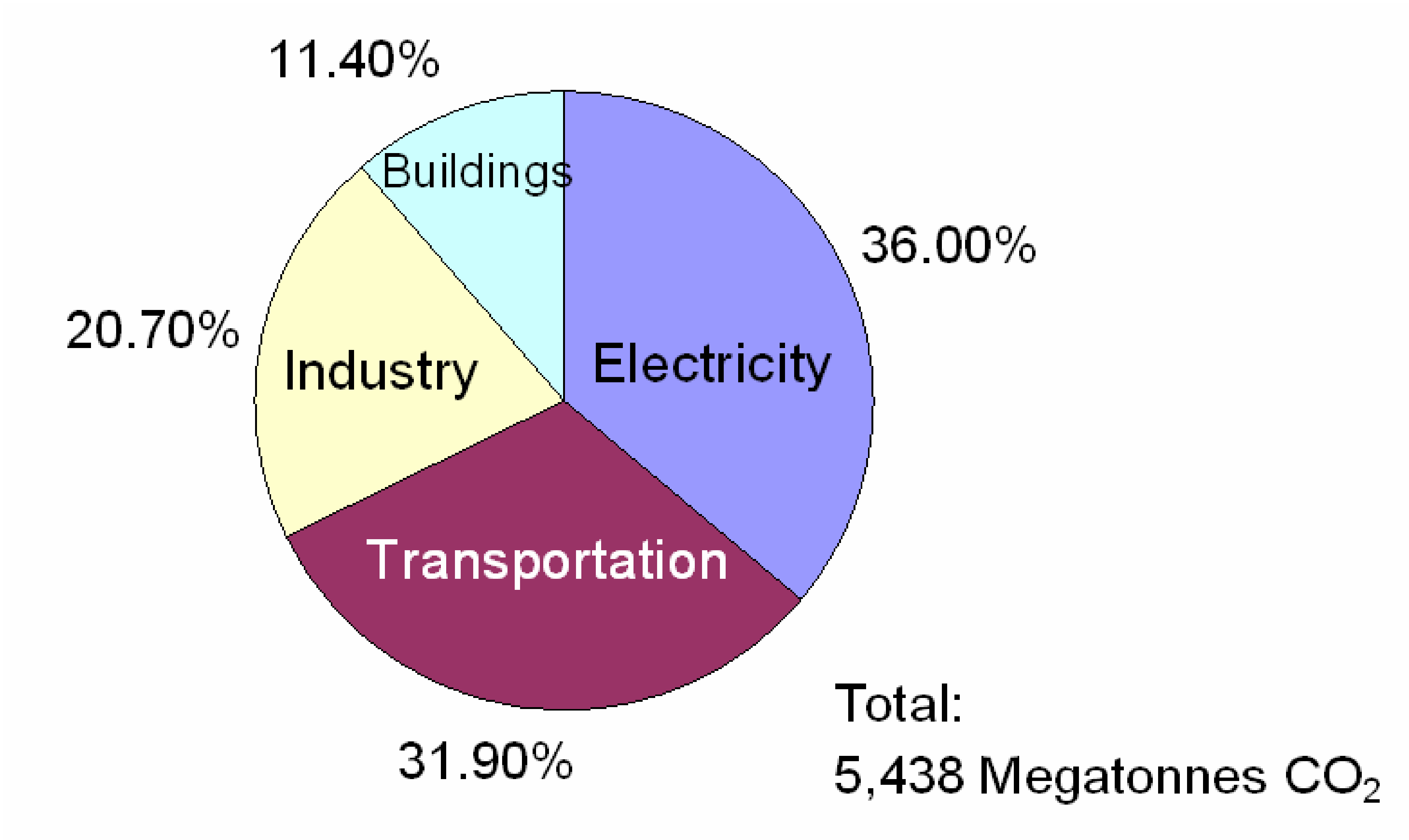




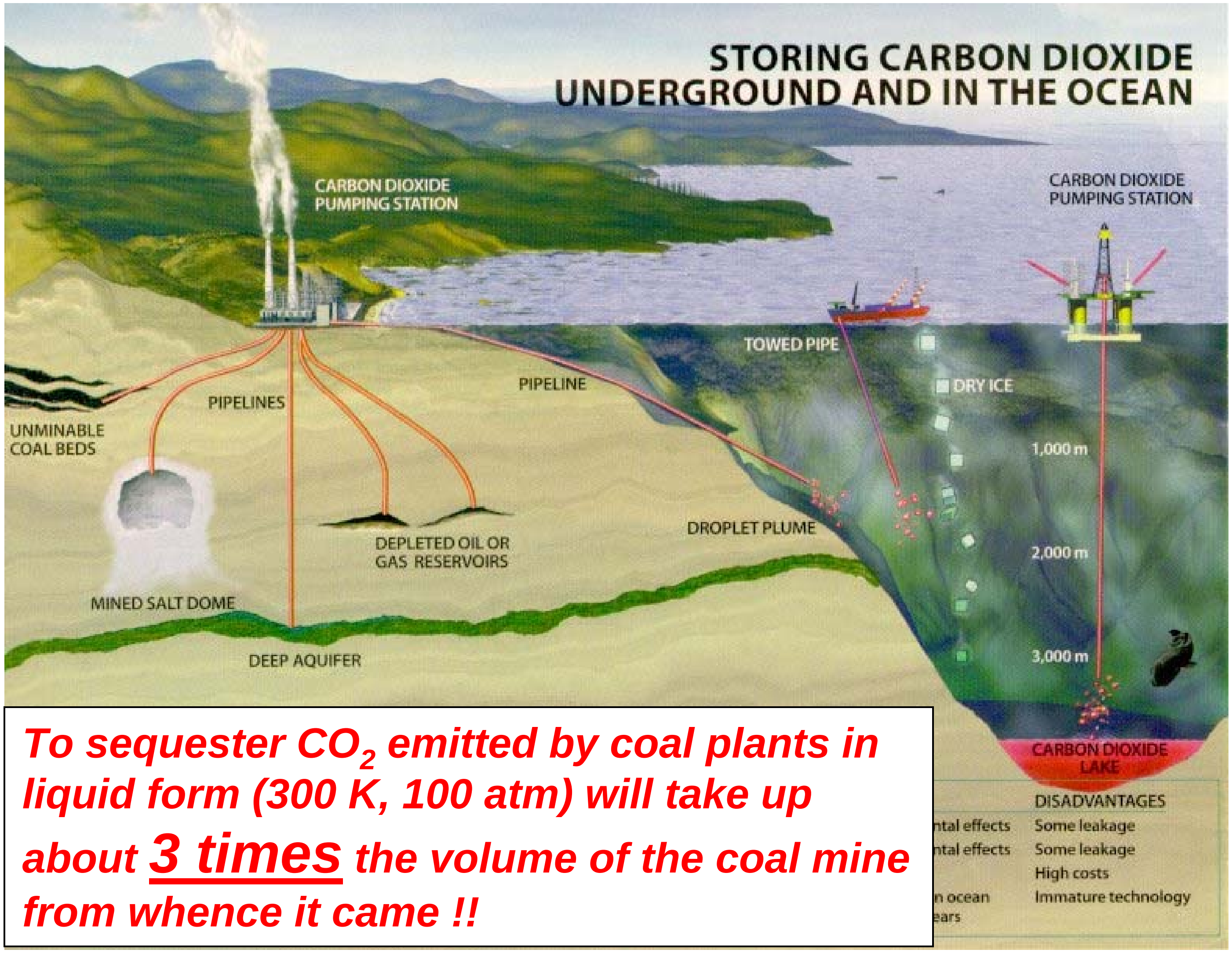




CO_2 Emission Sources



CO_2 Sequestration



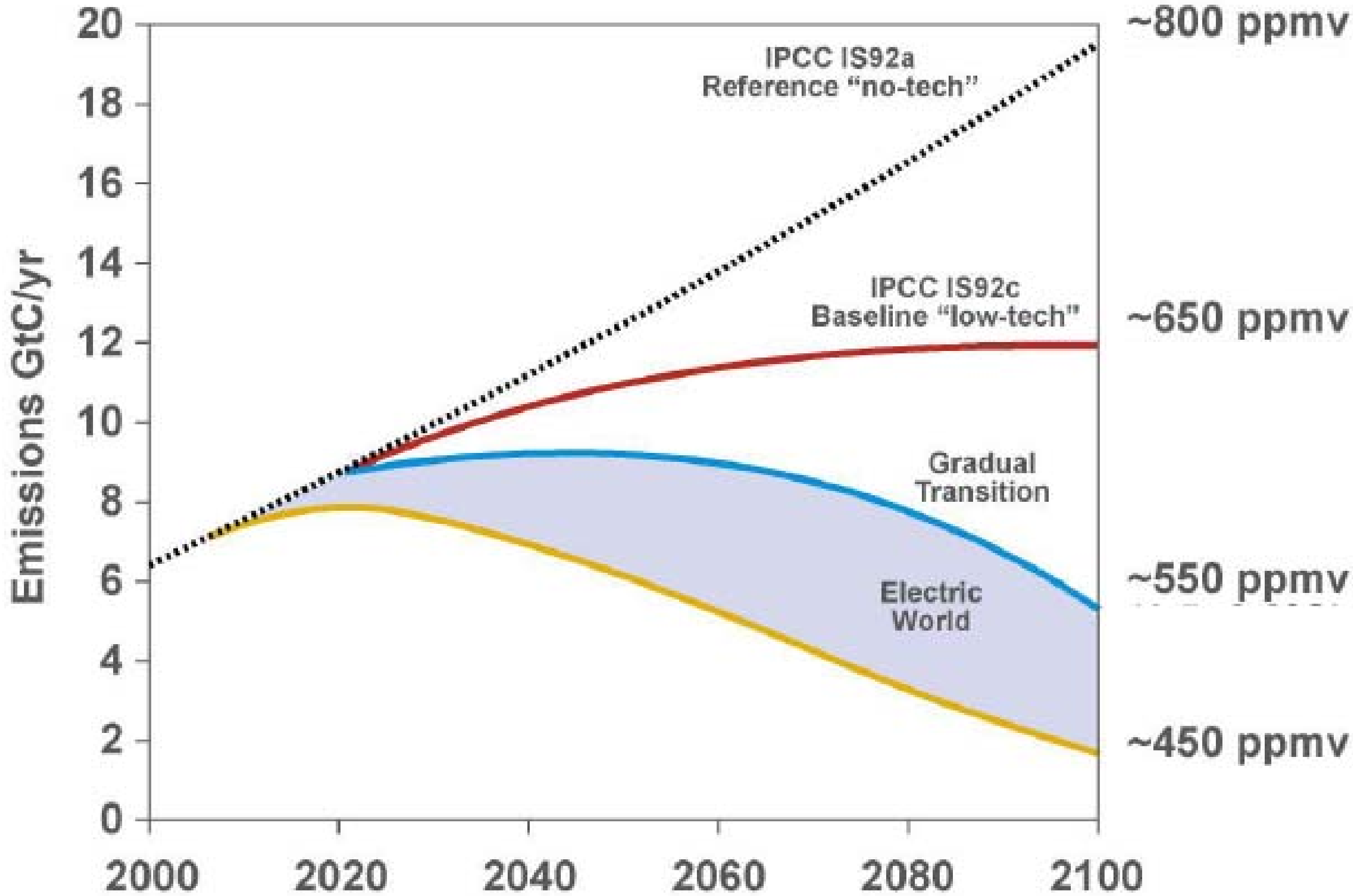
To sequester CO_2 emitted by coal plants in liquid form (300 K, 100 atm) will take up about <u>3 times</u> the volume of the coal mine from whence it came !!

“Exploding Lakes”

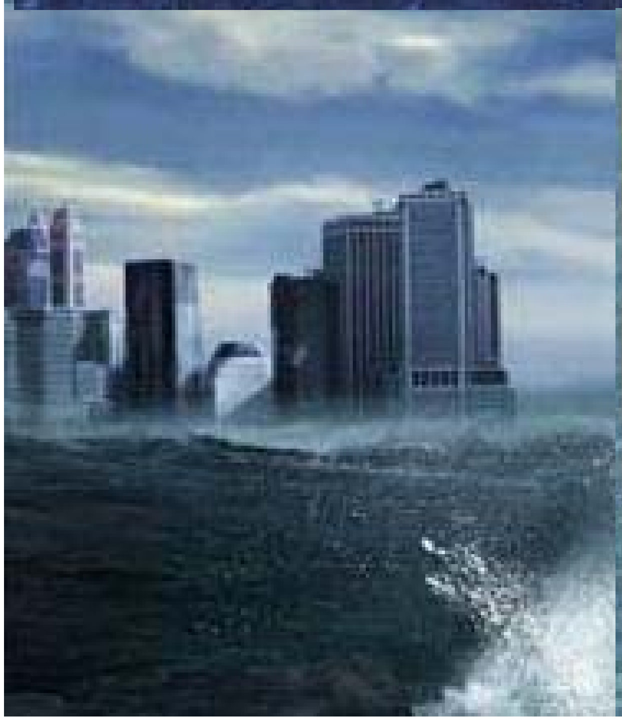
Lake Nyos, Cameroon

- Hot volcanic rocks beneath lake release CO_2 which then gets trapped at lake bottom
- Pressure builds up and lake “explodes”
- In 1986, Nyos carbon dioxide eruption killed 1800 people by asphyxiation

