The Global Energy SuperGrid

Powering the Thousand Year Old Man

Chauncey Starr
Founder & President Emeritus

Paul M. Grant
Science Fellow

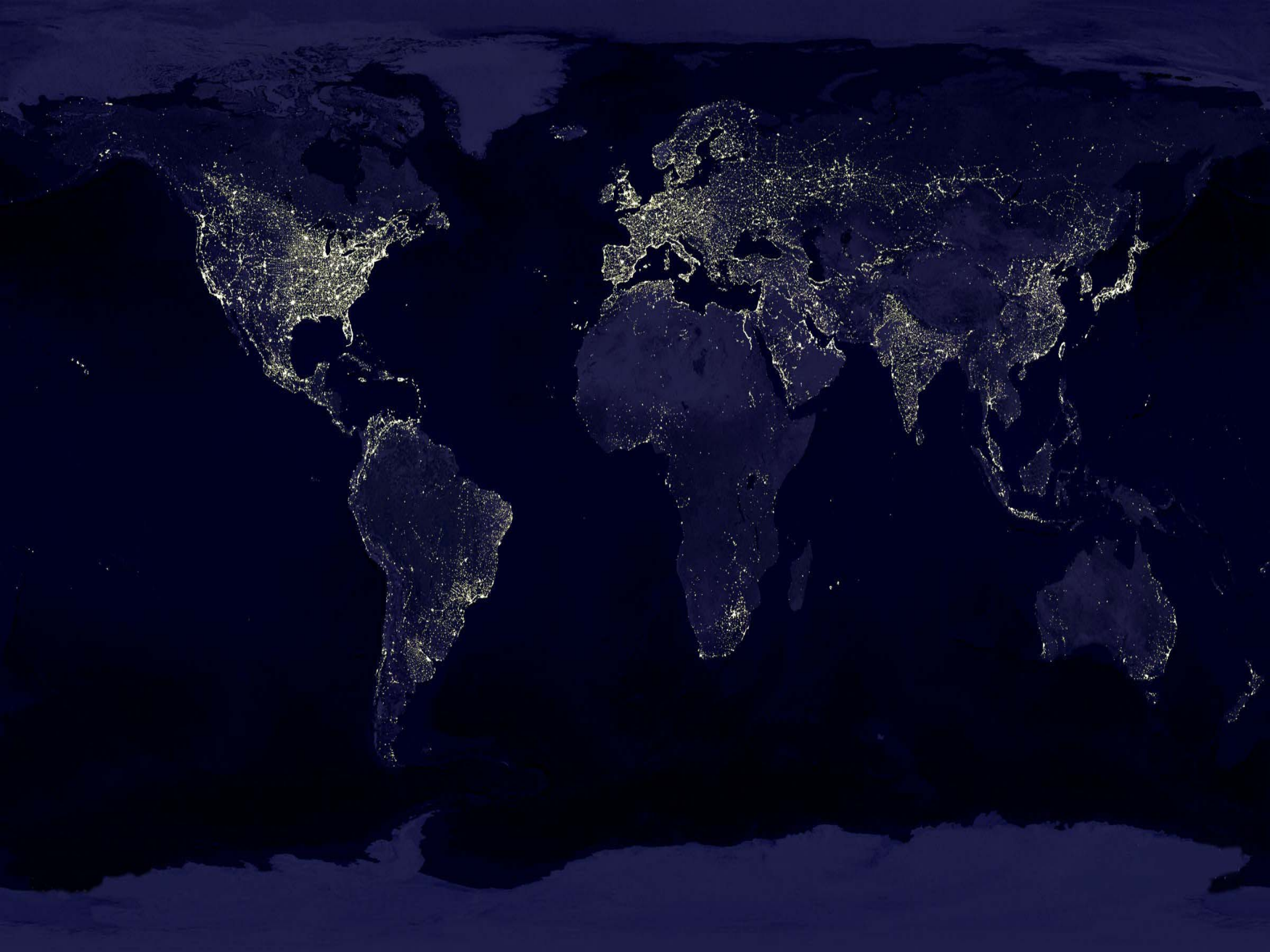
Electric Power Research Institute

EPRI

Chauncey Starr

"If scientists and engineers think they can build something, they will invariably do it…

without much thought to the consequences!"



The Energy Lemmas

I. Any discussion of the application of energy technology must involve, from the very start, an explicit social and political scenario

II. The unique aspect of energy as a life-sustaining necessity separates it from the jurisdiction of many of the usual "laws" of economics

The Challenge

- *Design a global energy economy to meet the needs of a densely populated industrialized world of 10^{10} souls in 2050 (10^{12} by 3000?)*

- *Accomplish this within the highest levels of environmental, esthetic, safe, reliable, efficient and secure engineering practice possible.*

The Solution

A Symbiosis of

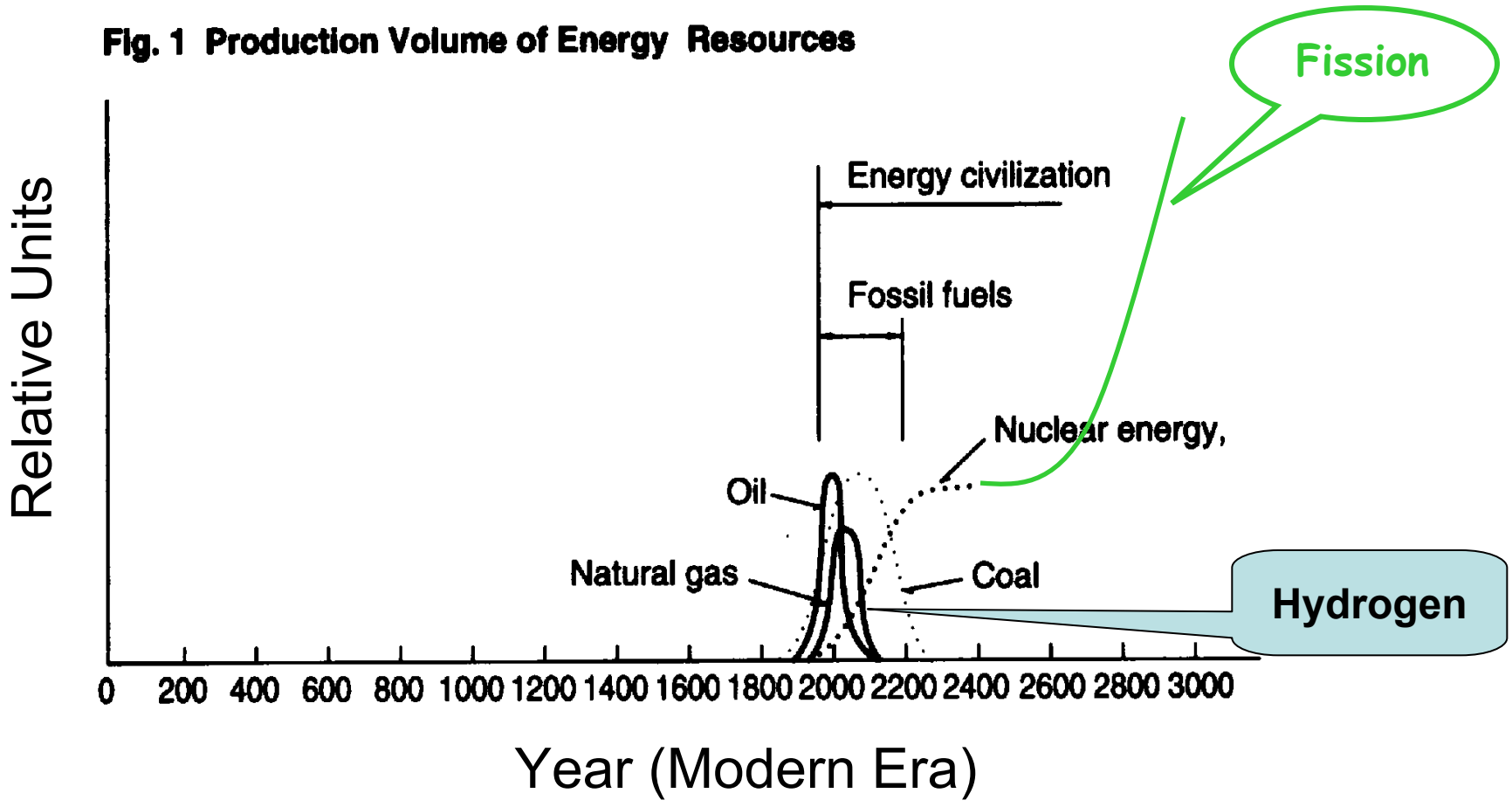
Nuclear/Hydrogen/Superconductivity

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

"The Magic Words"

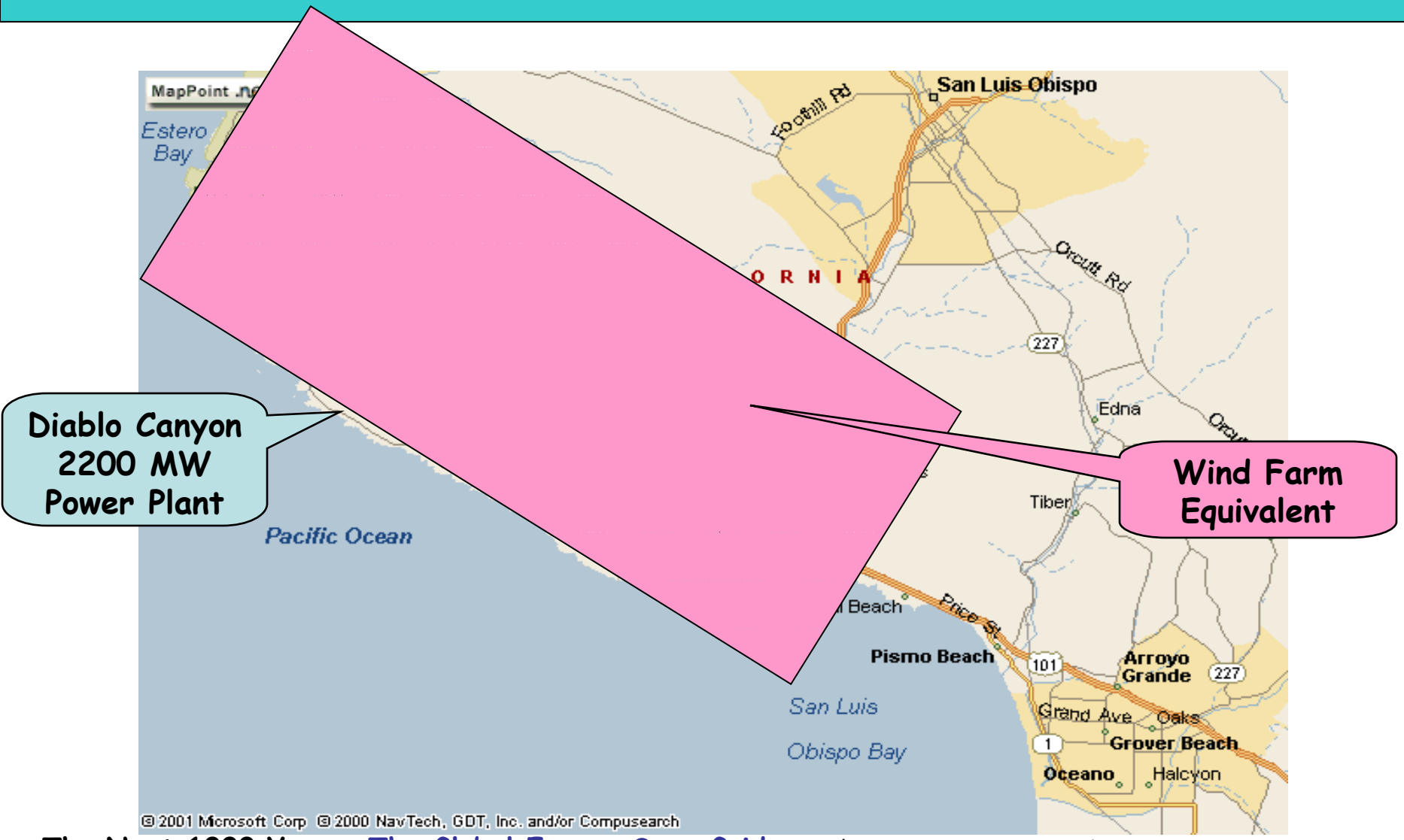
- Safe Nuclear Power (fission *and* fusion)
- Superconductivity
- Hydrogen
- Energy Storage
- Environmentally Friendly
- No Greenhouse Gases
- Non-Eco-Invasive
- Global in Scope