CO_2 Emission Scenarios

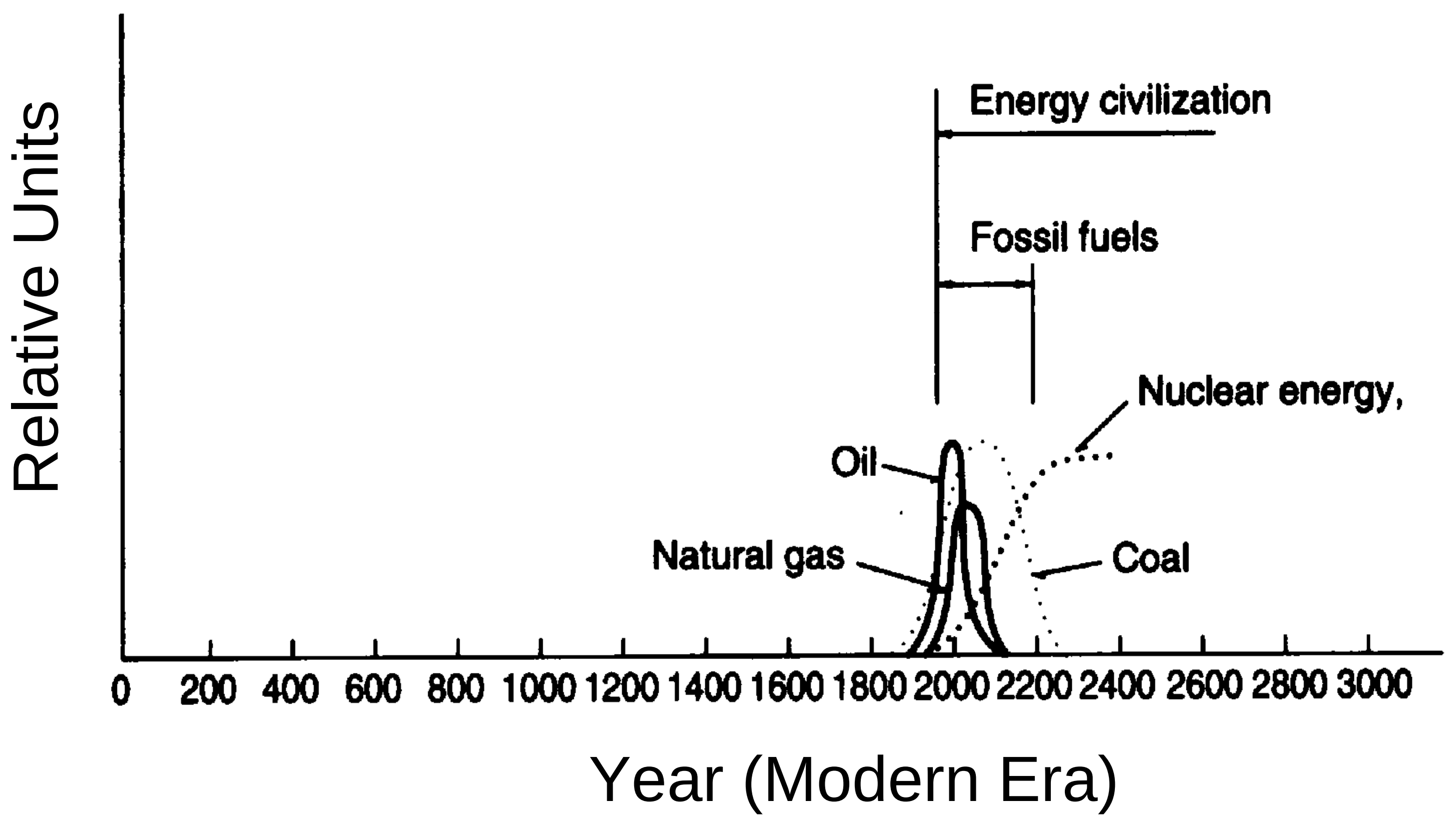


60 million years ago, the CO_2 concentration in the atmosphere was 7,000 ppmv!



The End of the Fossil Age
(Fossil Fuels Become Fossils)

Fig. 1 Production Volume of Energy Resources



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!

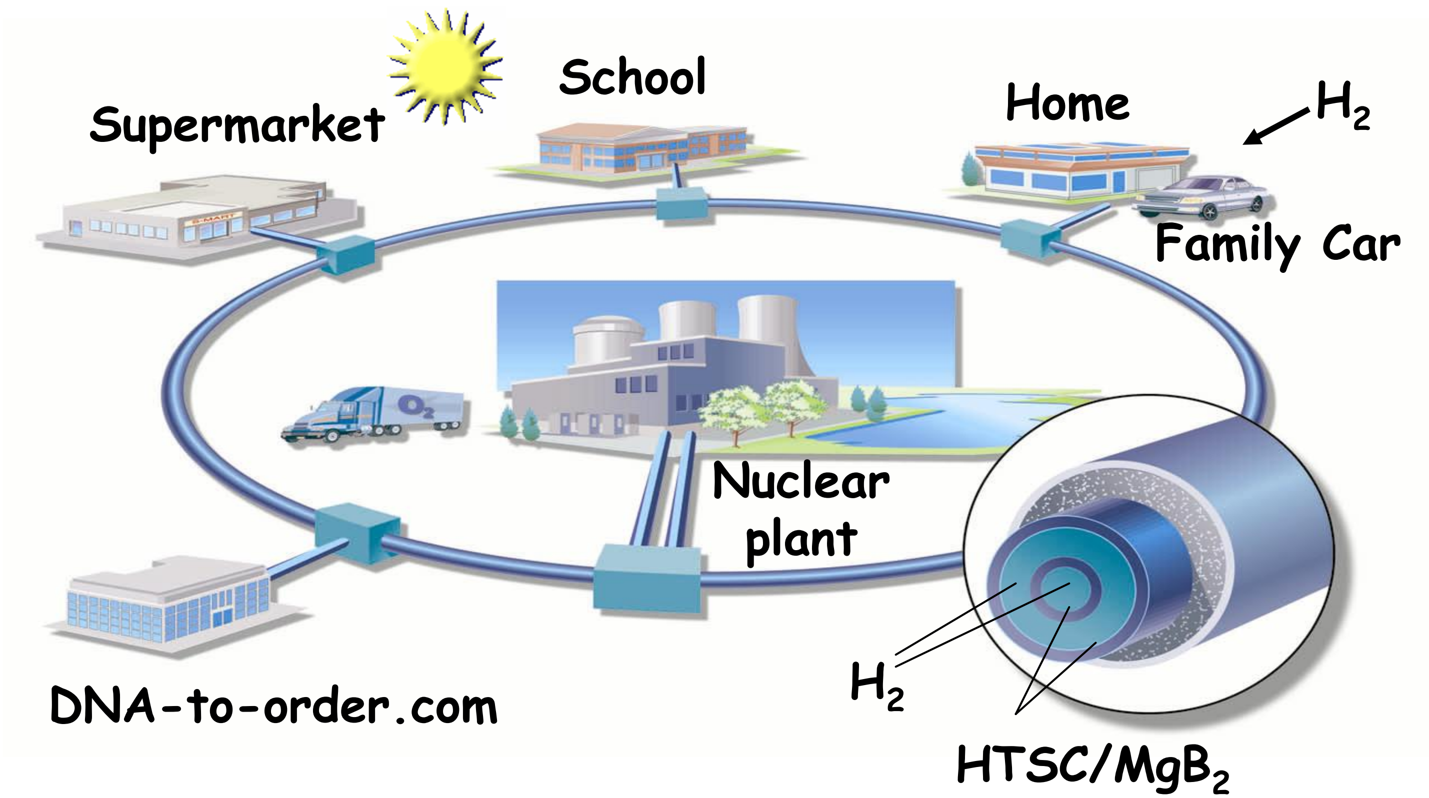
Its Solution

A Symbiosis of

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

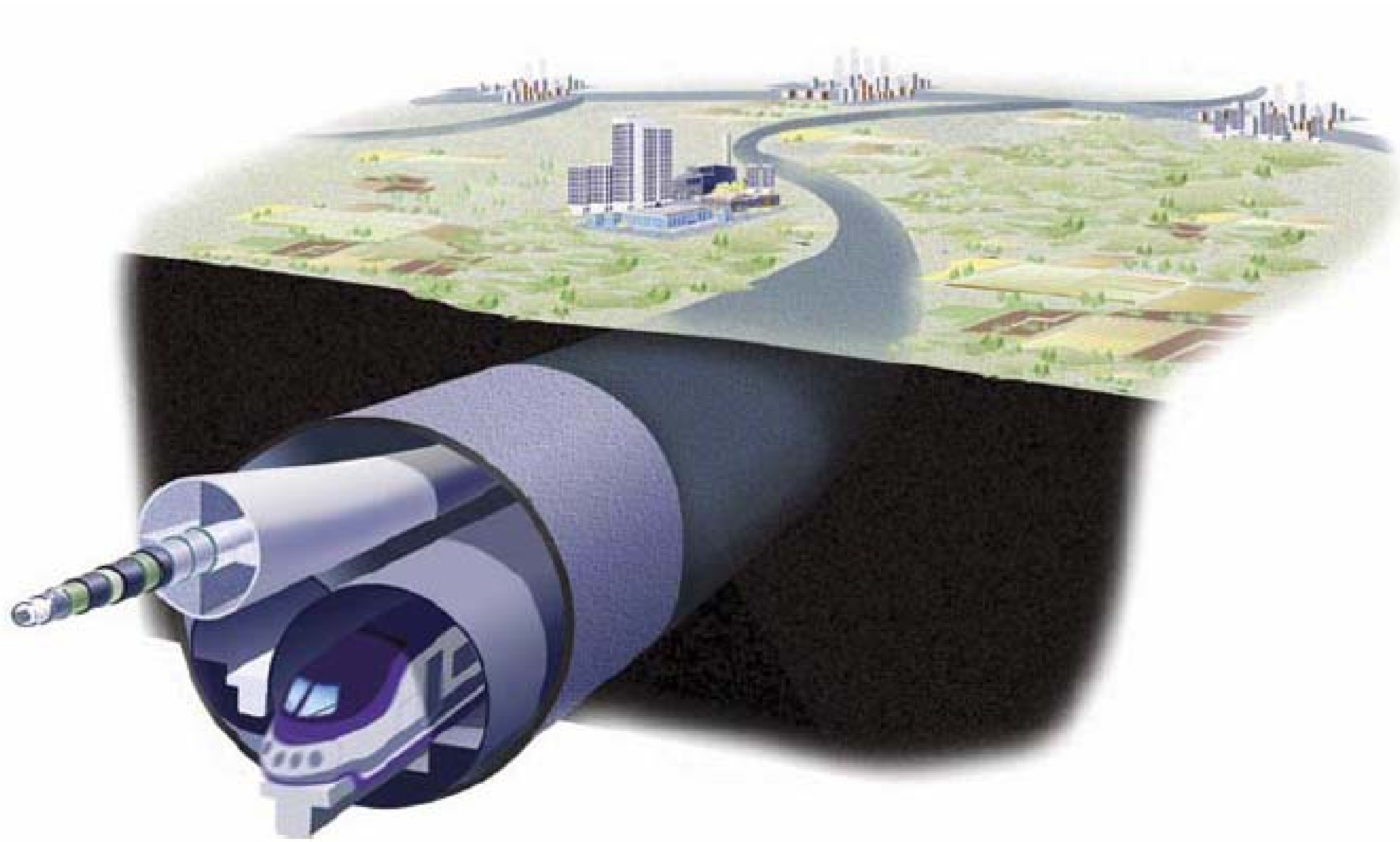
Technologies supplying Carbon-free, Non-Intrusive Energy for all Inhabitants of Planet Earth