Past & Future Energy Supply



Diablo Canyon

California Coast Power



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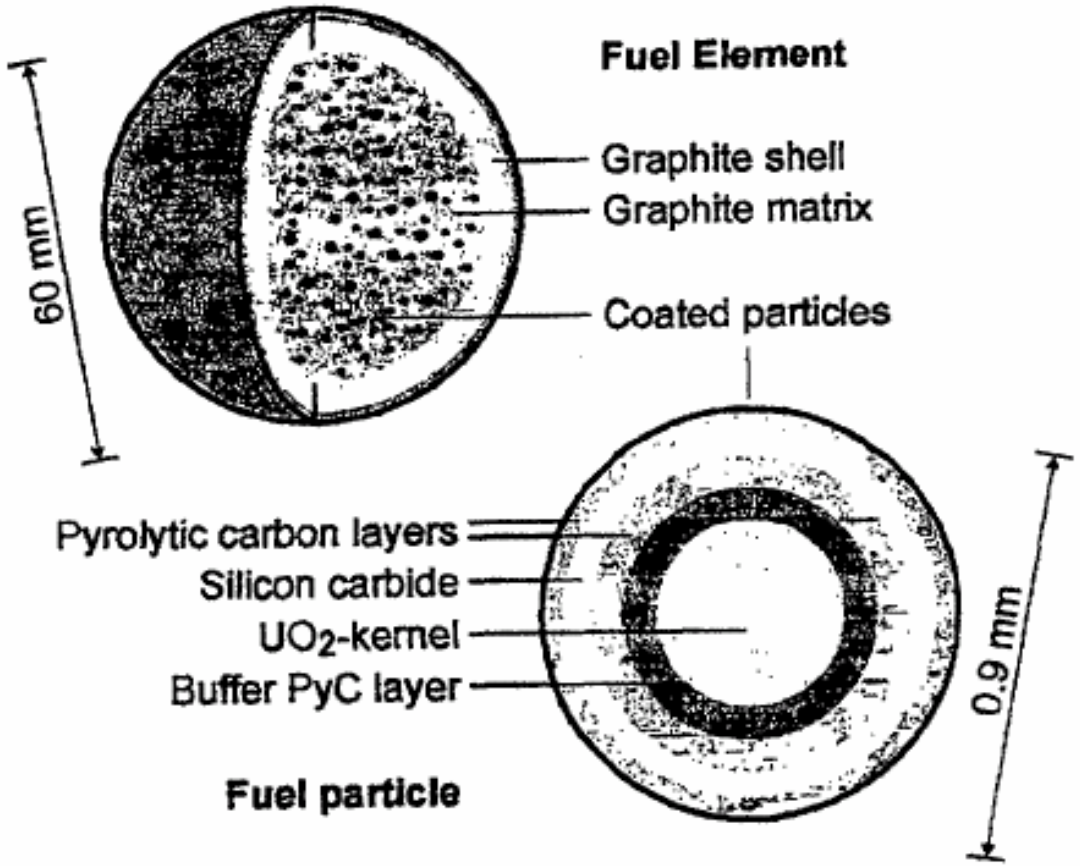
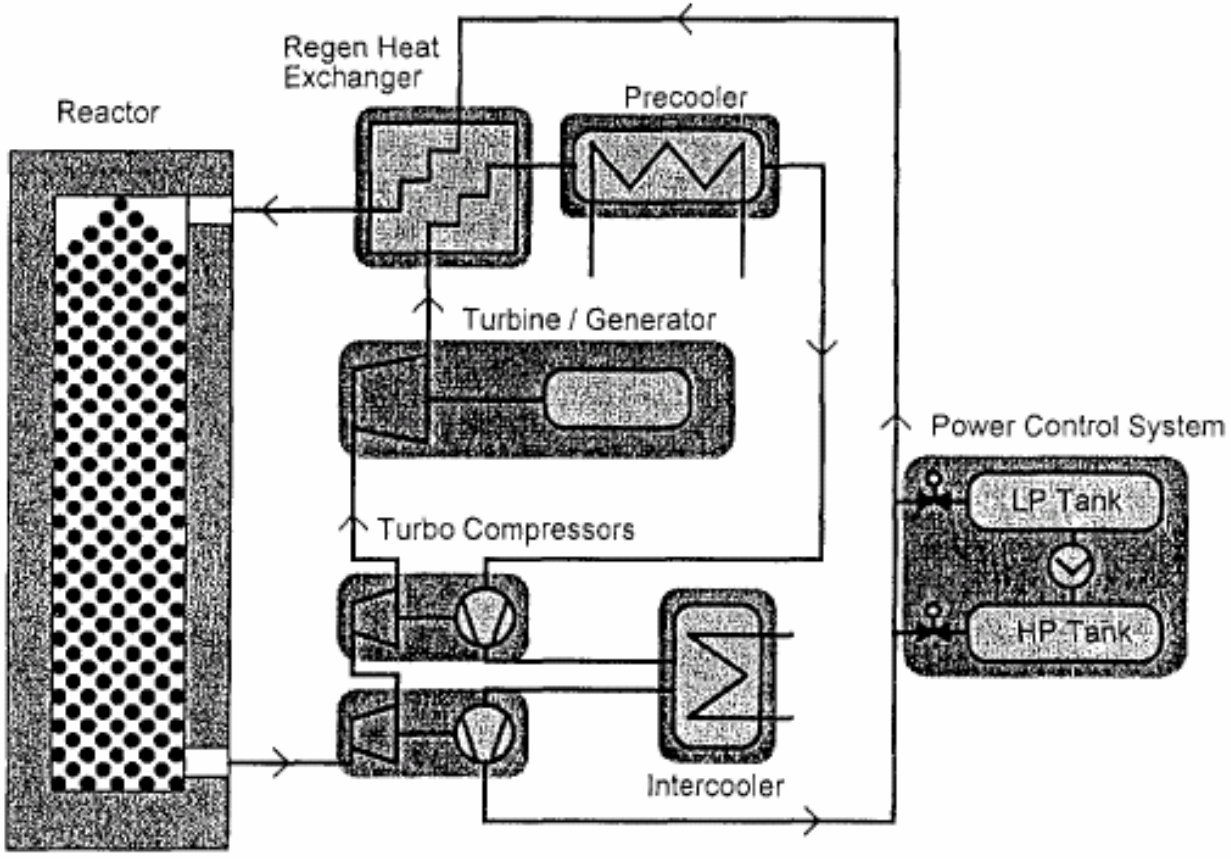
Particle/Pebble Nuclear Fuel



High Temperature Gas Cooled Reactor



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

Hindenburg Hysteria

The Hydrogen Economy

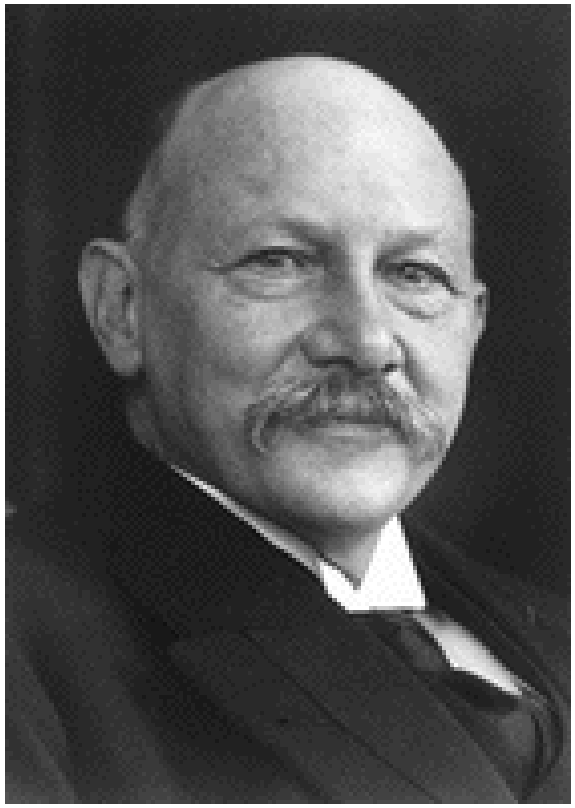
- You have to make it, just like electricity
- Electricity can make H_2, and H_2 can make electricity ($2H_2O \Leftrightarrow 2H_2 + O_2$)
- You have to make a lot of it
- You can make it cold, - 419 F (21 K)

P. M. Grant, "Hydrogen Lifts Off," Nature, 10 July 2003

Fathers of Cryogenics

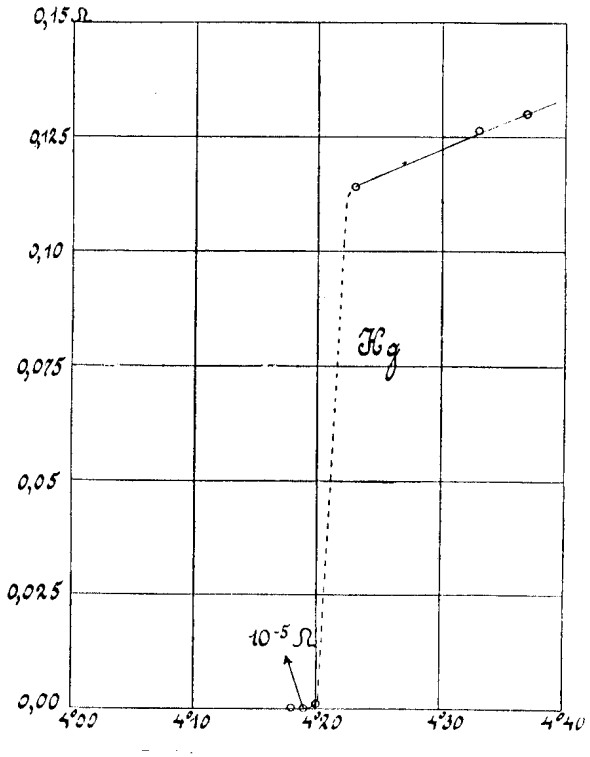
Dewar

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



Kammerlingh-Onnes

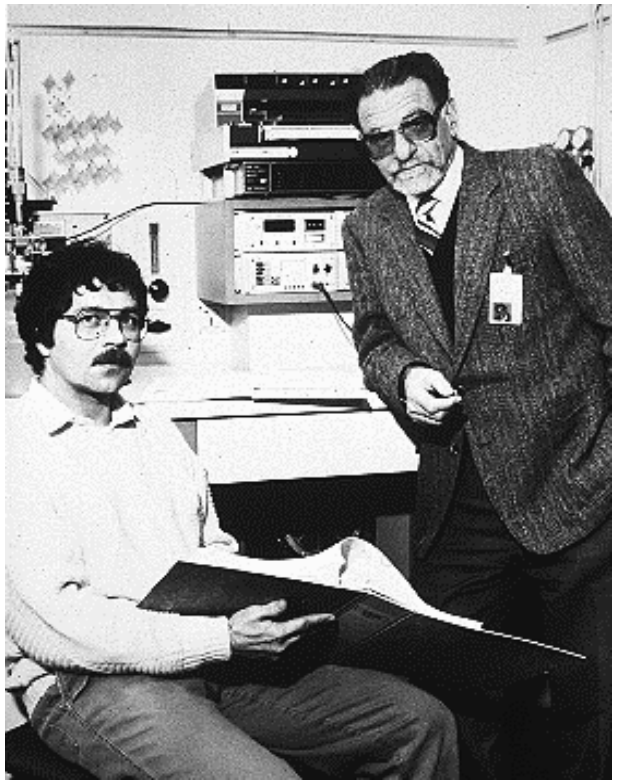
1911: A Big Surprise!