SuperCity



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

SuperGrid



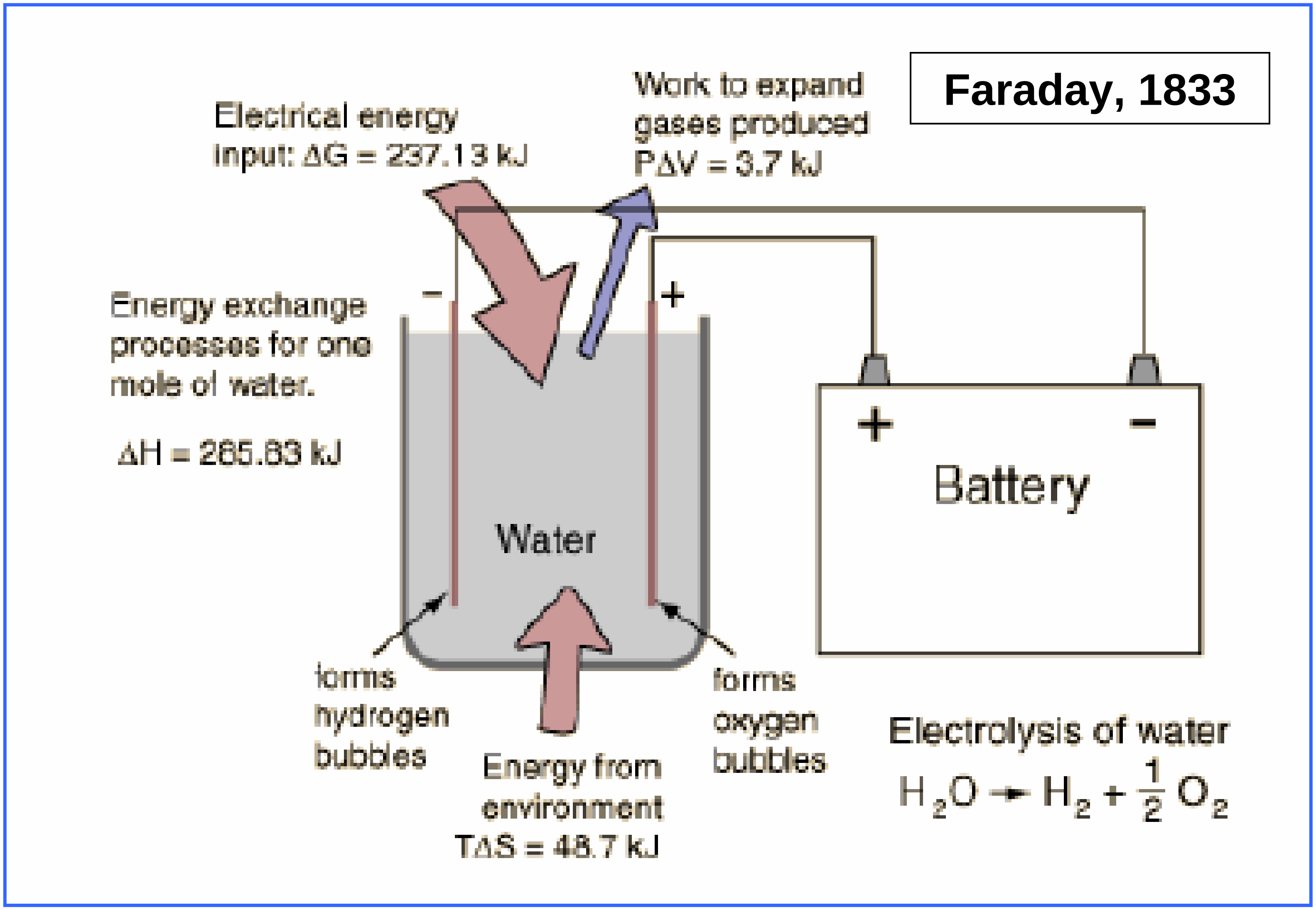
EPRI White Paper, 2006

The Hydrogen Economy

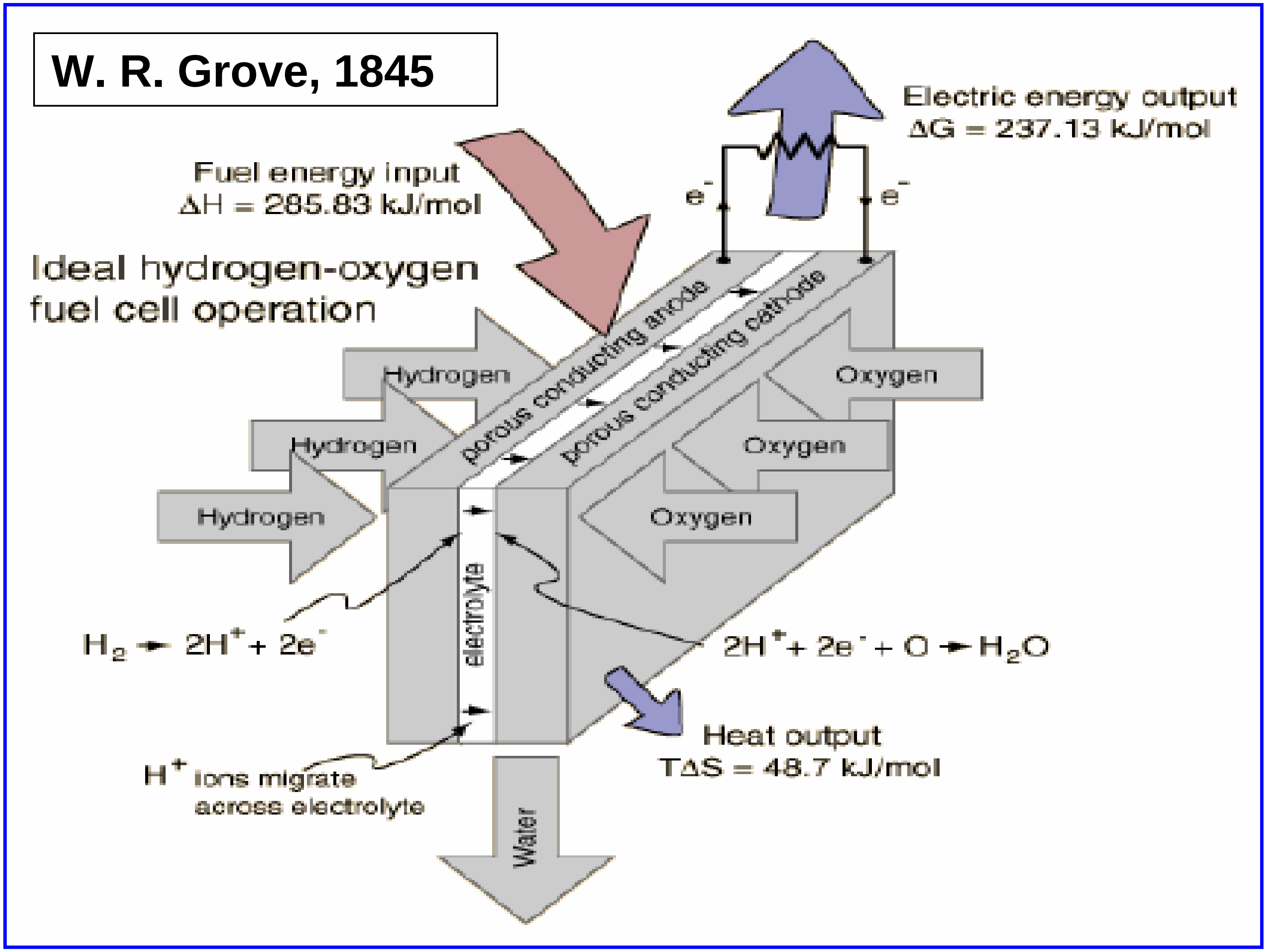
- You have to make it, just like electricity
- Electricity can make H_2, and H_2 can make electricity $(2H_2O \Leftrightarrow 2H_2 + O_2)$
- You have to make a lot of it
- You can make it cold, - 419 F (21 K)

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

Electrolysis



Fuel Cell



W. R. Grove, 1845
Electric energy output
ΔG = 237.13 kJ/mol
Fuel energy input
ΔH = 285.83 kJ/mol
Ideal hydrogen-oxygen
fuel cell operation
e-
e-
porous conducting anode
porous conducting cathode
Hydrogen
Hydrogen
Hydrogen
Oxygen
Oxygen
Oxygen
electrolyte
$H_2 \rightarrow 2H^+ + 2e^-$
$2H^+ + 2e^- + O \rightarrow H_2O$
Heat output
TΔS = 48.7 kJ/mol
H+ ions migrate
across electrolyte
Water

Hydrogen for US Surface Transportation

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

http://www.w2agz.com

Hydrogen per Day	
Tonnes	Shuttle
230,000	2,225

Water per	
Tonnes	Mete
2,055,383	

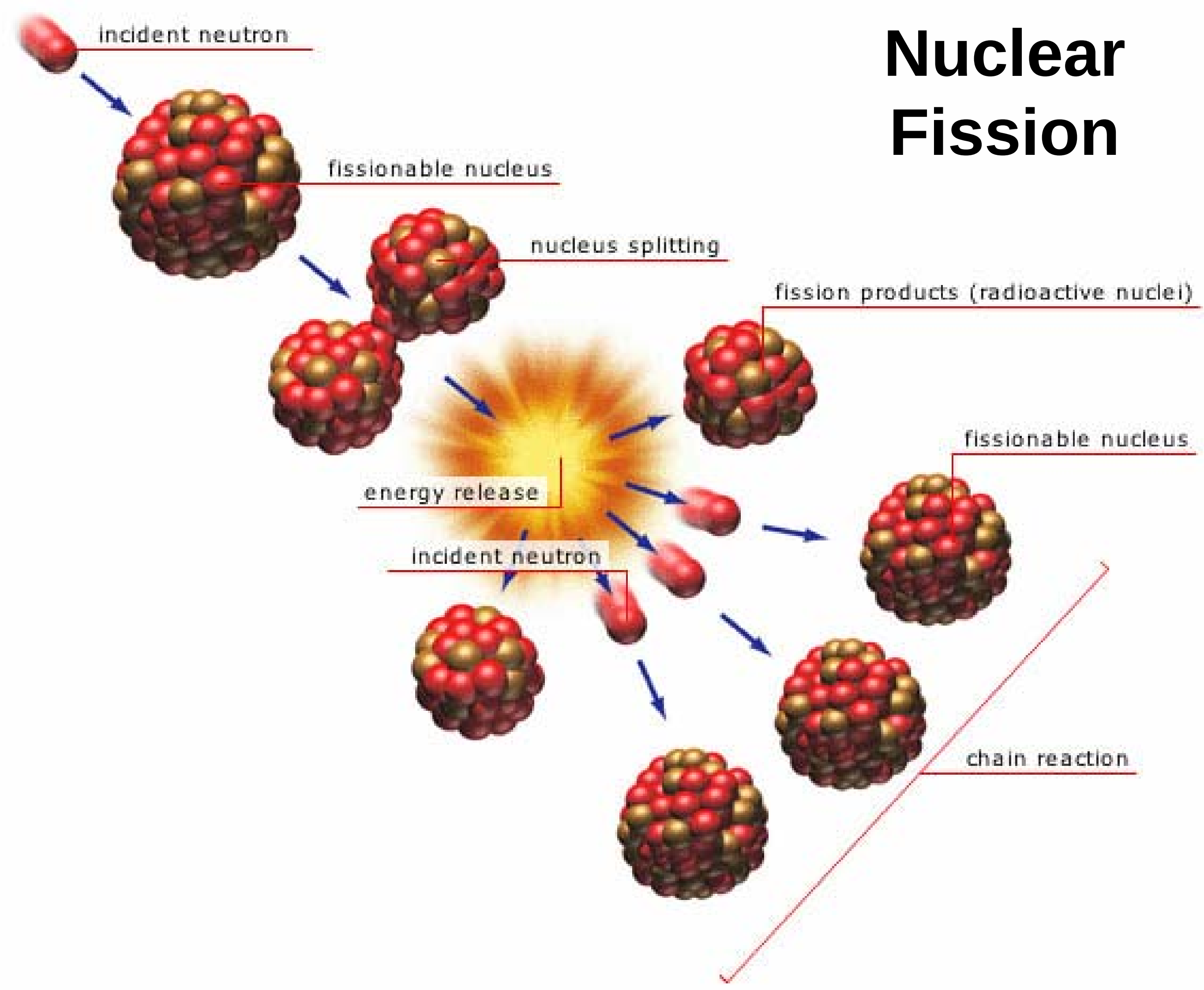
Hydrogen for US Surface Transportation

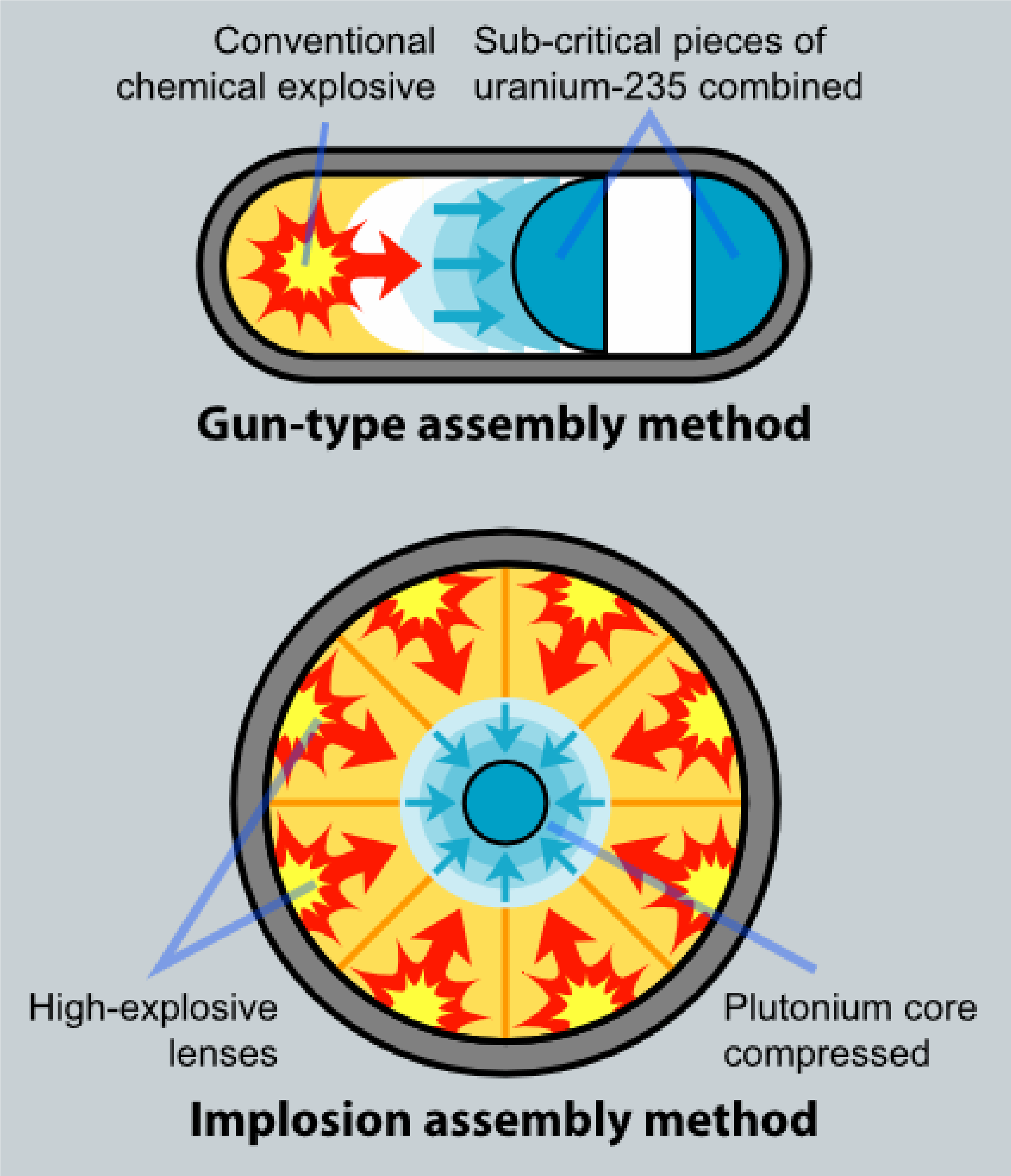
The "25% 80-80-80 400 GW" Scenario

http://www.w2agz.com

Renewable Land Area Requirements		
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 Fission



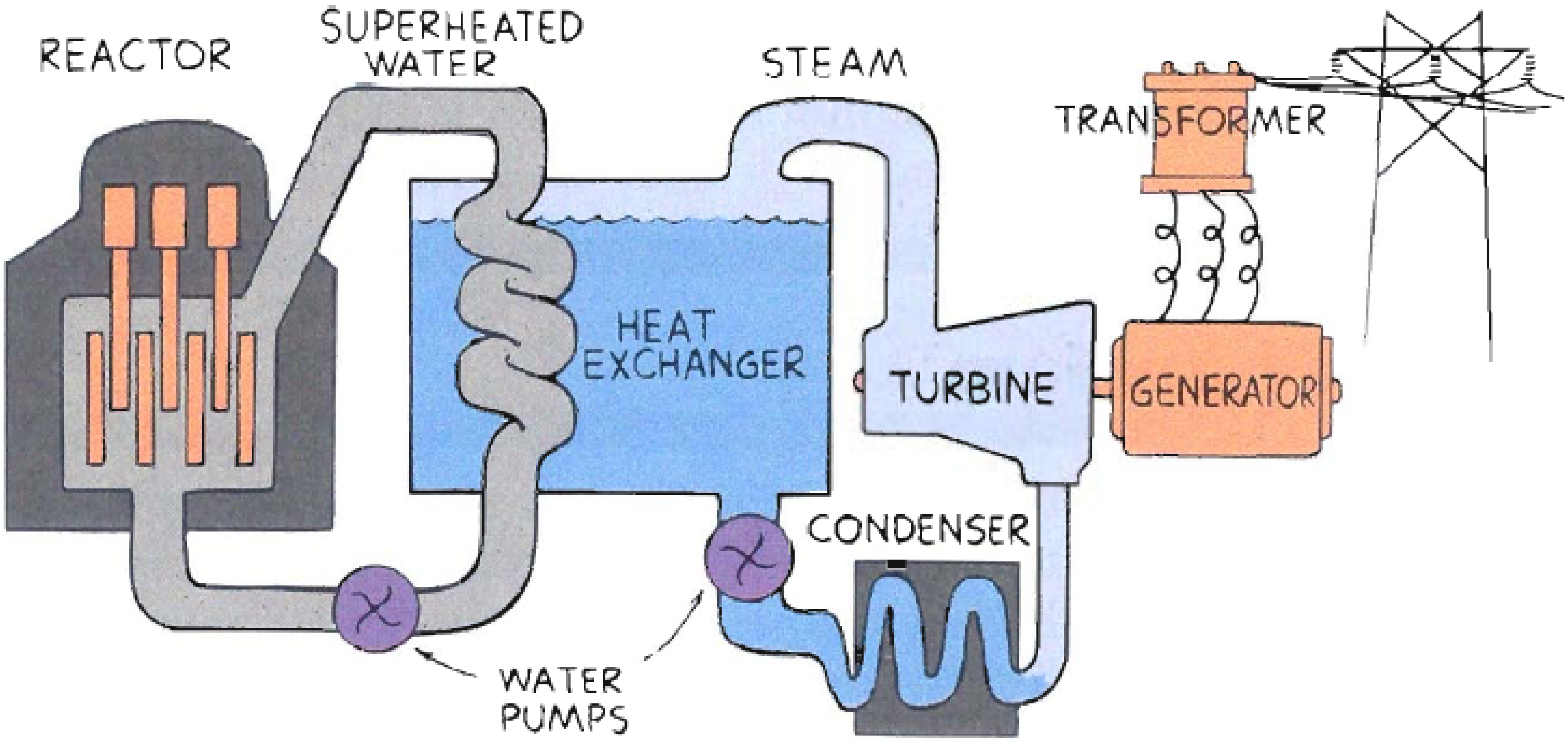


Atomic Bombs

"A 65-Year Old Technology"

Almost anyone can build one!

“Light Water Reactor”

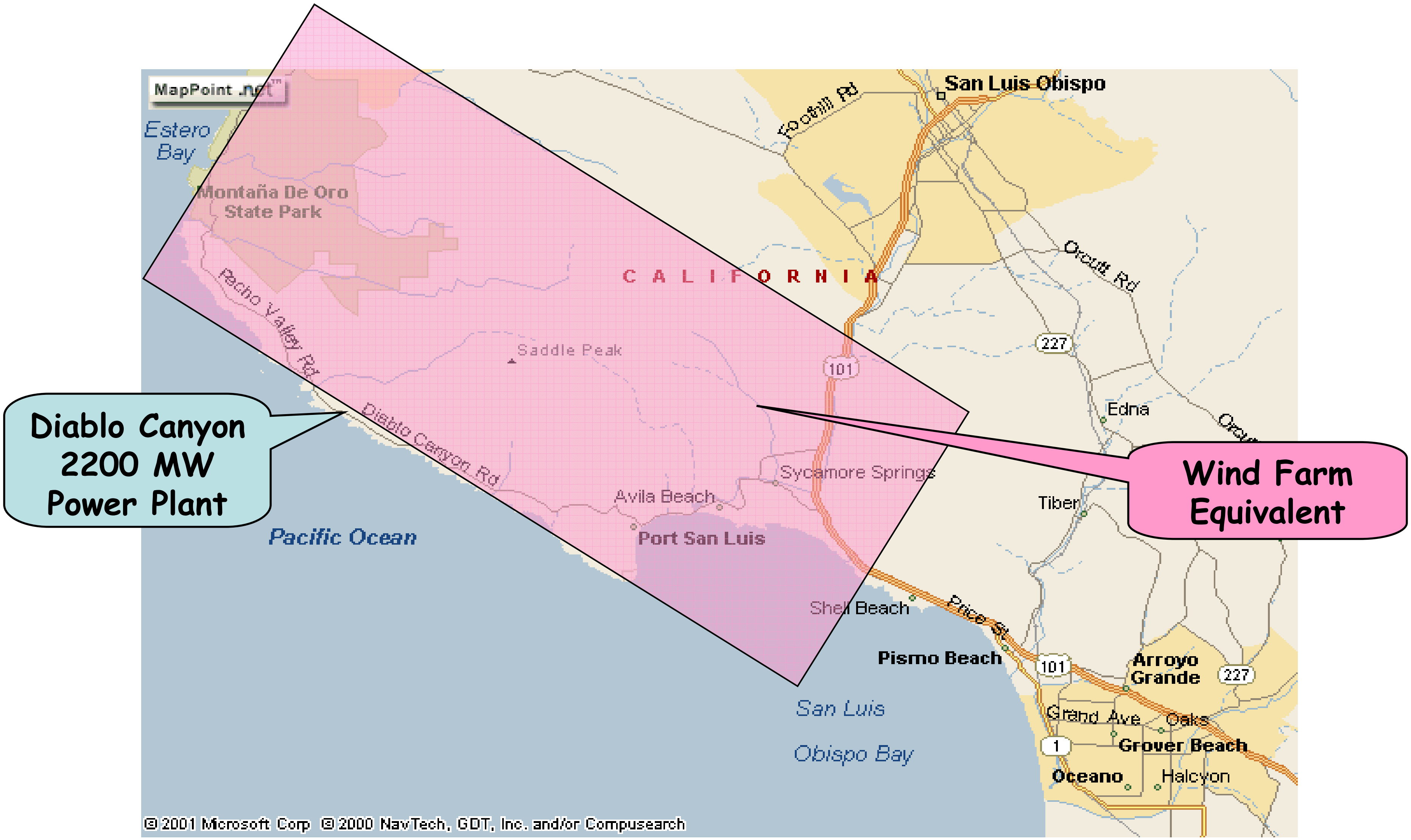


Oklo “Natural” Reactor

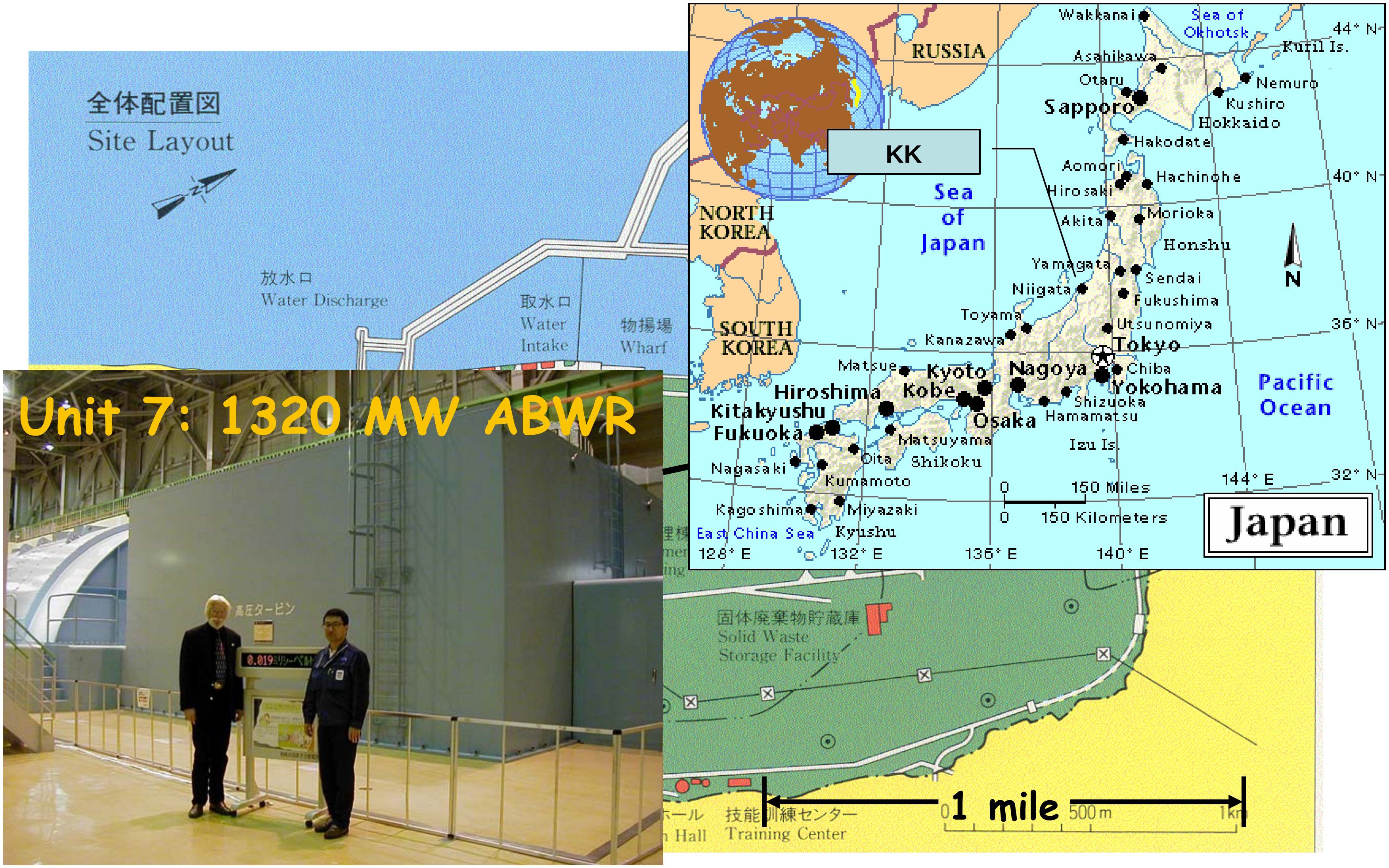
- Pu was created 2 billion years ago!
- Reactor produced 100 kW of power for 500,000 years!
- “Waste” has moved less than one meter.