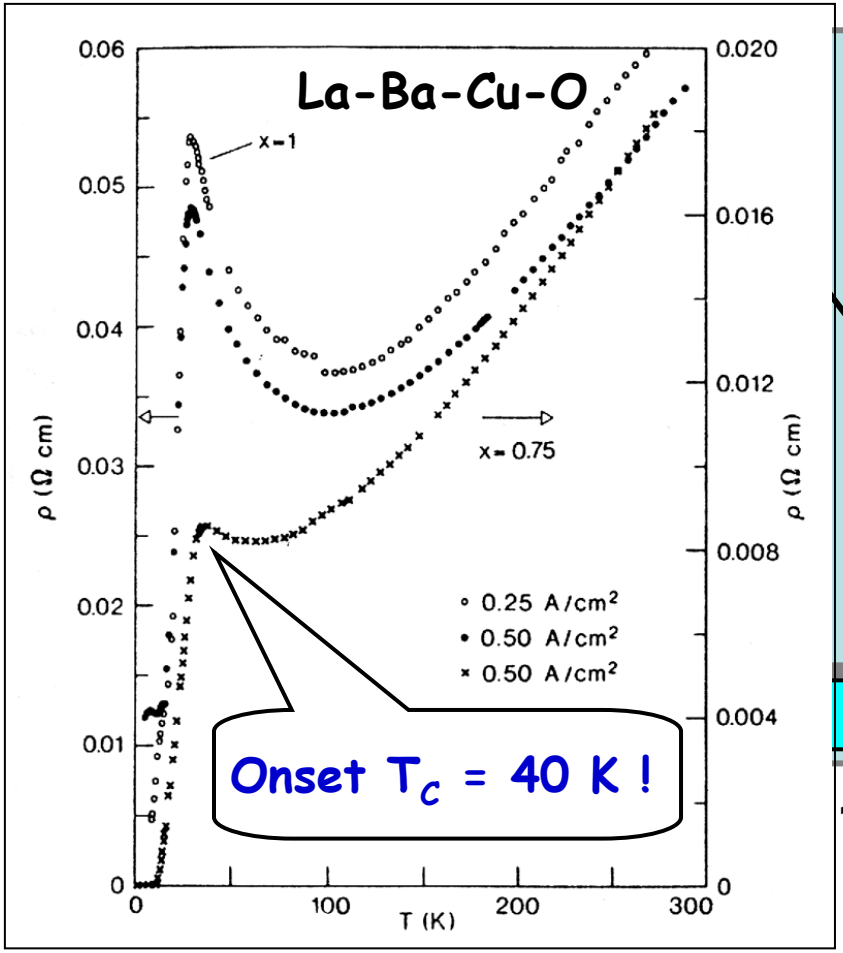
Thus the mercury at 4.2 K has entered a new state, which, owing to its particular electrical properties, can be called the state of *superconductivity*

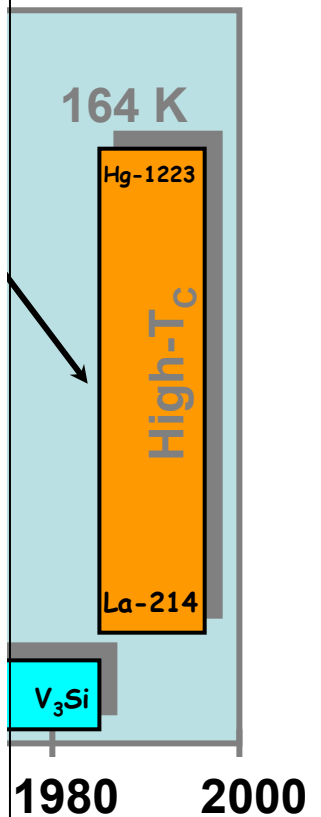
H. Kamerlingh-Onnes (1911)

1986: Another Big Surprise!



Bednorz and Mueller
IBM Zuerich, 1986





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1987: "The Prize!"

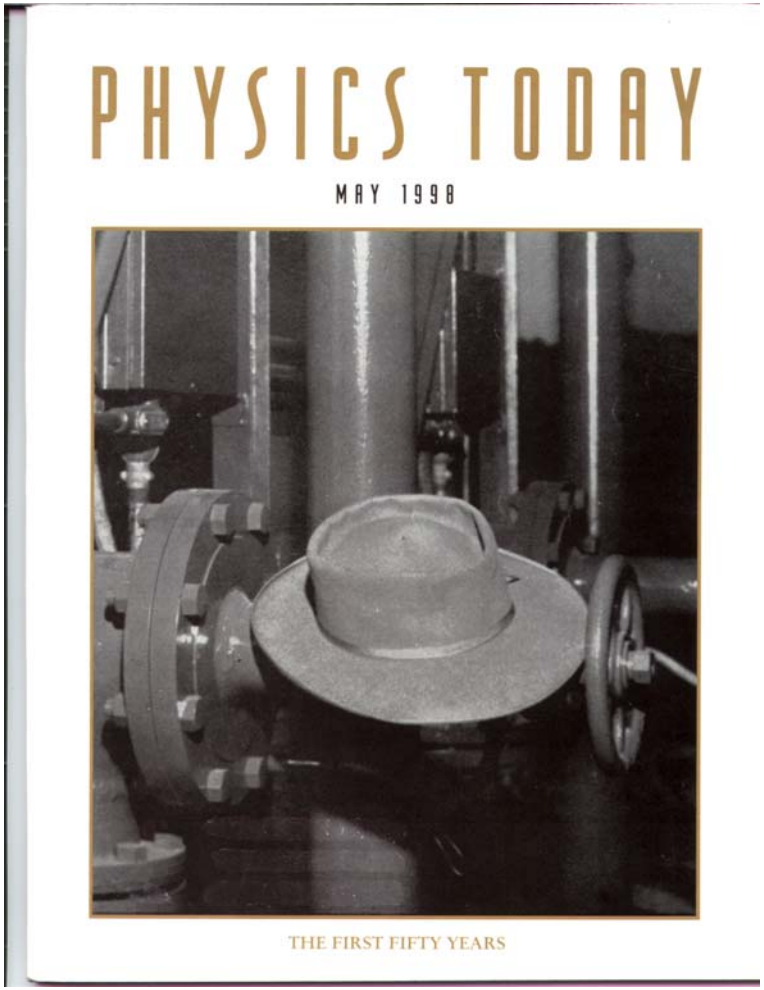
Associated Press

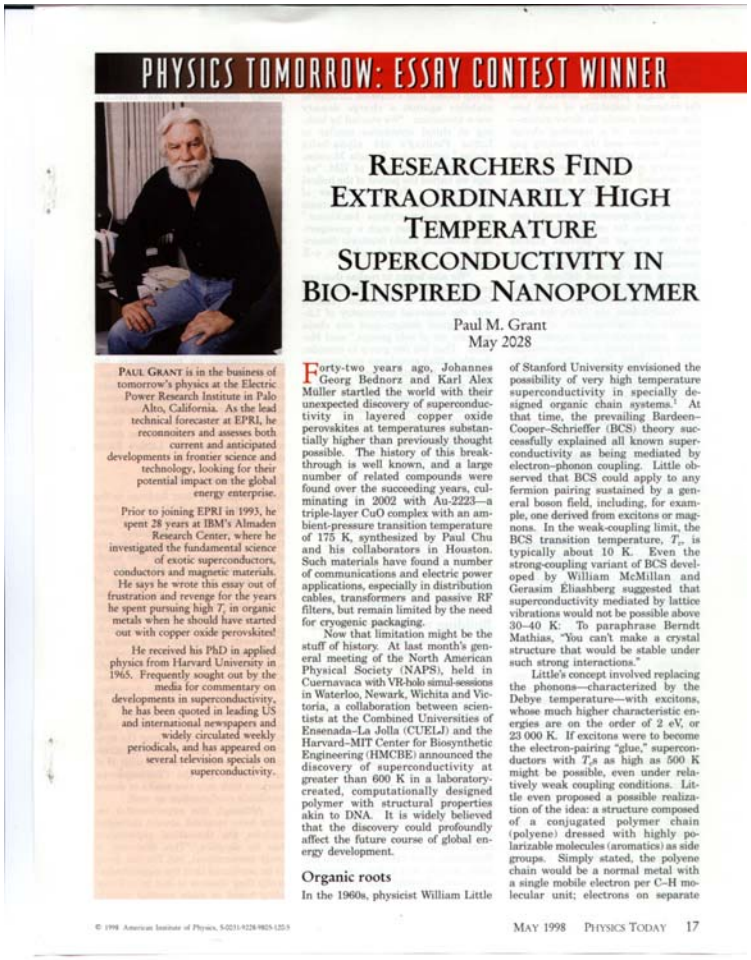
J. Georg Bednorz, left, and K. Alex Müller after learning they had won the Nobel Prize in physics.

2 Get Nobel for Unlocking Superconductor Secret

The Future

2028





PHYSICS TOMORROW: ESSAY CONTEST WINNER

RESEARCHERS FIND EXTRAORDINARILY HIGH TEMPERATURE SUPERCONDUCTIVITY IN BIO-INSPIRED NANOPOLYMER

Paul M. Grant
May 2028

PAUL GRANT is in the business of tomorrow's physics at the Electric Power Research Institute in Palo Alto, California. As the lead technical forecaster at EPRI, he reconnoiters and assesses both current and anticipated developments in frontier science and technology, looking for their potential impact on the global energy enterprise.

Prior to joining EPRI in 1993, he spent 28 years at IBM's Almaden Research Center, where he investigated the fundamental science of exotic superconductors, conductors and magnetic materials. He says he wrote this essay out of frustration and revenge for the years he spent pursuing high T_c in organic metals when he should have started out with copper oxide perovskites!

He received his PhD in applied physics from Harvard University in 1965. Frequently sought out by the media for commentary on developments in superconductivity, he has been quoted in leading US and international newspapers and widely circulated weekly periodicals, and has appeared on several television specials on superconductivity.

Forty-two years ago, Johannes Georg Bednorz and Karl Alex Müller startled the world with their unexpected discovery of superconductivity in layered copper oxide perovskites at temperatures substantially higher than previously thought possible. The history of this breakthrough is well known, and a large number of related compounds were found over the succeeding years, culminating in 2002 with Au-2223—a triple-layer CuO complex with an ambient-pressure transition temperature of 175 K, synthesized by Paul Chu and his collaborators in Houston. Such materials have found a number of communications and electric power applications, especially in distribution cables, transformers and passive RF filters, but remain limited by the need for cryogenic packaging.

Now that limitation might be the stuff of history. At last month's general meeting of the North American Physical Society (NAPS), held in Cuernavaca with VR-holo simul-sessions in Waterloo, Newark, Wichita and Victoria, a collaboration between scientists at the Combined Universities of Ensenada–La Jolla (CUELJ) and the Harvard–MIT Center for Biosynthetic Engineering (HMCBE) announced the discovery of superconductivity at greater than 600 K in a laboratory-created, computationally designed polymer with structural properties akin to DNA. It is widely believed that the discovery could profoundly affect the future course of global energy development.

Organic roots

In the 1960s, physicist William Little of Stanford University envisioned the possibility of very high temperature superconductivity in specially designed organic chain systems.[1] At that time, the prevailing Bardeen–Cooper–Schrieffer (BCS) theory successfully explained all known superconductivity as being mediated by electron–phonon coupling. Little observed that BCS could apply to any fermion pairing sustained by a general boson field, including, for example, one derived from excitons or magnons. In the weak-coupling limit, the BCS transition temperature, T_c, is typically about 10 K. Even the strong-coupling variant of BCS developed by William McMillan and Gerasim Eliashberg suggested that superconductivity mediated by lattice vibrations would not be possible above 30–40 K. To paraphrase Berndt Mathias, "You can't make a crystal structure that would be stable under such strong interactions."

Little's concept involved replacing the phonons—characterized by the Debye temperature—with excitons, whose much higher characteristic energies are on the order of 2 eV, or 23 000 K. If excitons were to become the electron-pairing "glue," superconductors with T_cs as high as 500 K might be possible, even under relatively weak coupling conditions. Little even proposed a possible realization of the idea: a structure composed of a conjugated polymer chain (polyene) dressed with highly polarizable molecules (aromatics) as side groups. Simply stated, the polyene chain would be a normal metal with a single mobile electron per C–H molecular unit; electrons on separate

The Next 1000 Years: The Global Energy SuperGrid - Paul M. Grant, 23 September 2003