Diablo Canyon

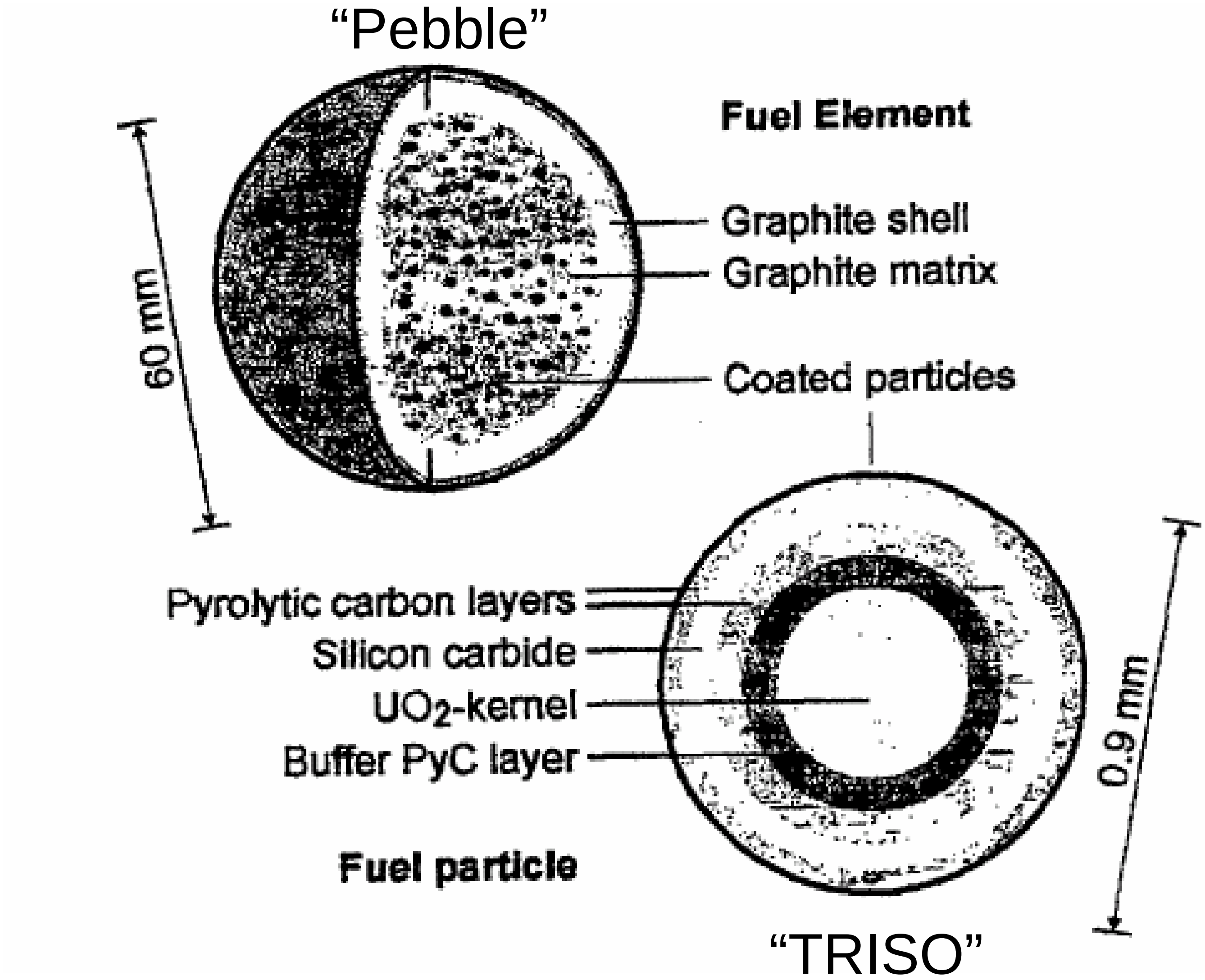
California Coast Power



Kashiwazaki Kariwa: 8000 MW



Particle/Pebble Nuclear Fuel

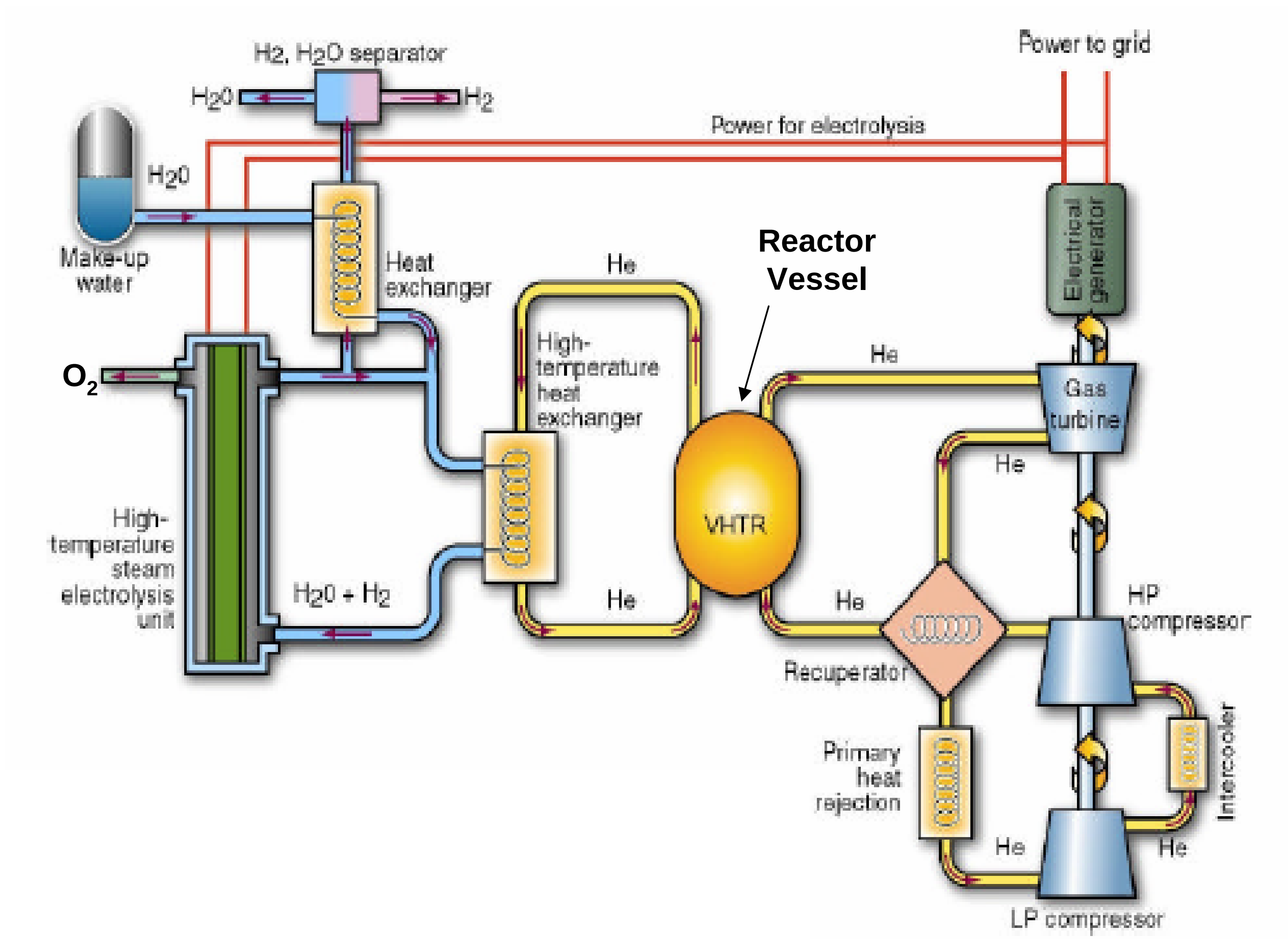


…Back

Eskom Pebble Bed Modular Reactor

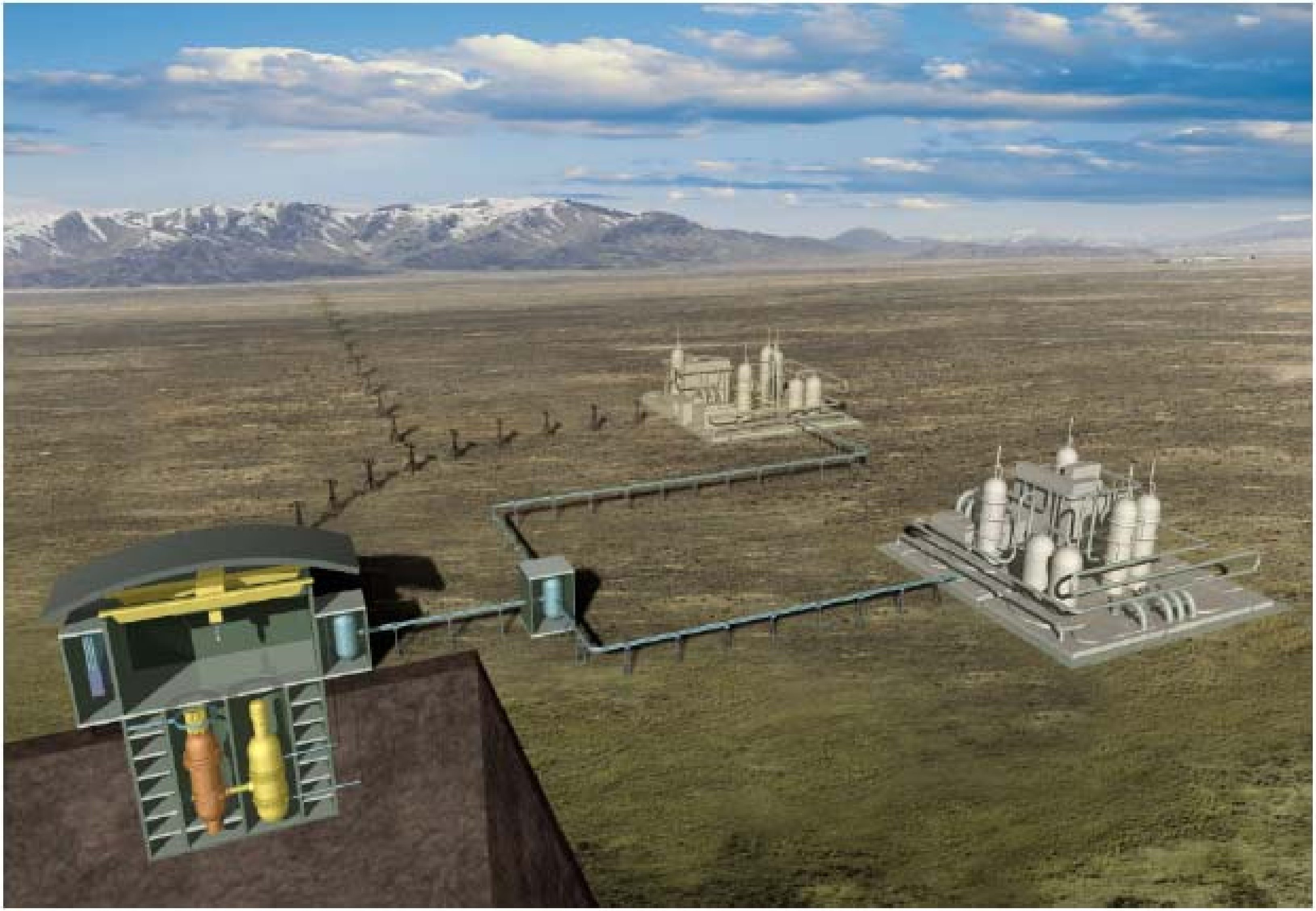
- Helium gas cooled (Brayton Cycle)
  - Won’t melt down
  - Direct turbine drive
- “Baseball” packaged fuel
  - Continuous fuel replenishment and removal
  - Theoretical 100% availability
- Modular Design
  - Scalable: 100 – 500 MW units
  - High safety and security factor