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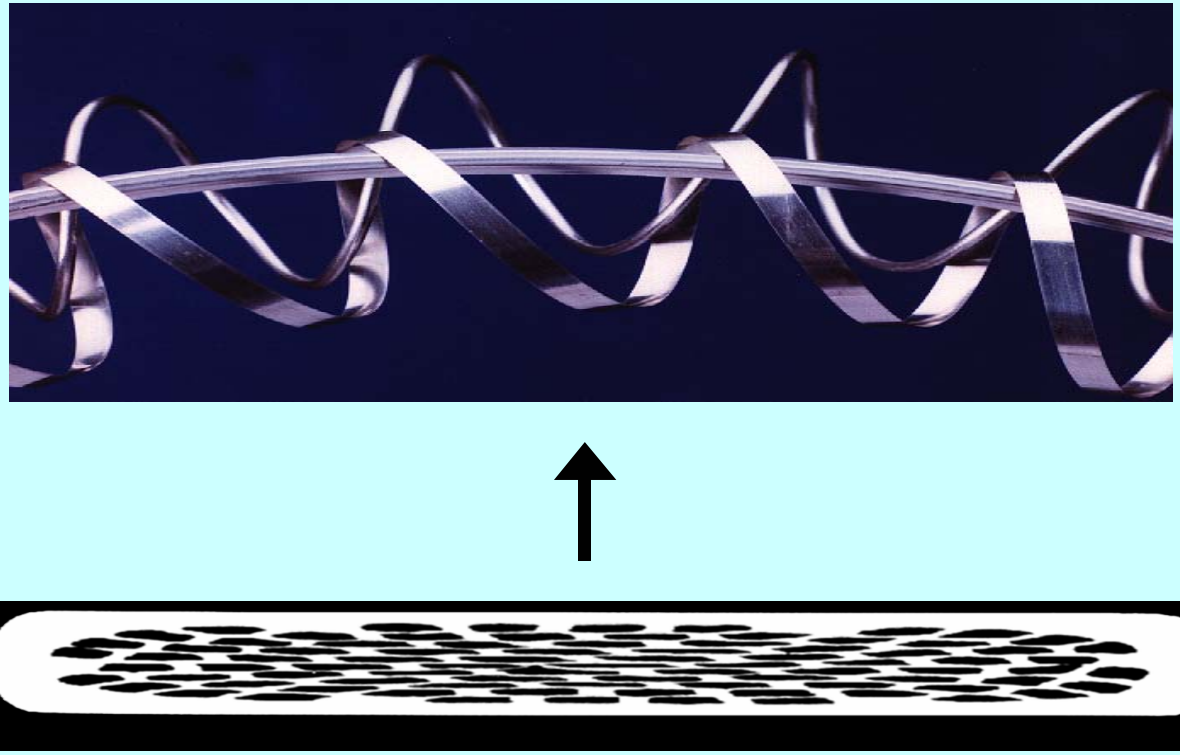
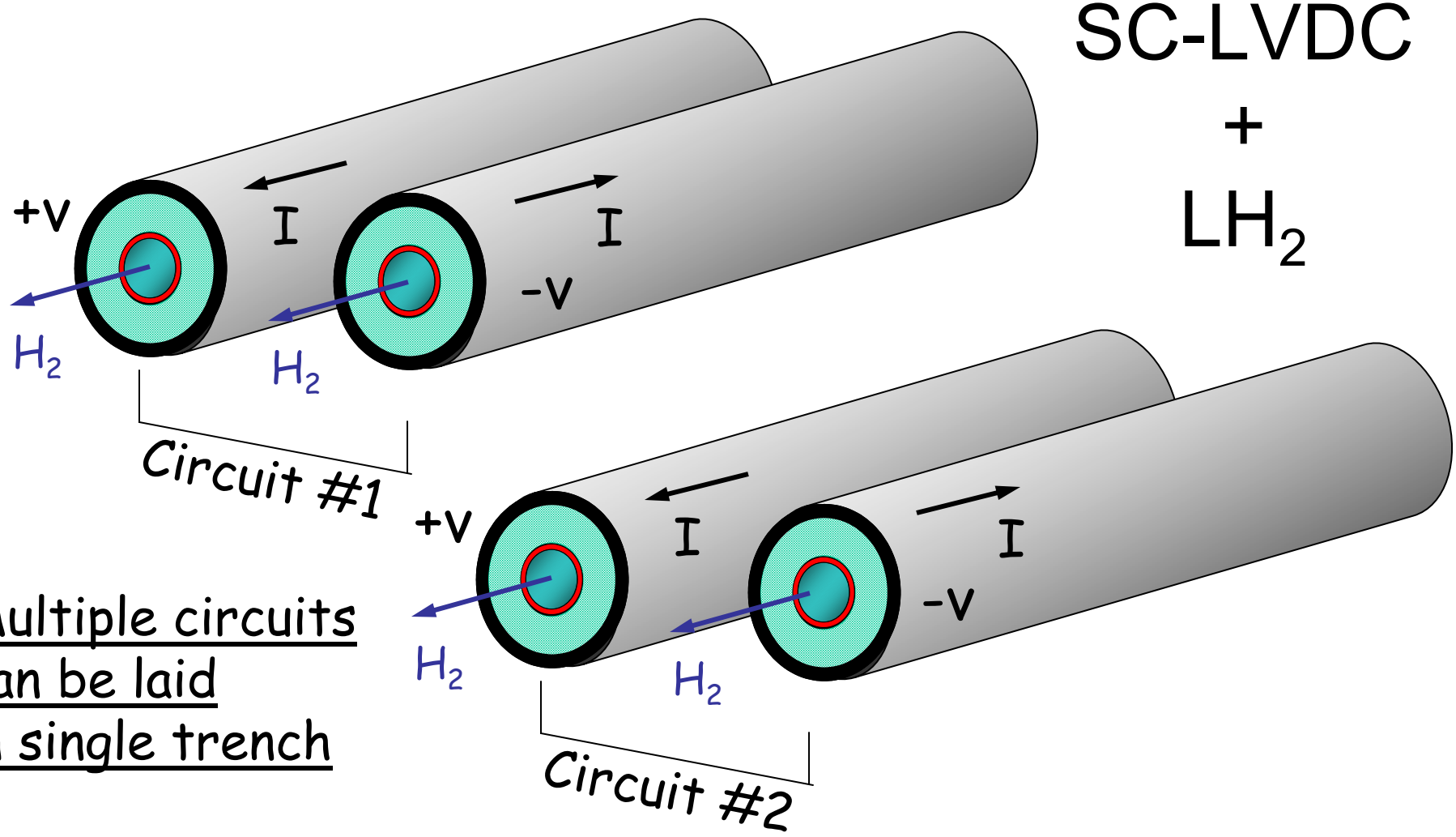
HTSC Wire Can Now Be Made!

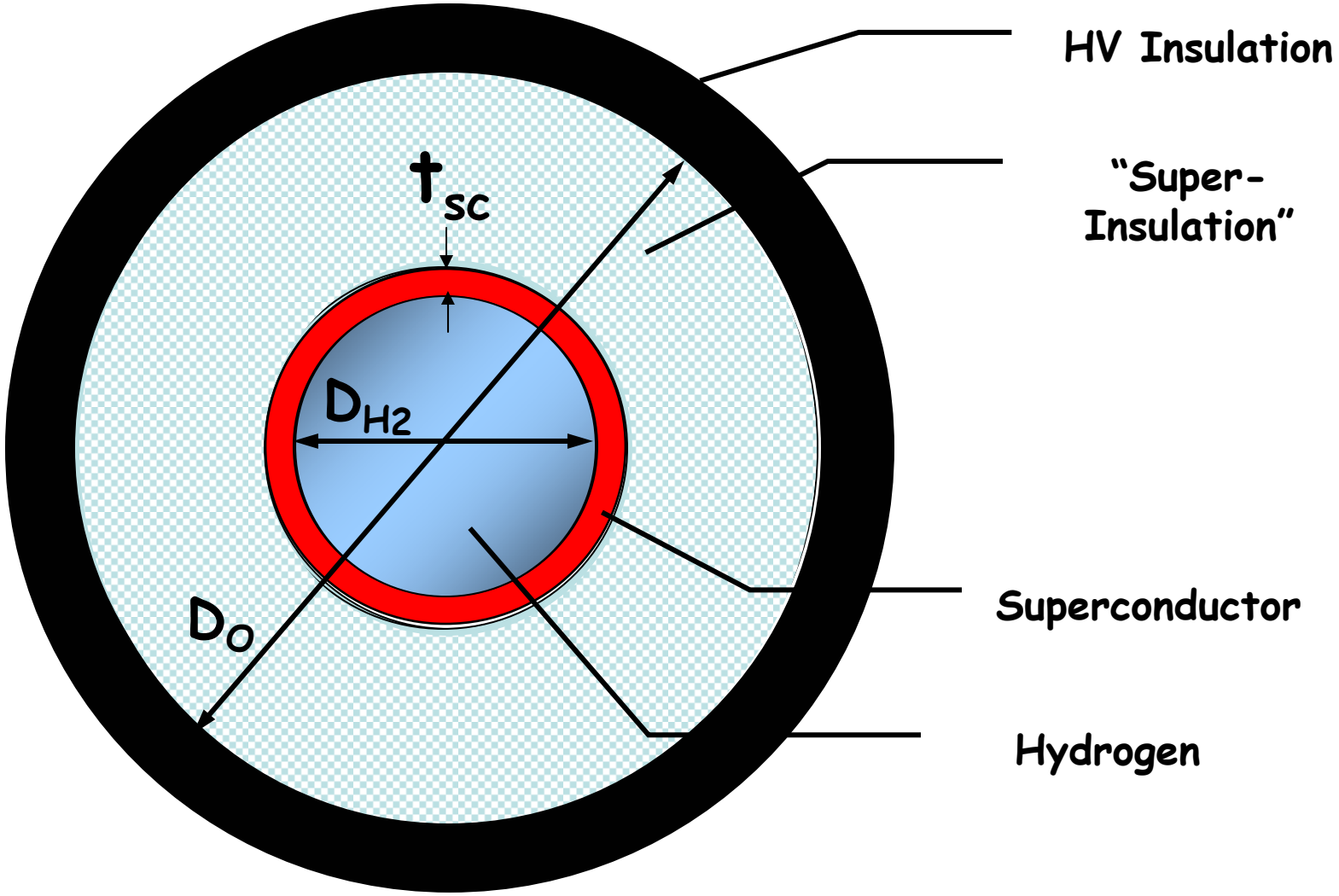


SuperCables

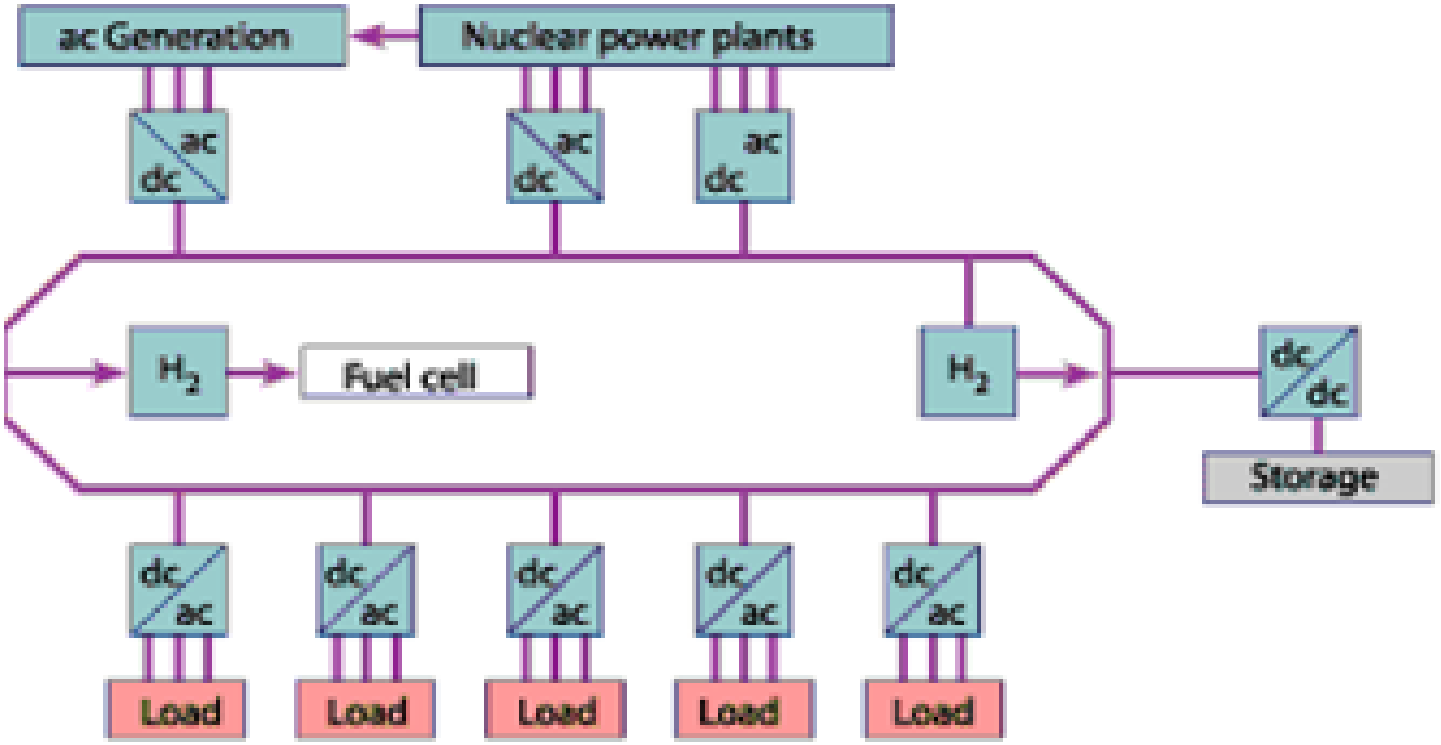


Multiple circuits can be laid in single trench

LH_2 SuperCable



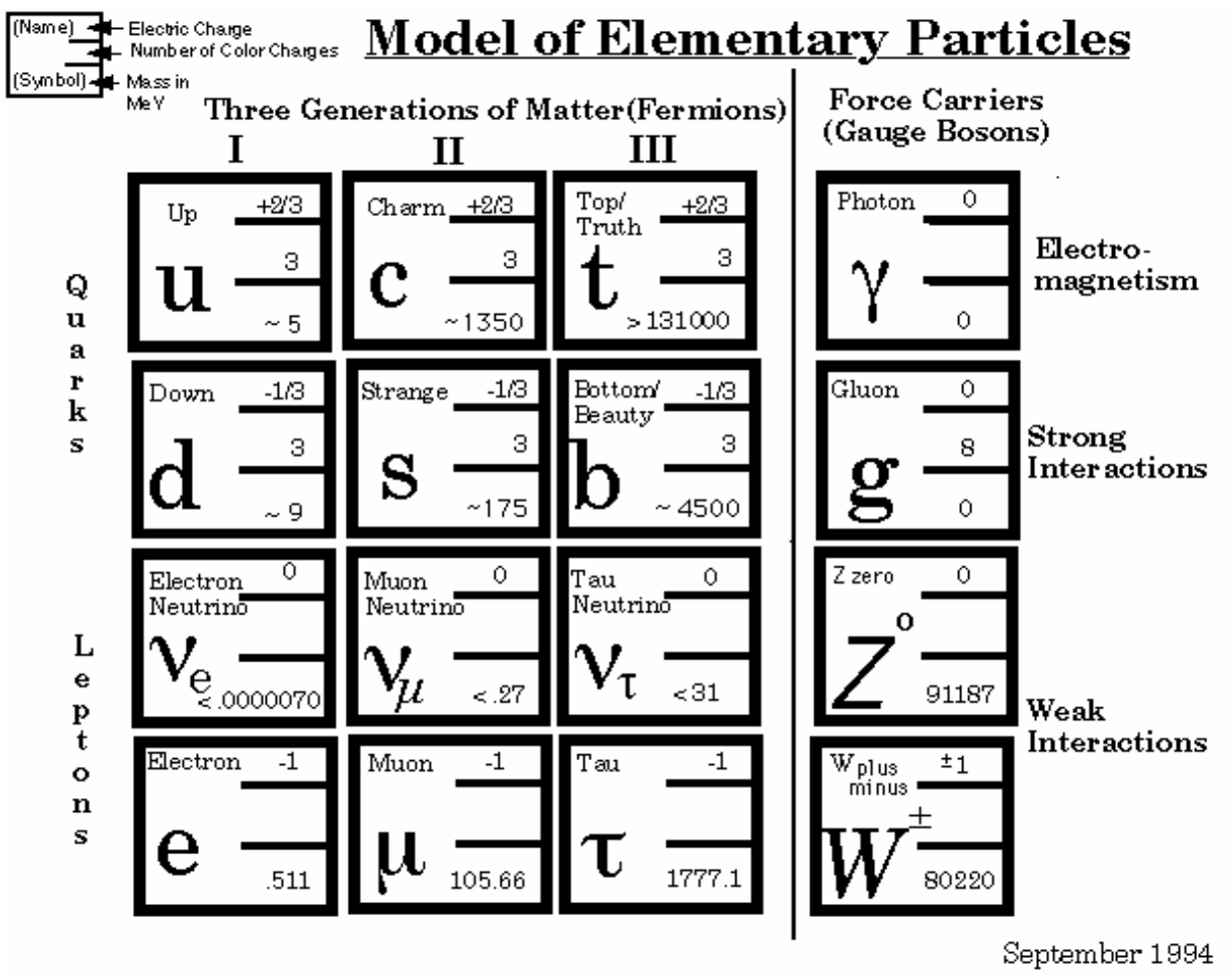
SuperGrid



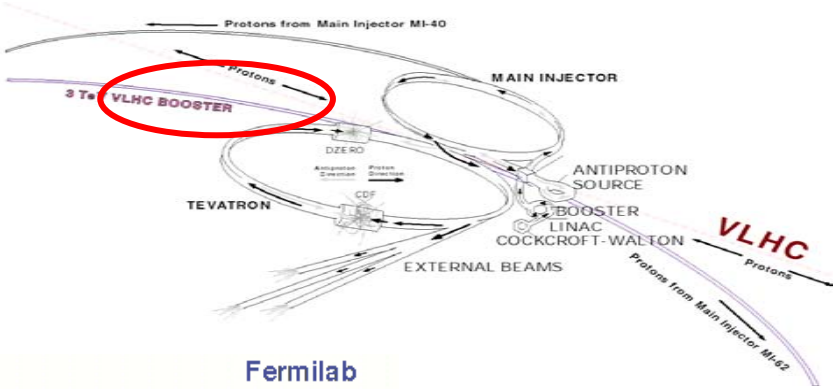
Continental SuperGrid

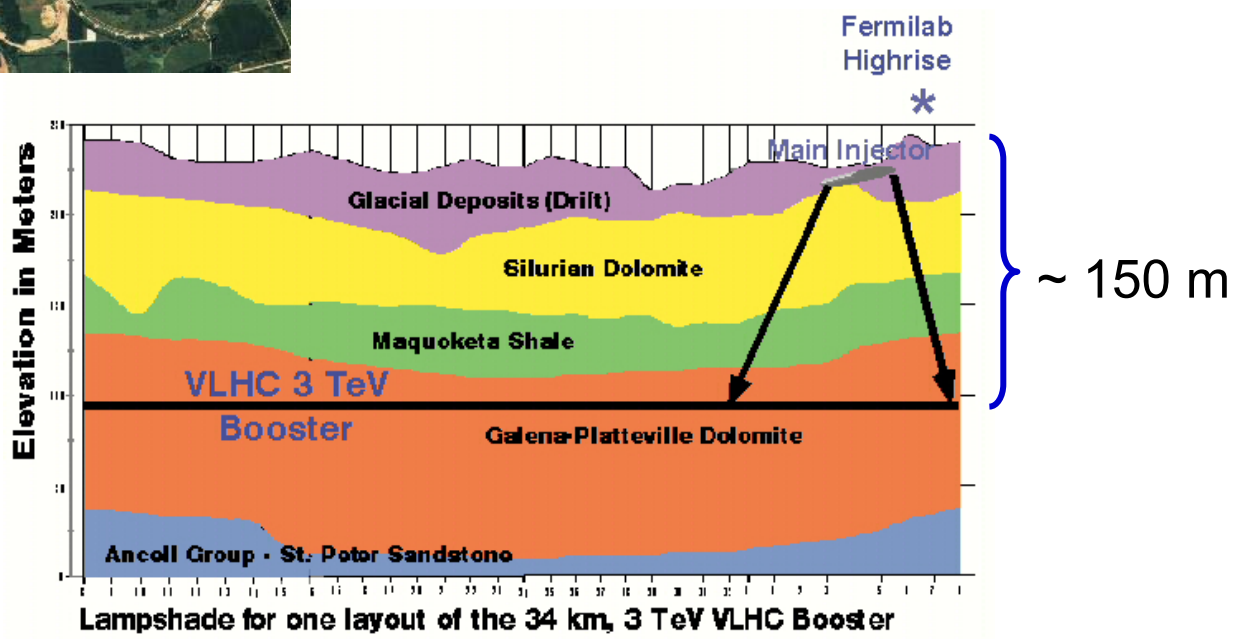
C. S. Starr, "Continential SuperGrid," Nuclear News, Spring Issue, 2002