Co-Production of Hydrogen and Electricity



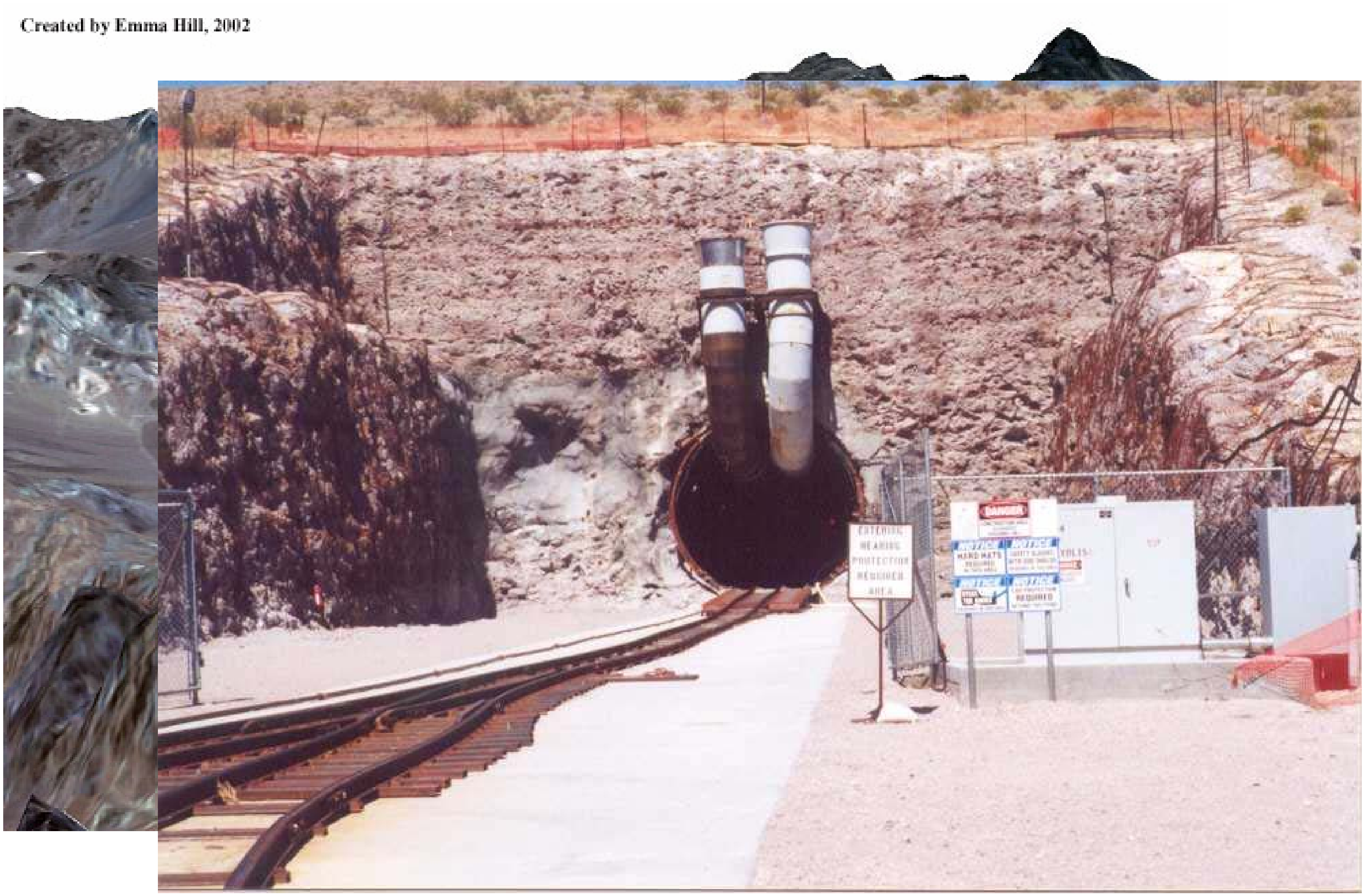
Source: INEL & General Atomics

Nuclear “Hydricity” Production Farm

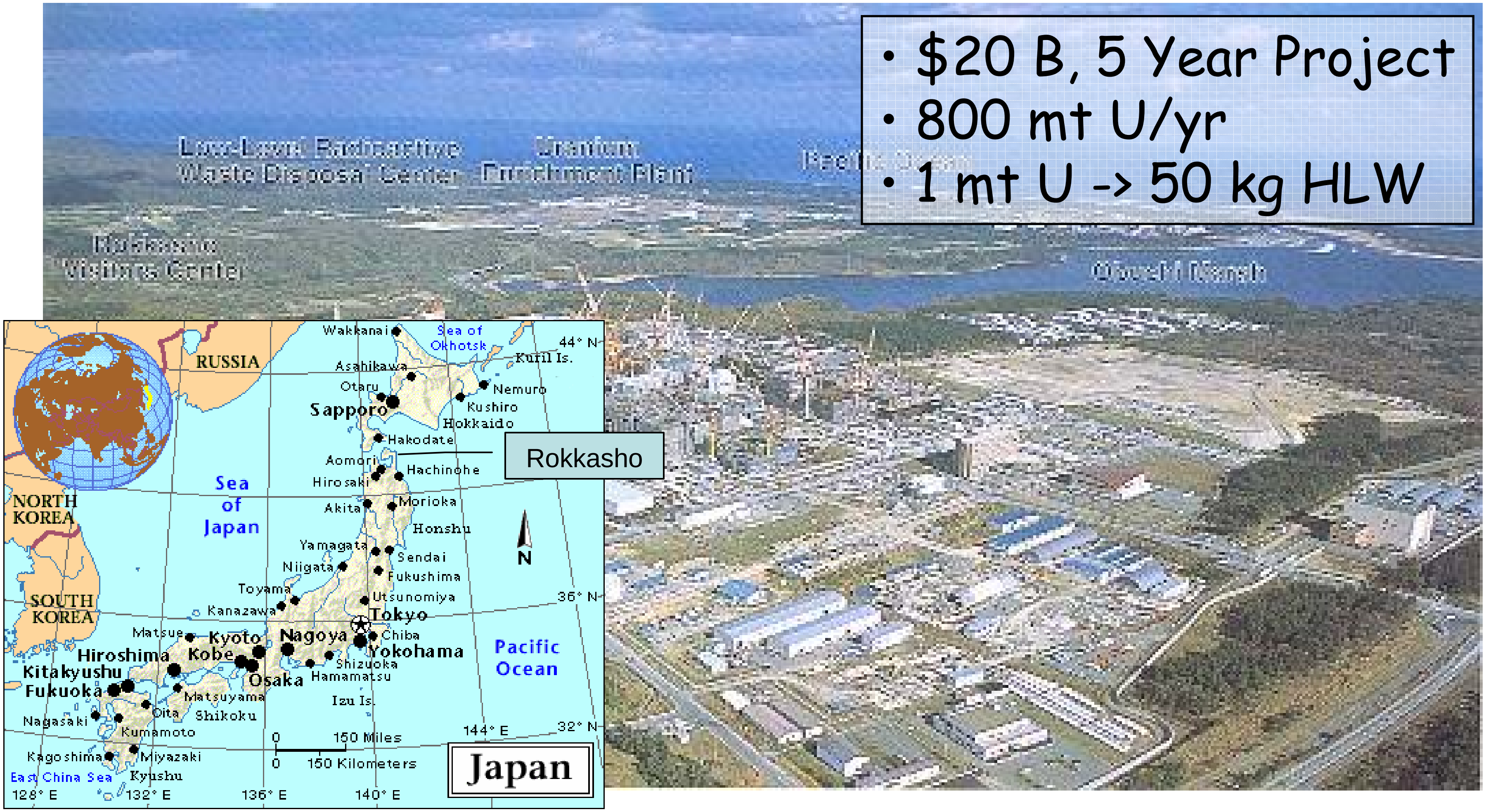


Source: General Atomics

Yucca Mountain



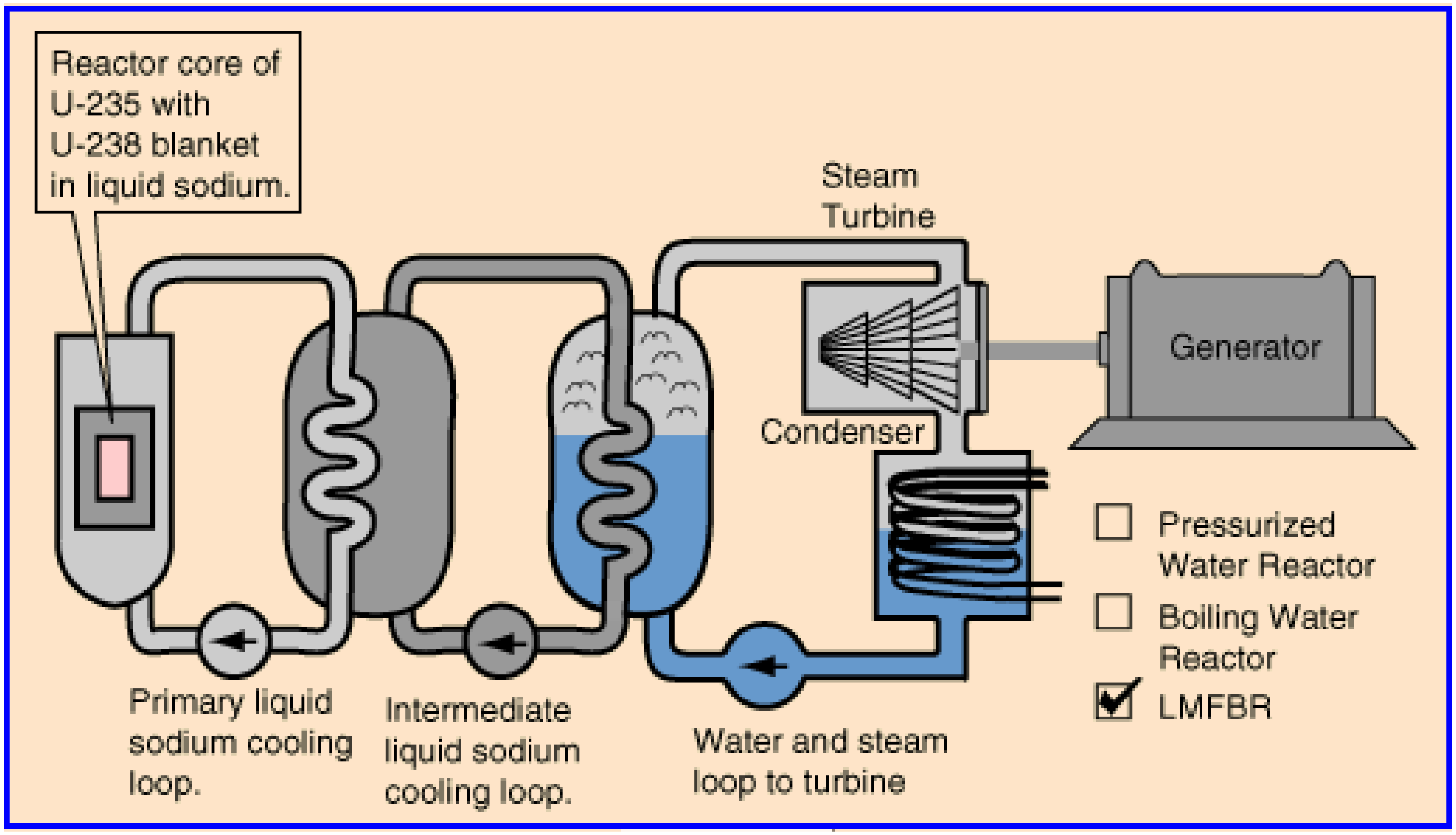
JNFL Rokkasho Reprocessing Plant



- $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

Fast Breeder Technologies



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

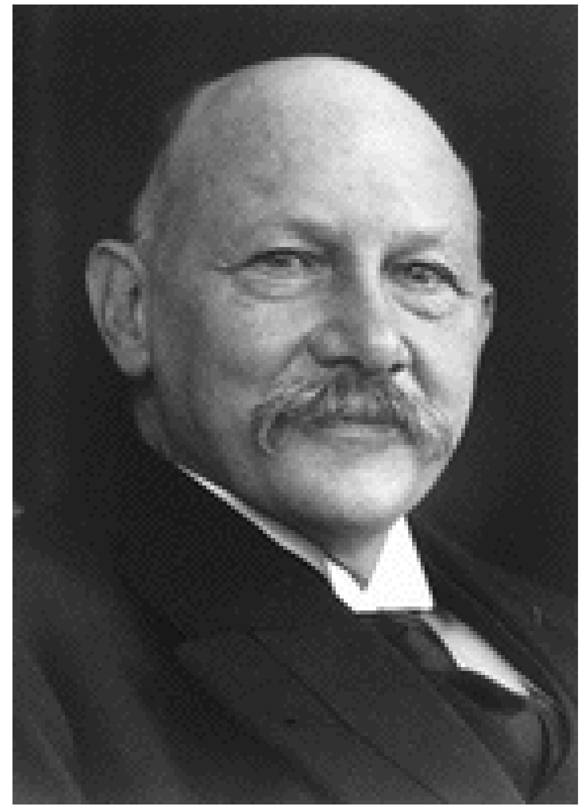
“Million Solar Roofs”

- Thermal/Photovoltaic Solar Roofs
- Ecologically Gentle
  - Everyone has to live somewhere
  - Everyone has to work somewhere
  - No extra area is required!
- Could provide 10% of urban/suburban electricity requirements
- Downsides:
  - Sun doesn’t shine all the time
  - Therefore storage is required (H_2 ?, Swimming Pool ?)

Fathers of Cryogenics

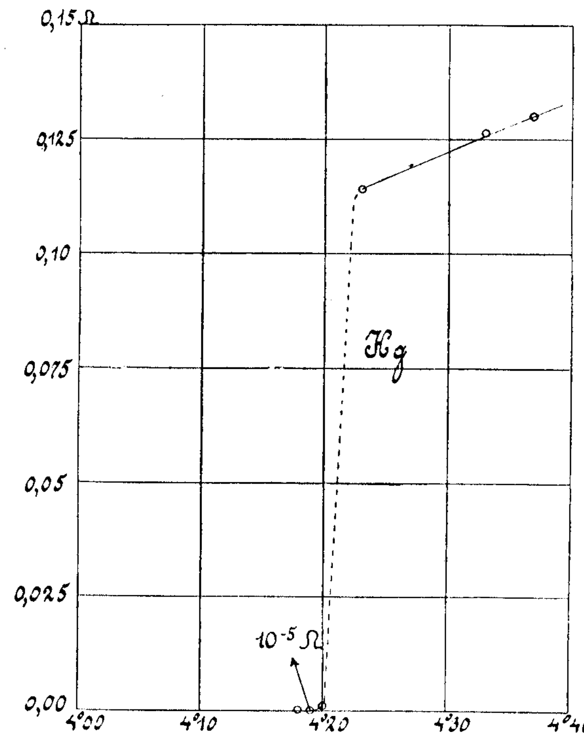
Dewar

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



Kammerlingh-Onnes

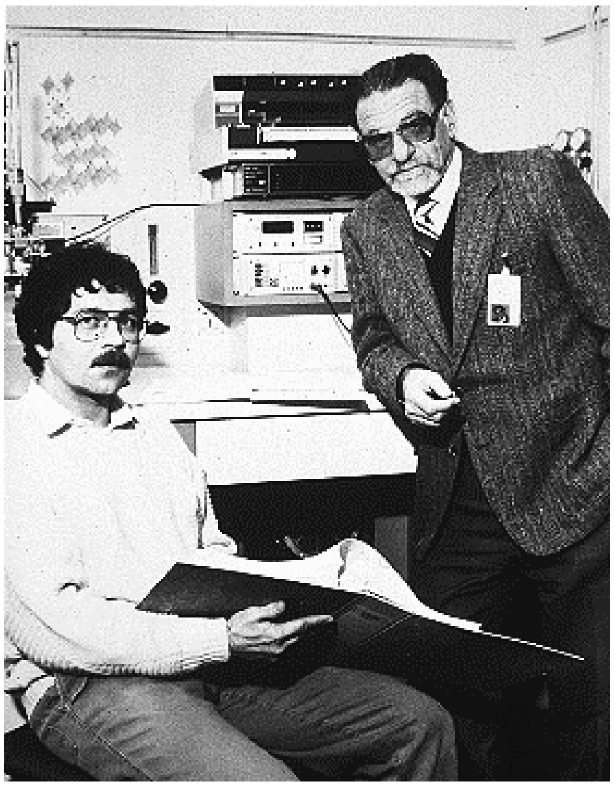
1911: A Big Surprise!

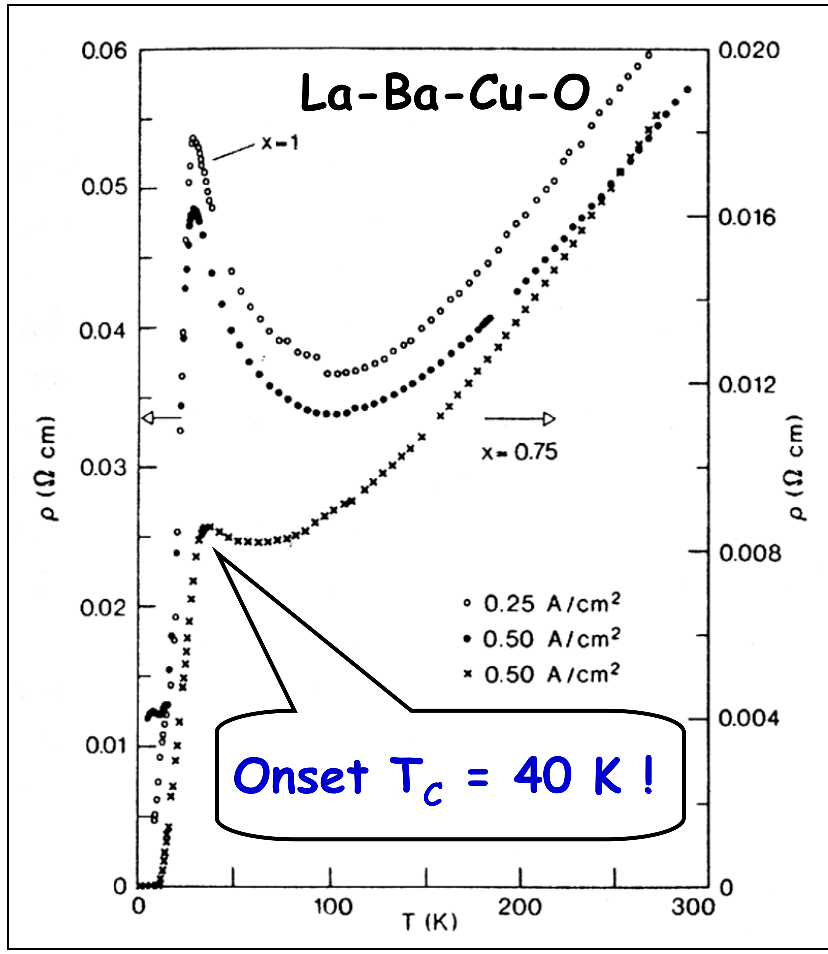


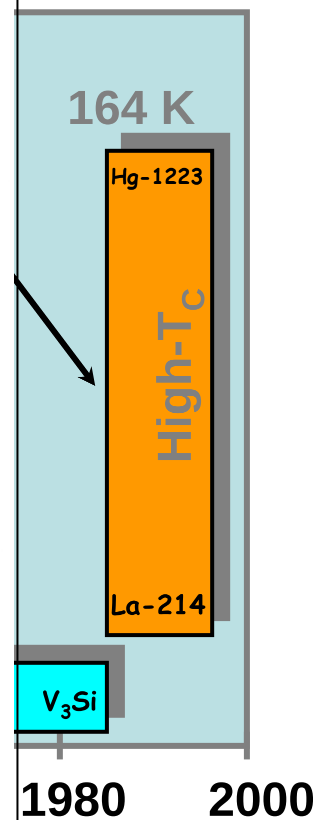
Thus the mercury at 4.2 K has entered a new state, which, owing to its particular electrical properties, can be called the state of *superconductivity*

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!

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.

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.

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 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.

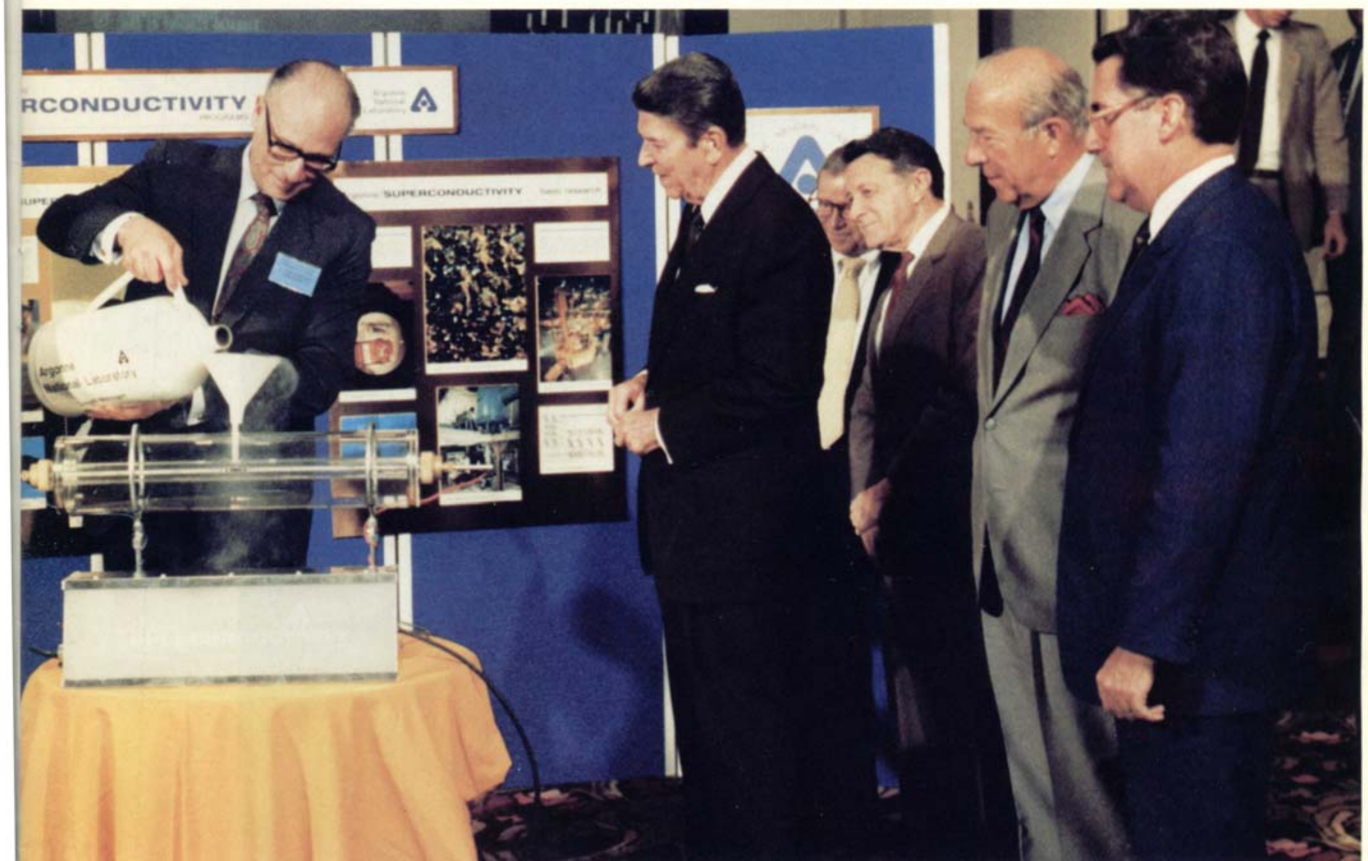
All those wishing to report results would be granted five minutes each, in order of the arrival of their request to take part — and did the requests rain in, reaching a downpour in the two weeks before the meeting, as confirmations of the Wu–Chu measurements were made. All in all, 51 presentations were 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.