The Standard Model

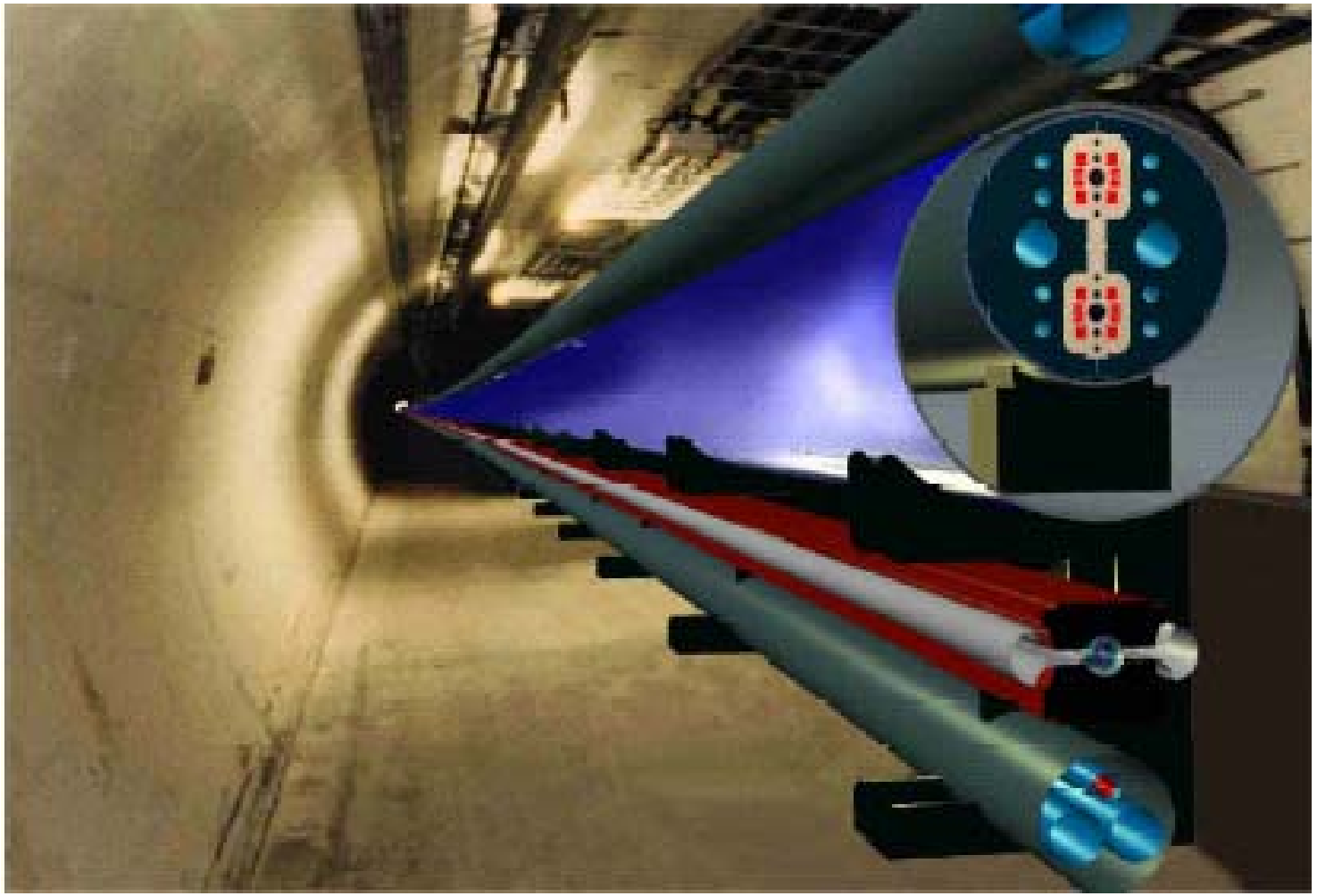


Next American Big-Bang-atron

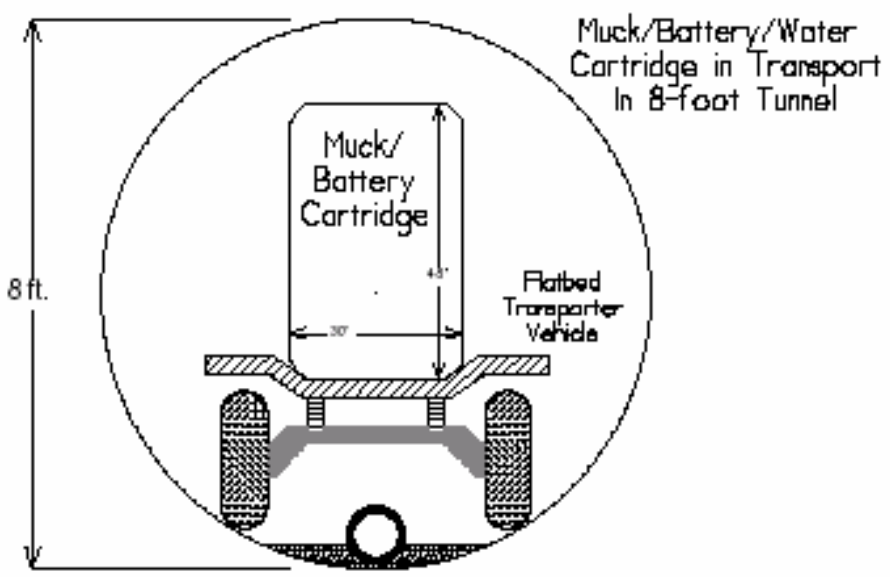


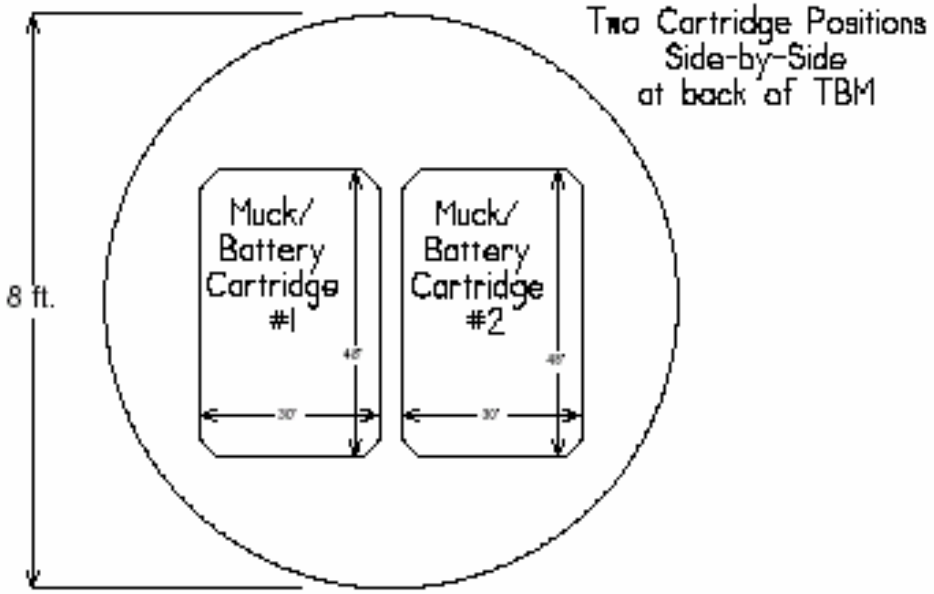


Low-Field VLHC

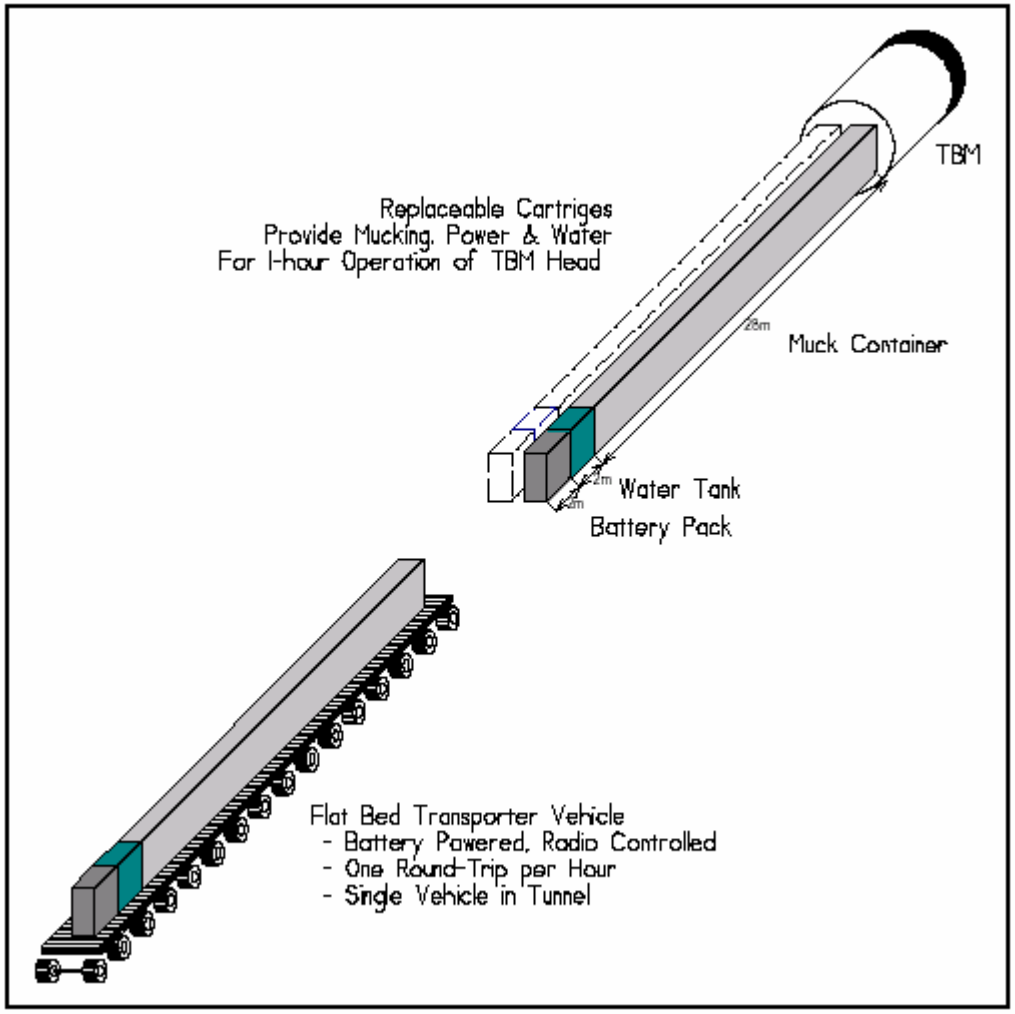


Battery Powered TBM

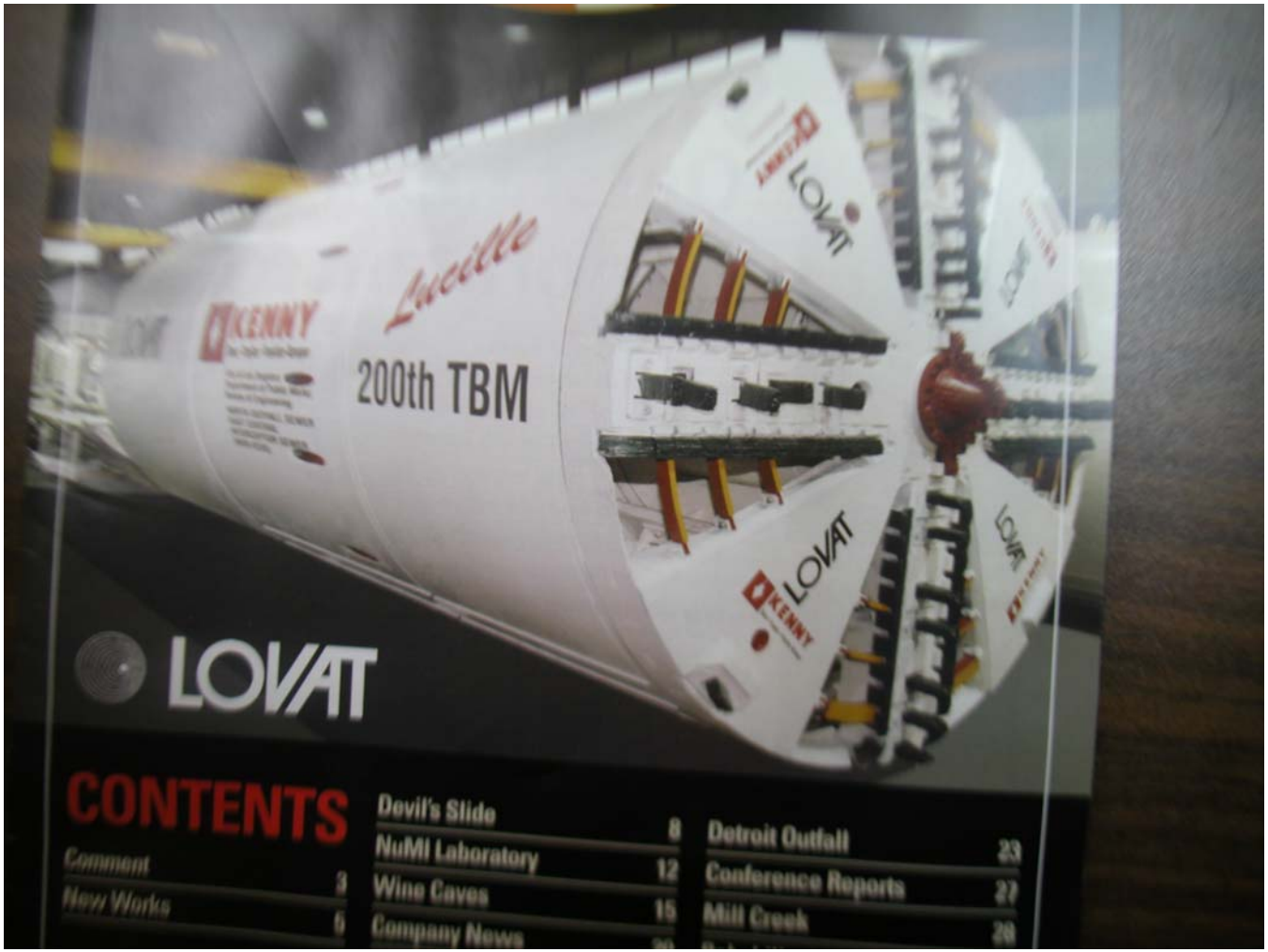




Little Bites



LOVAT TBM


KENNY
Lucille
200th TBM
LOVAT
LOVAT
LOVAT
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Detroit Outfall 23
Conference Reports 27
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Big Bites

Tunnels Have Multiple Uses

- Energy Transport
- Communication
- People
- Material

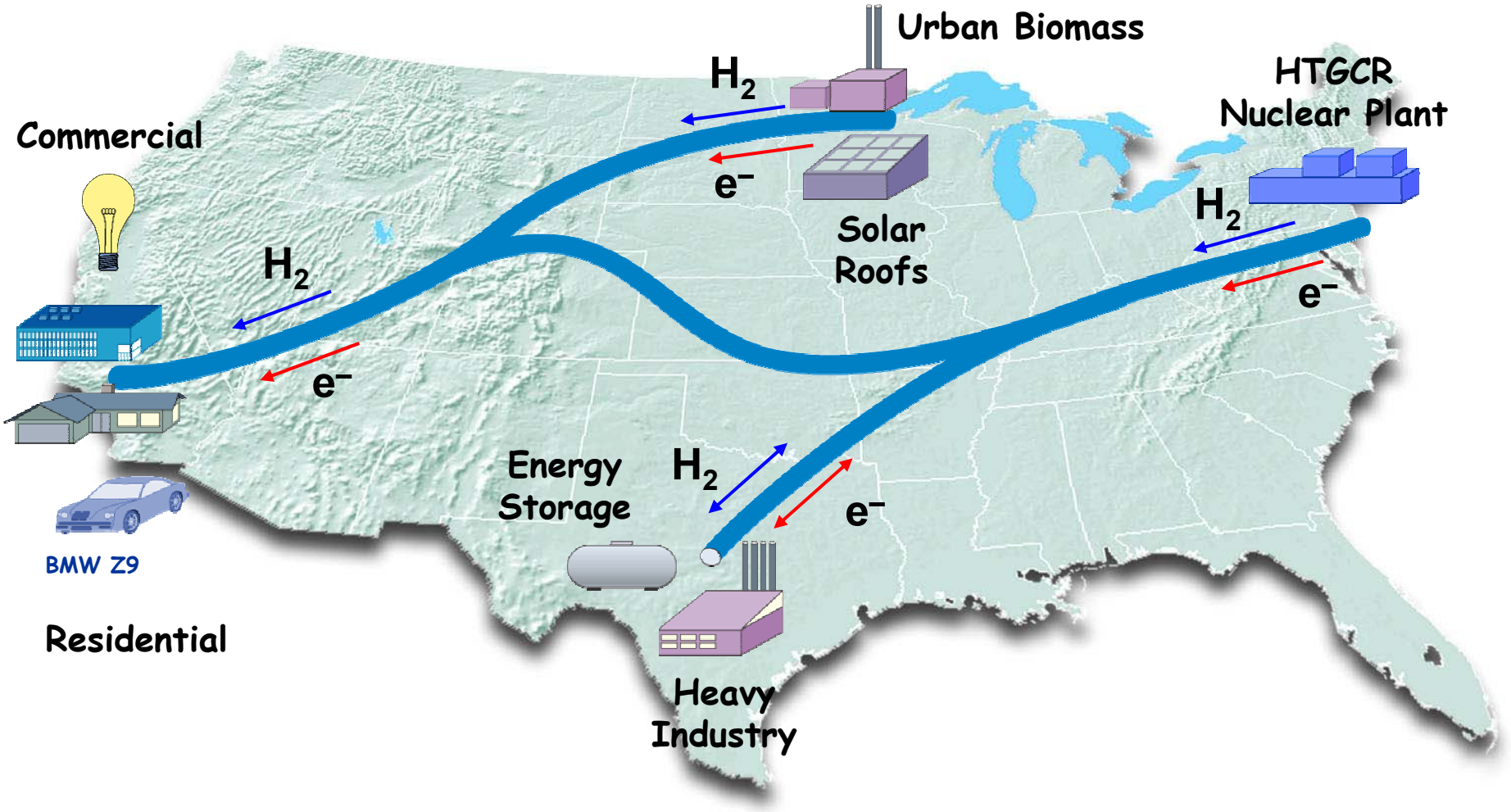
Tunnels are an enabling technology for the SuperGrid

...and, with minimal maintenance, once constructed, they're there for millenia! (unless they carry water!)