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

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.

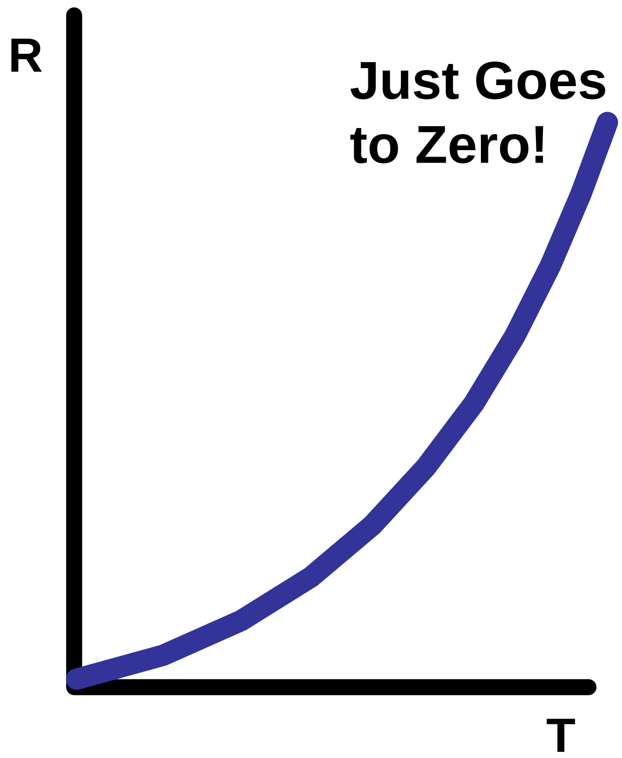
“The Great Communicator”

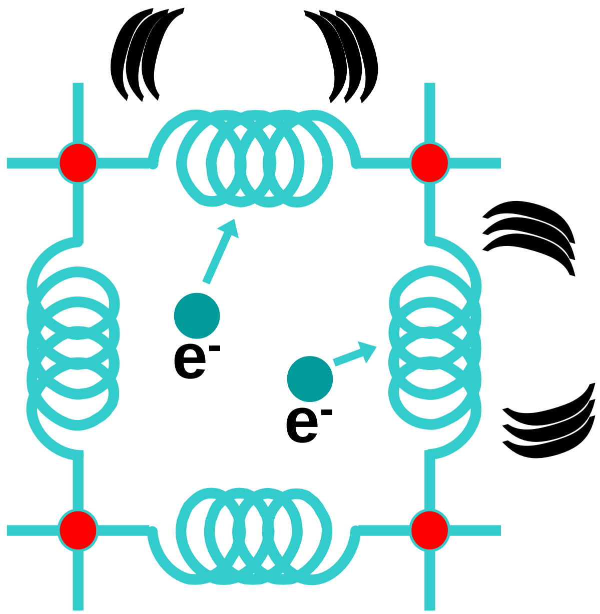


Alan Schriesheim, Director of Argonne National Laboratory, demonstrates superconductivity to the President, Chief of Staff Howard Baker, Secretary of Defense Caspar Weinberger, Secretary of State George Shultz and Secretary Herrington.

Models of Electrical Conductivity 1900

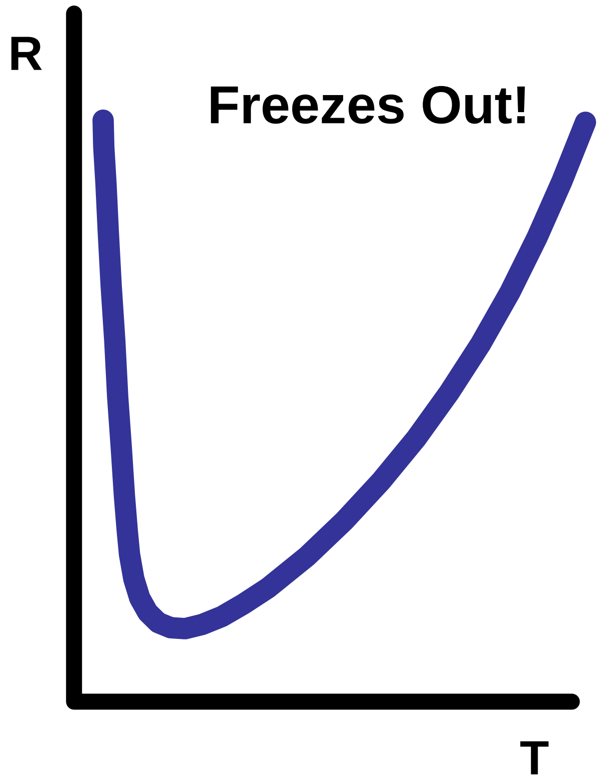
One Idea:

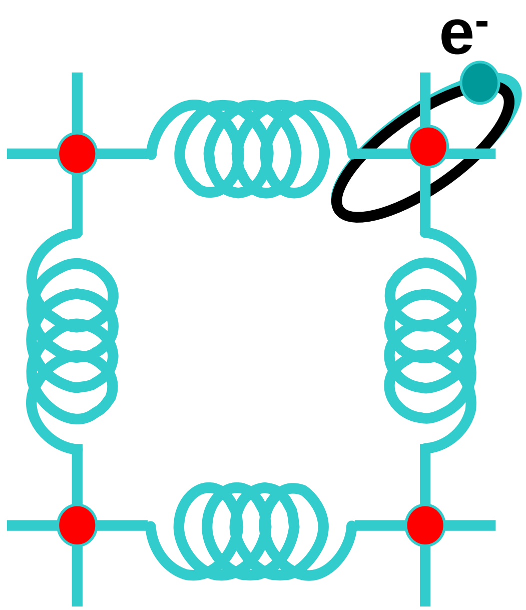




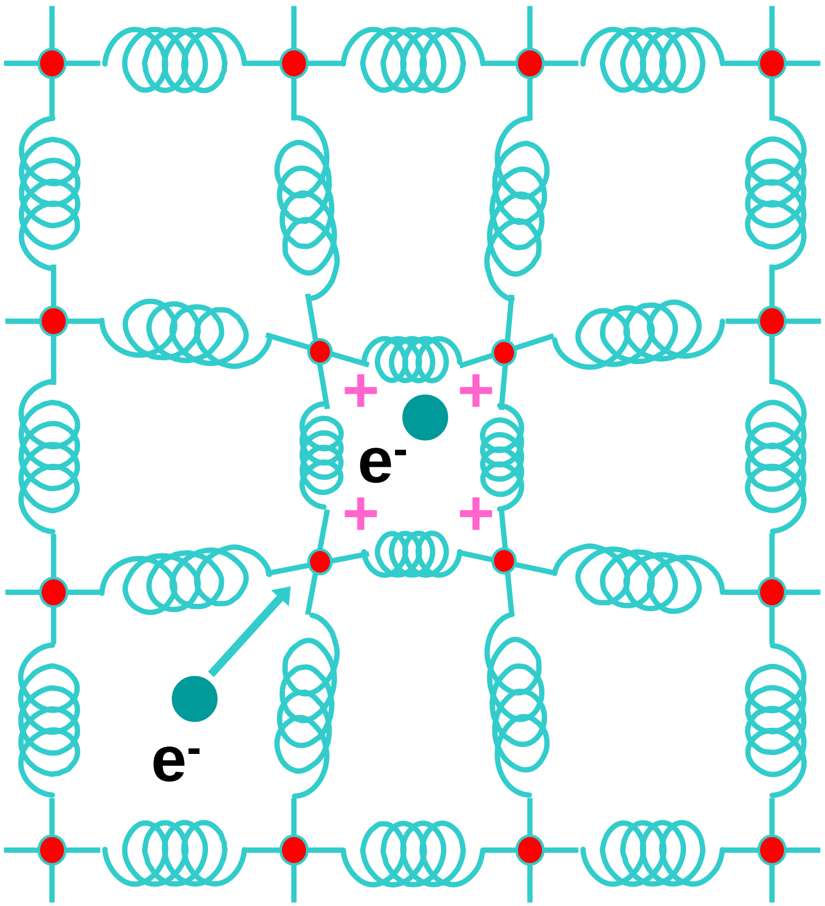
Models of Electrical Conductivity 1910

The Most Popular:





Physics of Superconductivity (1957 – 2006)



Electrons Pair Off!

BCS Equation

$$T_C = 1.14\,\theta_D \exp(-1/\lambda)$$

$\theta_D = 275$ K,

$\lambda = 0.28$,

$\therefore T_C = \underline{9.5 \text{ K}}$ (Niobium)

GLAG

$$G[\phi] \approx \int d^3r[\frac{1}{2m*}(-i\hbar\nabla + e*A)\phi*(i\hbar\nabla + e*A)\phi + a\phi\phi* + \tfrac{1}{2}b\phi\phi*\phi\phi*]$$

$$-(i\partial\nabla - \mathcal{A})^2 f + f(1 - f^2) = 0$$

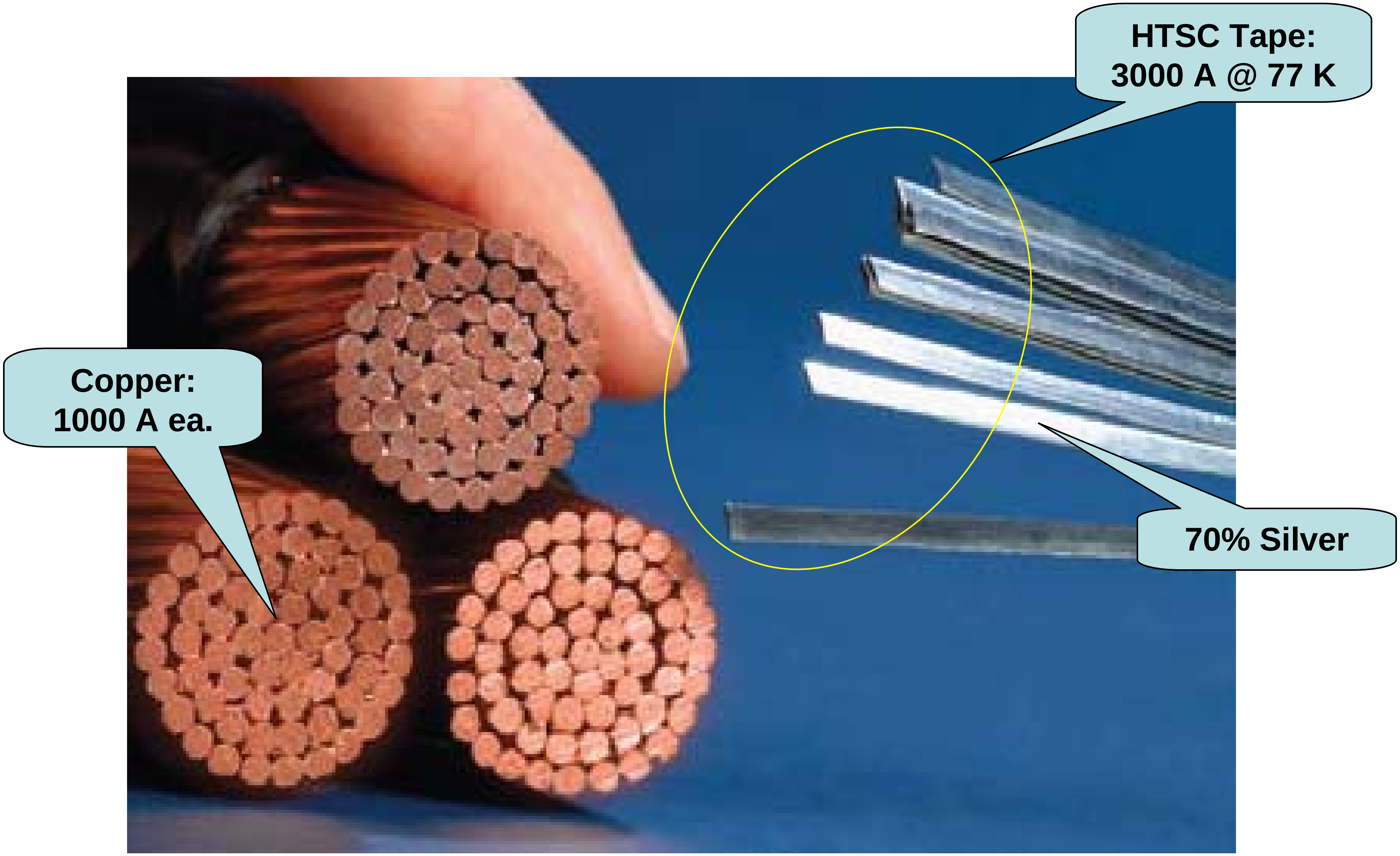
$$\kappa^2\nabla\times(\nabla\times\mathcal{A}) + \tfrac{1}{2}i(f^*\nabla f - f\nabla f^*) + \mathcal{A}f^2 = 0$$

$$\phi = (|a|/b)^{1/2} f$$

$$A = (\Phi_0 / 2\pi\xi)\mathcal{A}$$

$$\kappa = \lambda_L / \xi$$

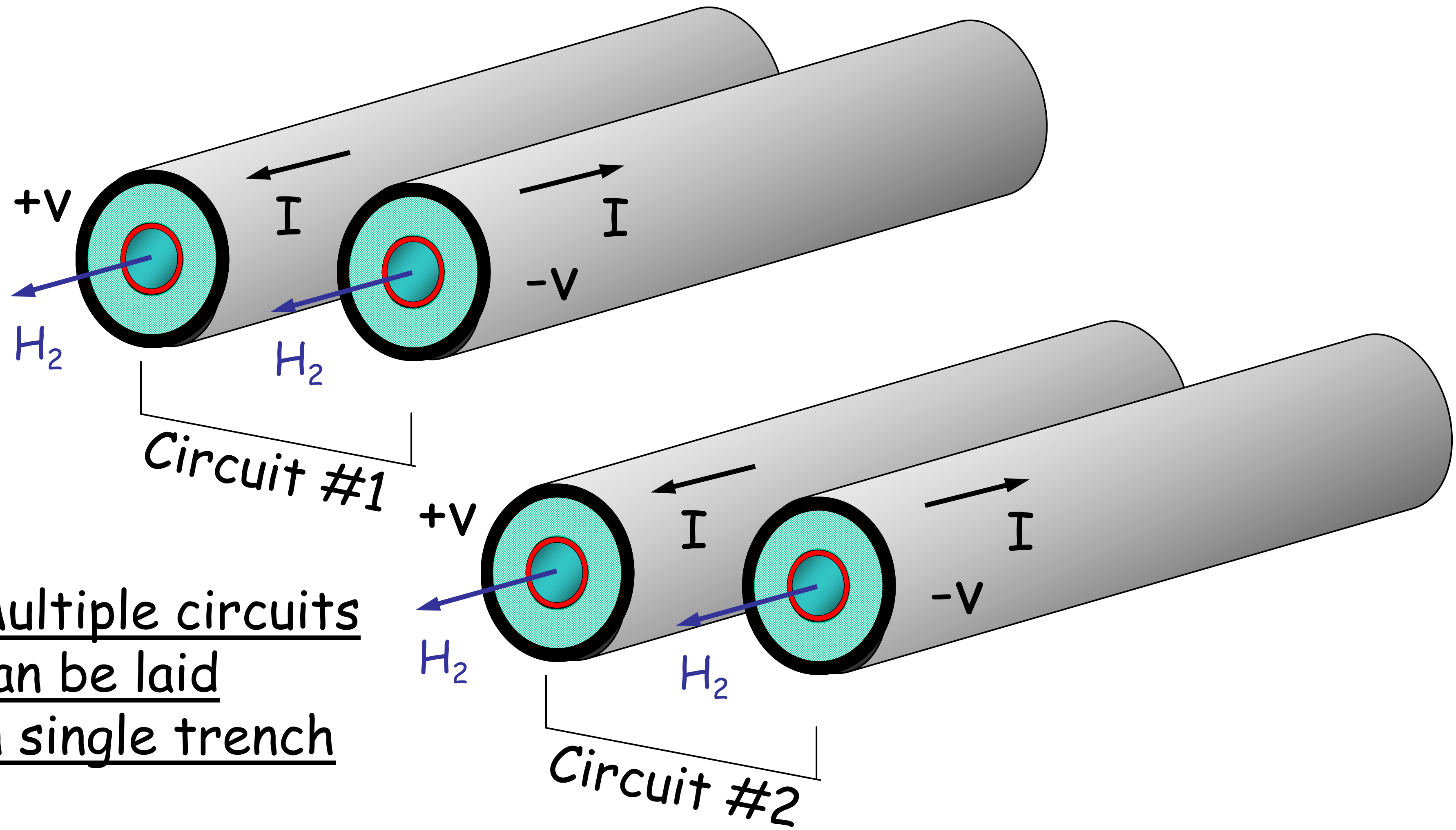
HTSC Tape (AMSC)



Finished Cable

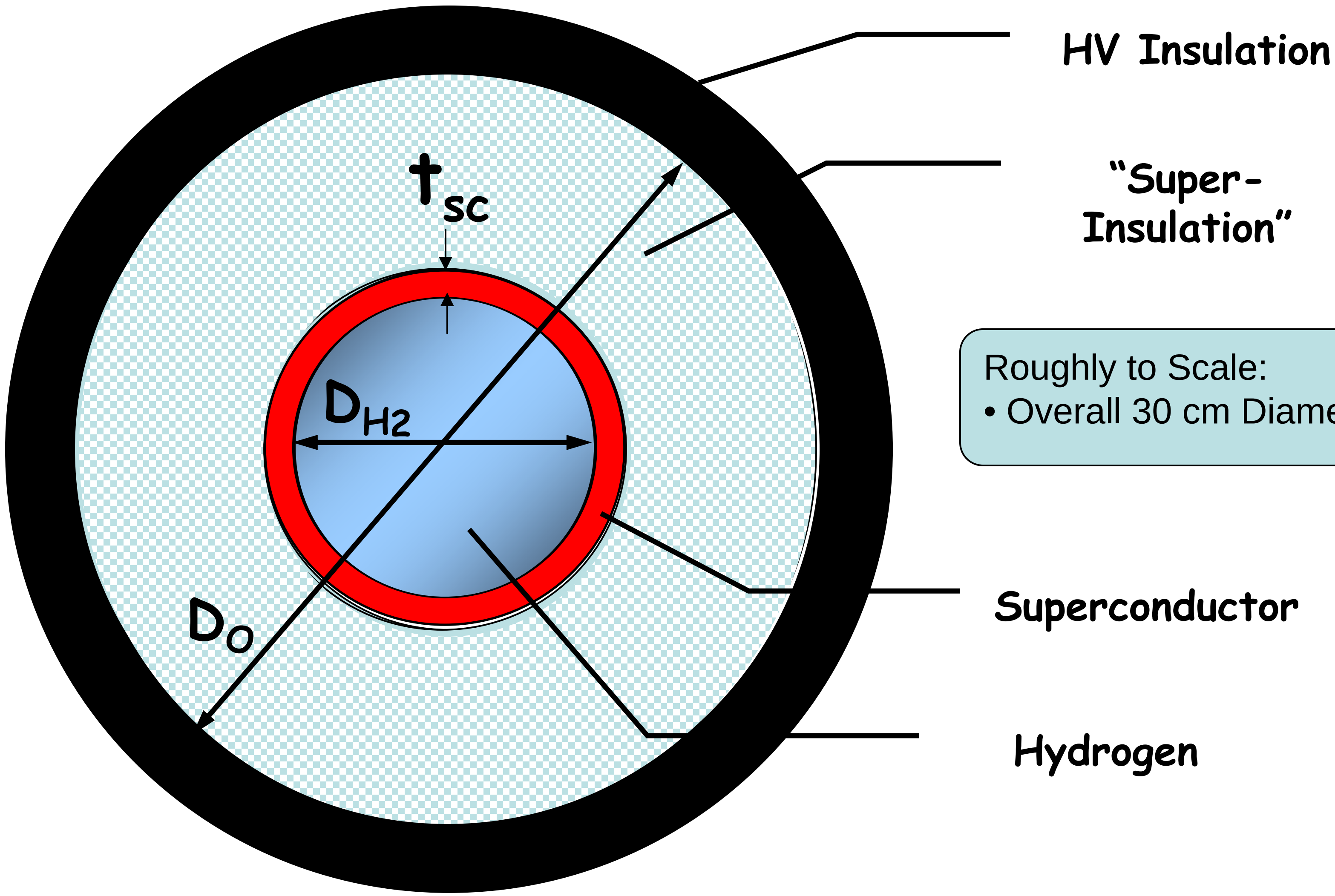
Puji Substation (Kunming City)

"Hydricity" SuperCables



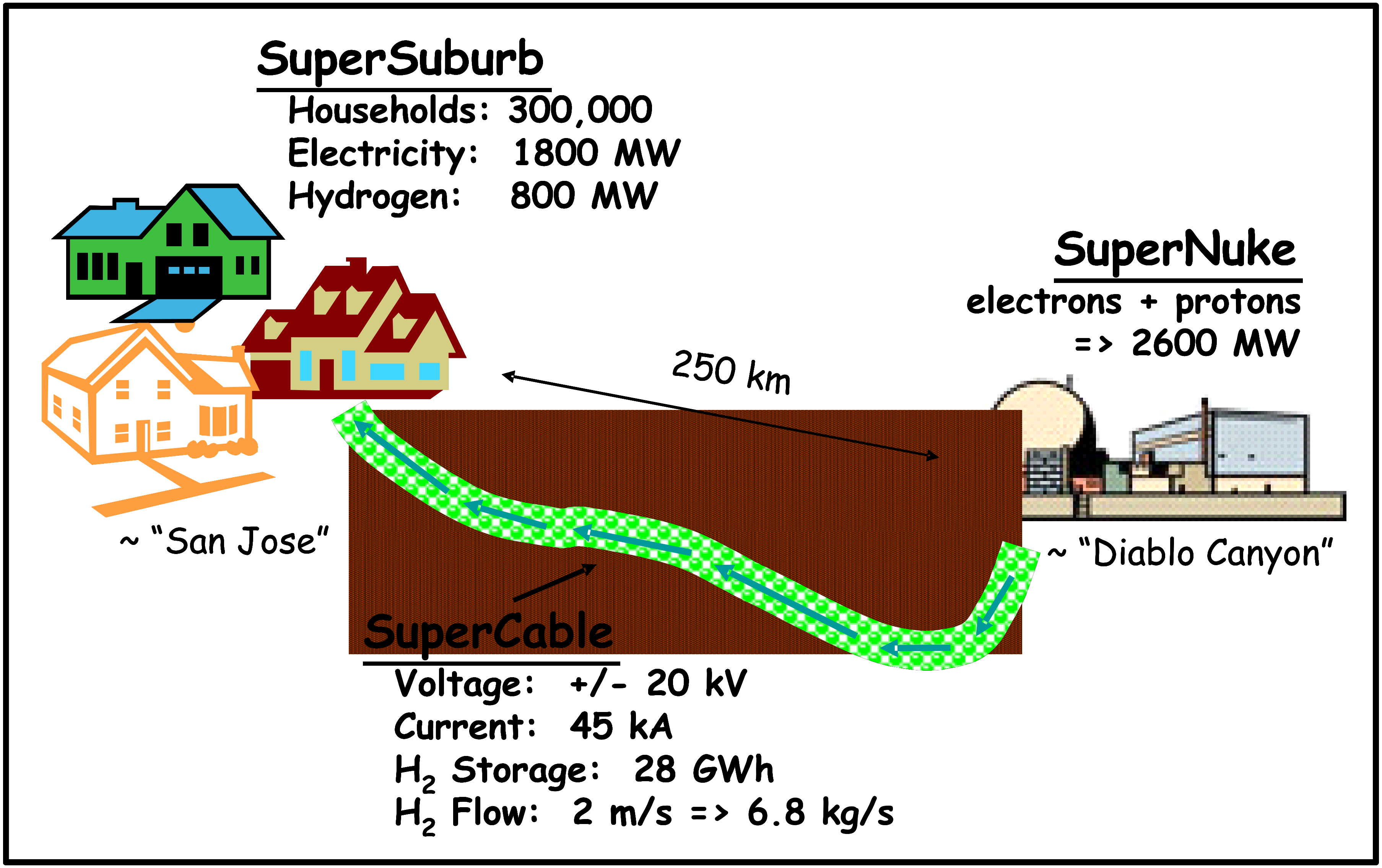
<u>Multiple circuits</u>
<u>can be laid</u>
<u>in single trench</u>

LH_2 SuperCable



Roughly to Scale:
• Overall 30 cm Diameter

SuperSuburb



A Canadian’s View of the World

The Mackenzie Valley Pipeline

http://www.mackenziegasproject.com

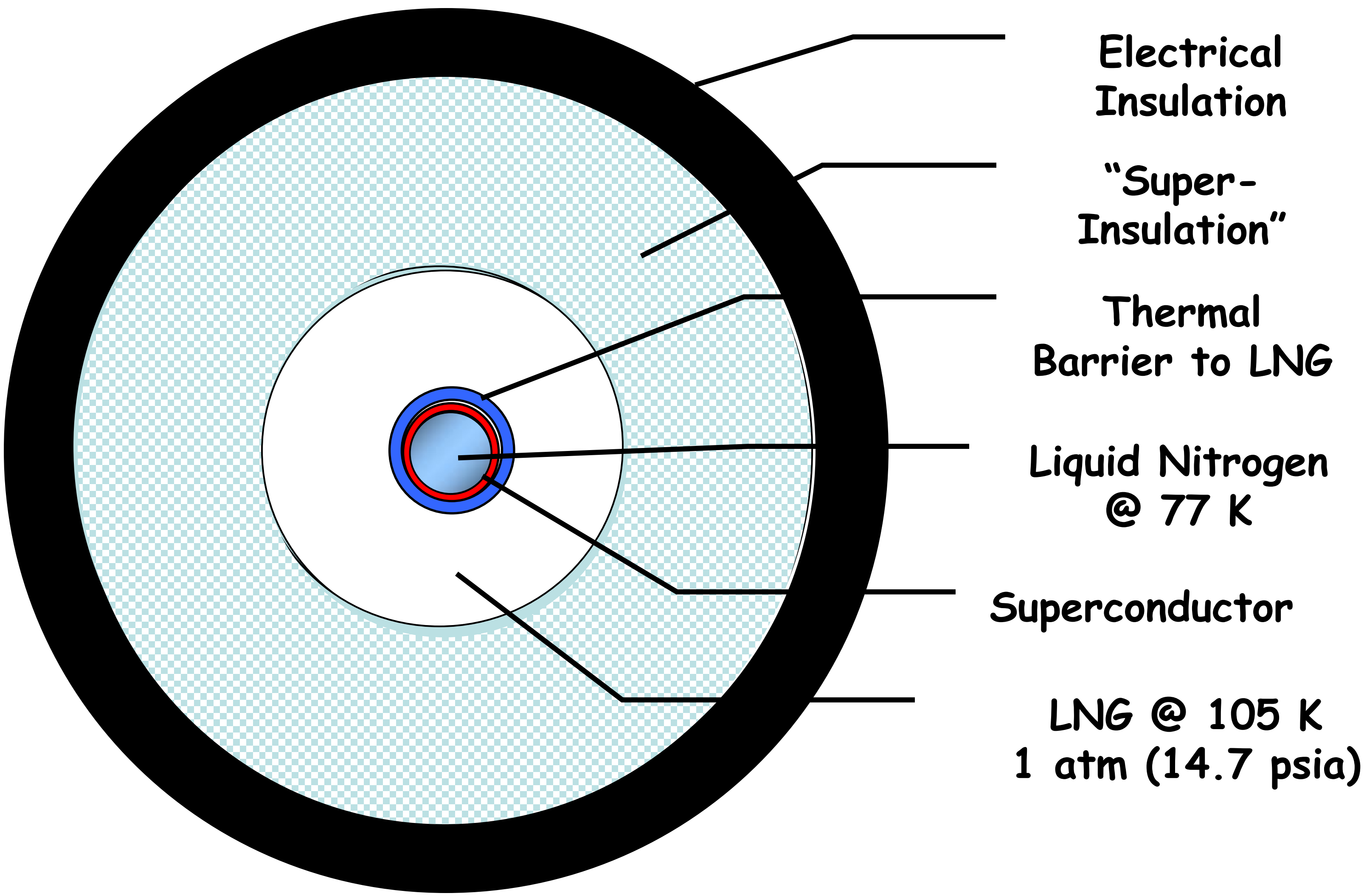
1220 km

18 GW-thermal

2006 - 2009

LNG SuperCable

Design for eventual conversion to high pressure cold or liquid H_2



It's 2050!

- *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

Where there is no vision,
the people perish…

Proverbs 29:18

“You can’t always get what you want…”

“…you get what you need!”