New Yorker, 9/1/03. "City of Water"

Rock Group

The US Energy SuperGrid



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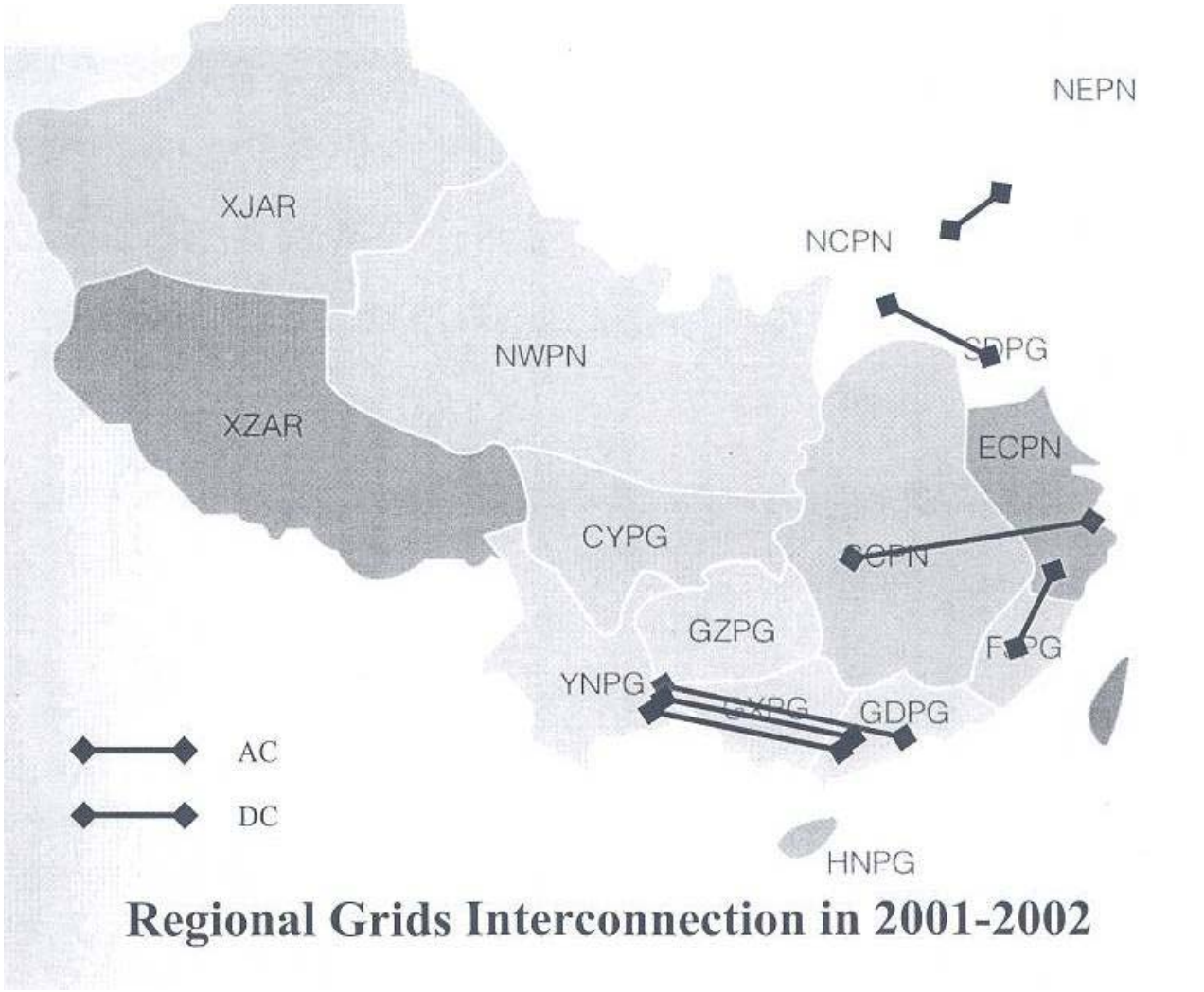
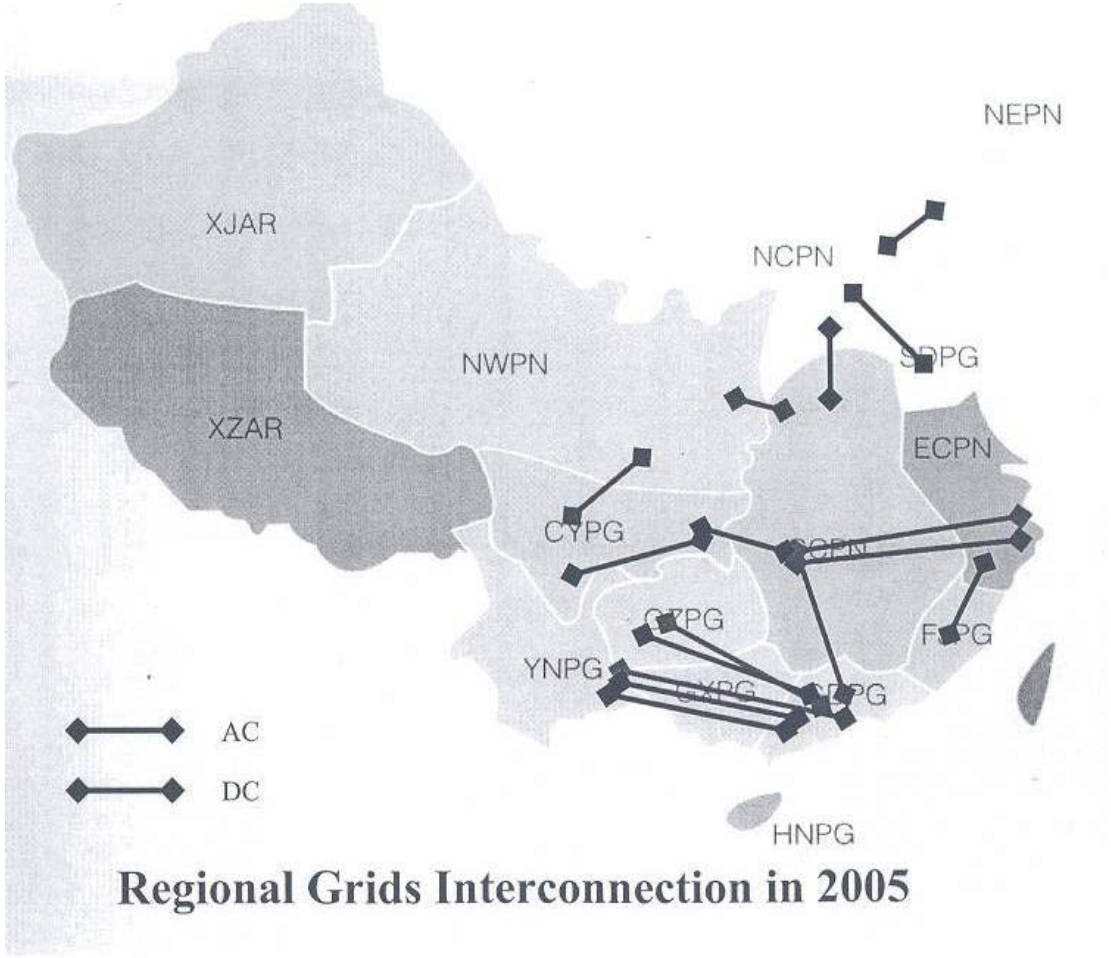
North America

China: Present



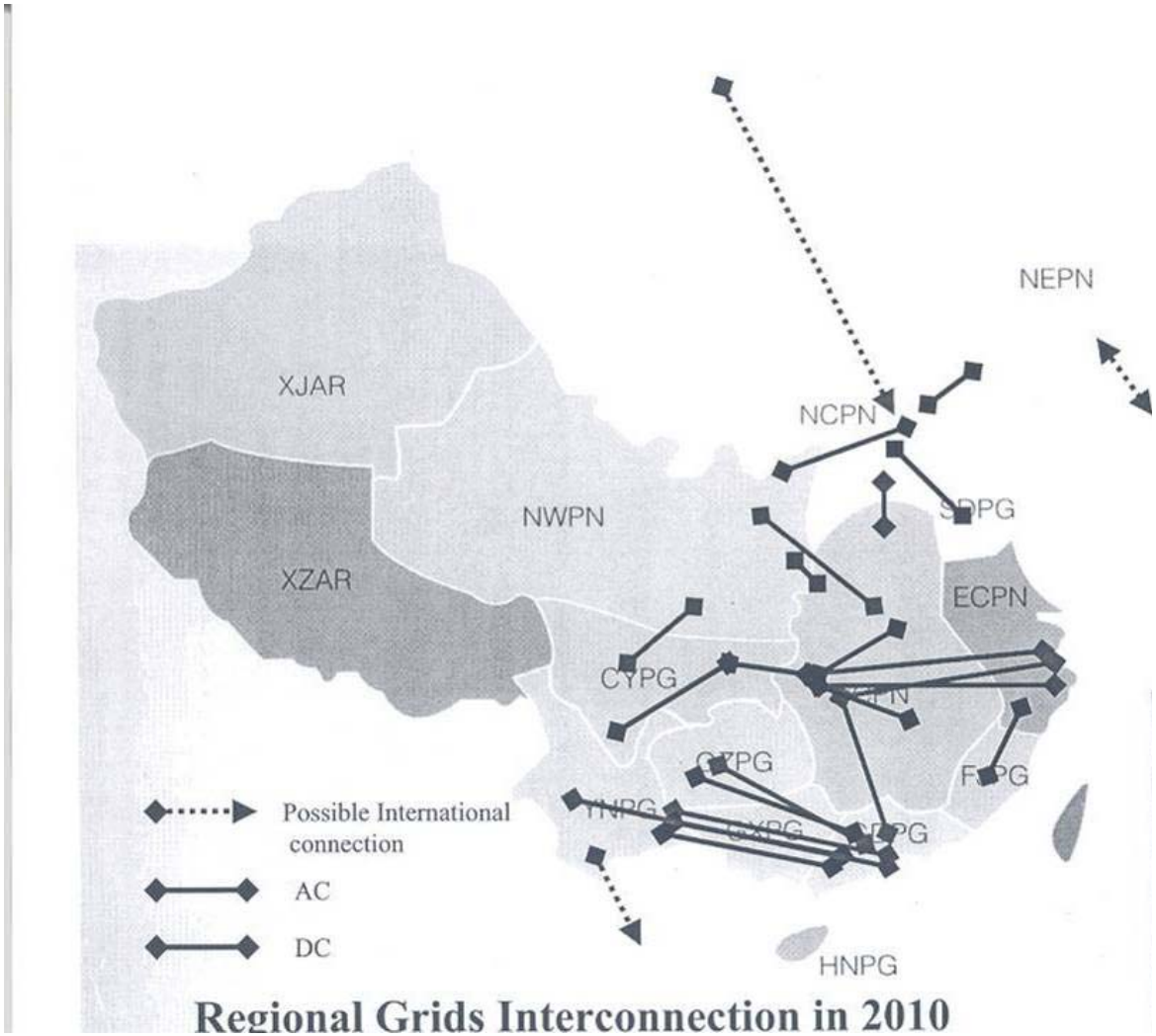
Regional Grids Interconnection in 2001-2002

China: 2005

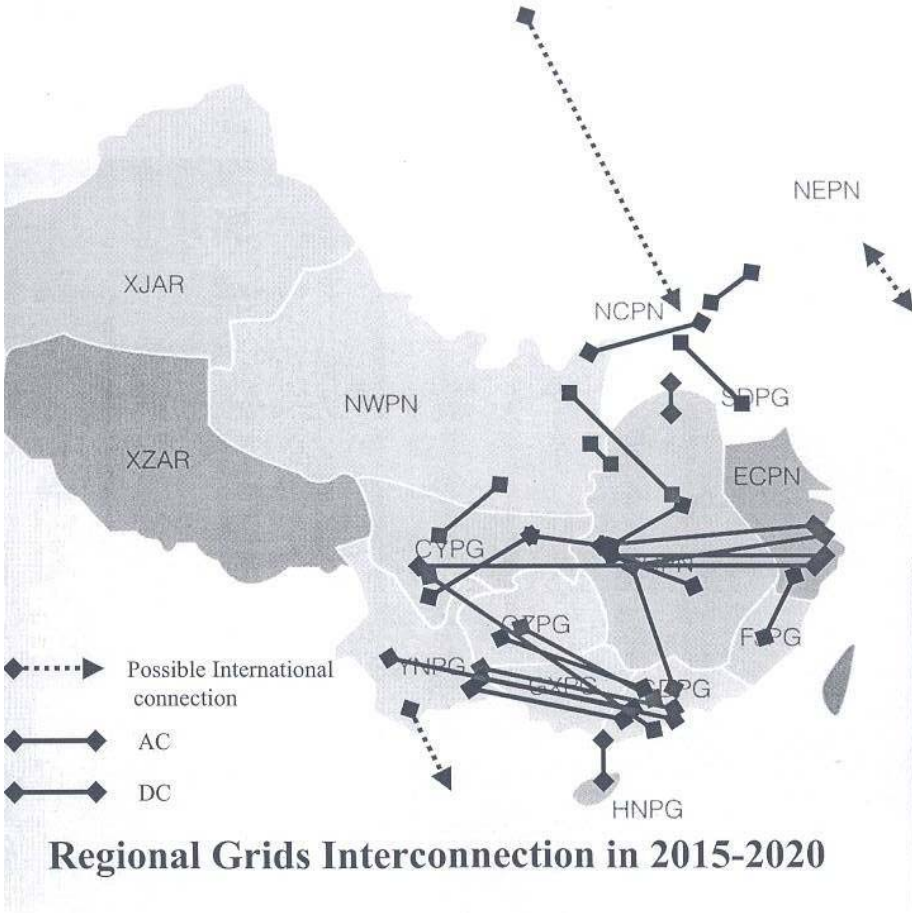


Regional Grids Interconnection in 2005

China: 2010

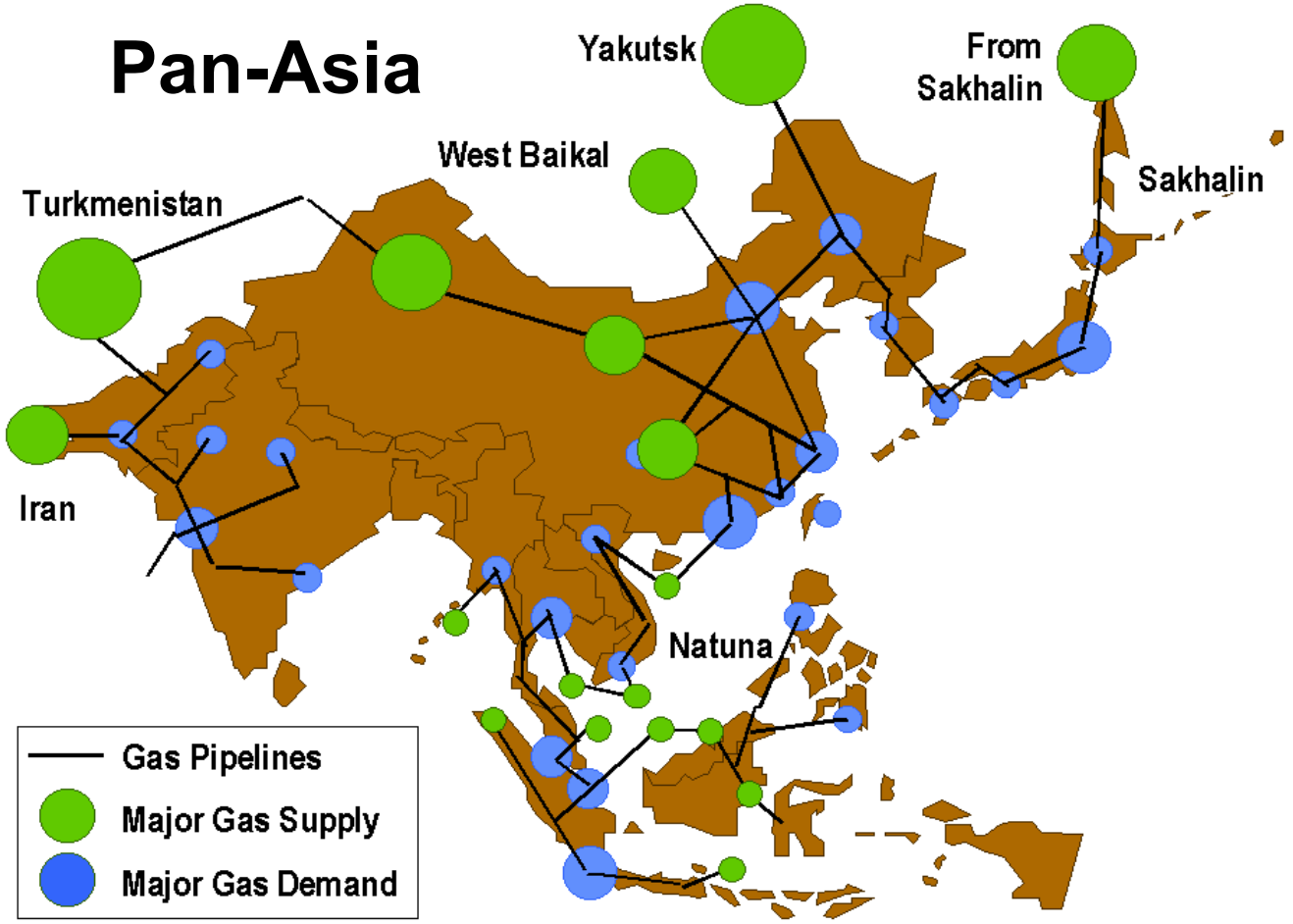

NEPN
XJAR
NCPN
NWPN
XZAR
ECPN
CYPG
HNPG
Possible International connection
AC
DC
HNPG
Regional Grids Interconnection in 2010

China: 2015 - 2020

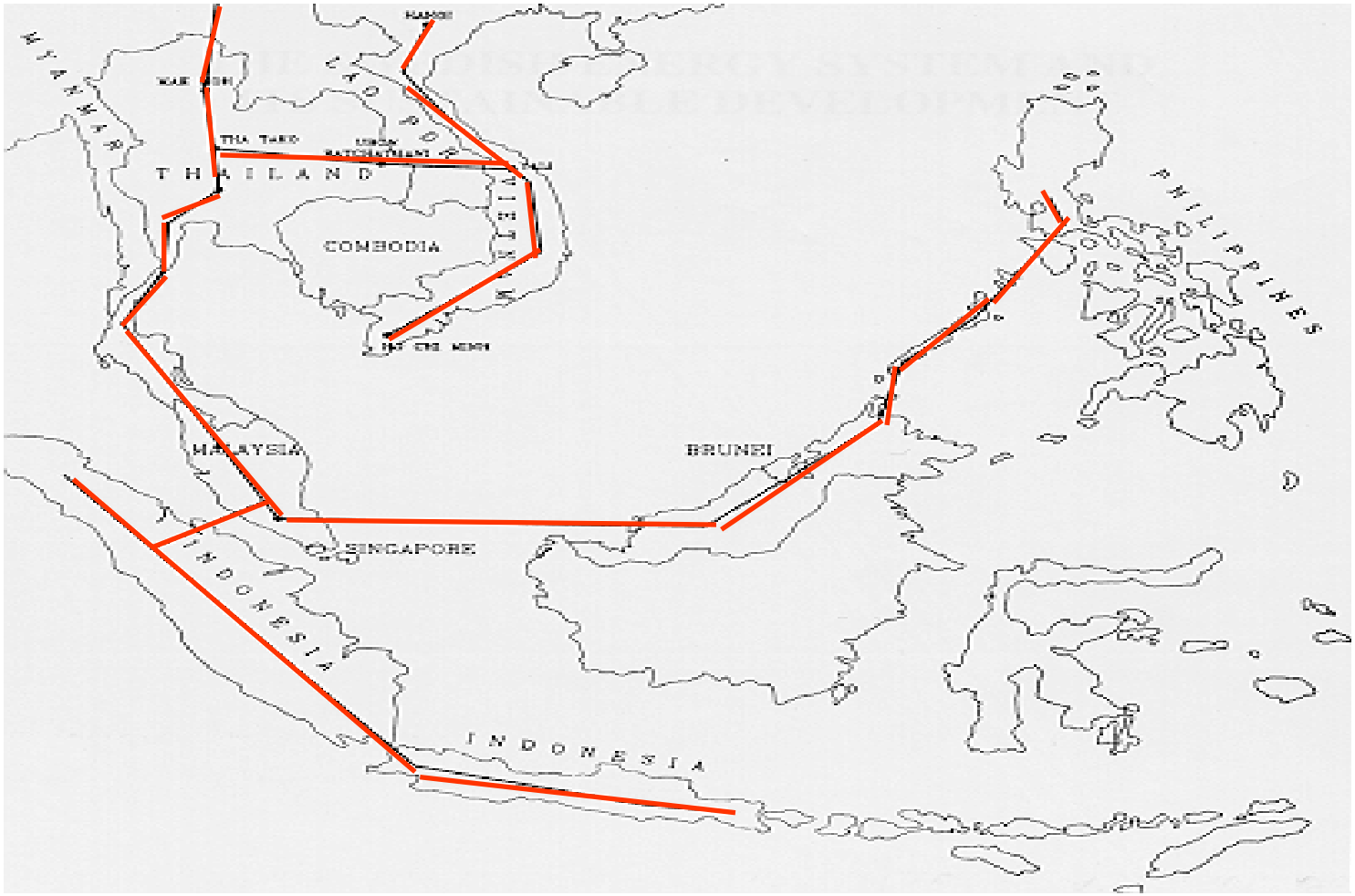


Regional Grids Interconnection in 2015-2020

"Fuel-Head" and/or Nuclear Generation



Future Power Lines: Southeast Asia



Middle East


CYPRUS
Nicosia
Latakia
SYRIA
Mosul
Karkūk
Tehrān
Qom
Mediterranean Sea
Beirut
Ḥimṣ
Damascus
LEBANON
Tigris
Bākhtarān
Arak
Baghdad
Haifa
Golan Heights
ISRAEL
IRAQ
Dezful
Esfaha
Jerusalem
Amman
Al Ḥillah
Al Kūt
Gaza Strip
Alexandria
Ahvāz
JORDAN
An Nāṣirīyah
Cairo
Ābādān
Al Baṣrah
Al 'Aqabah
KUWAIT
Kuwait
Bandar-e Būshehr
Gulf of Aqaba
Gulf of Suez
Tabūk
Ḥafar al Bāṭin
EGYPT
Ha'il
Persian Gulf
Dhahran
Manama
Luxor
Riyadh
Aswān
SAUDI
Tropic of Cancer
Medina
Yanbu' al Bahr
ARABIA
Administrative Boundary
Hala'ib

South America

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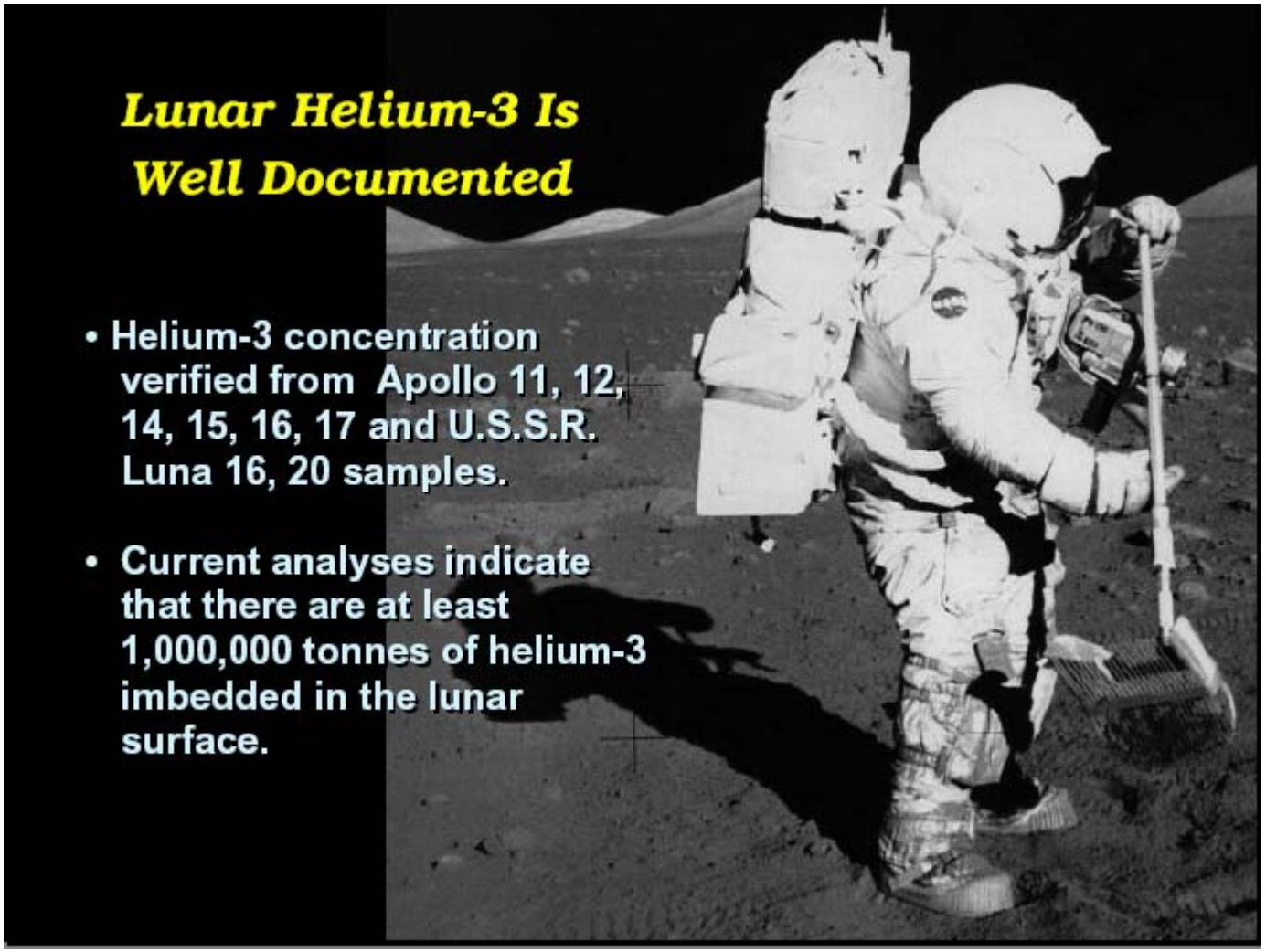
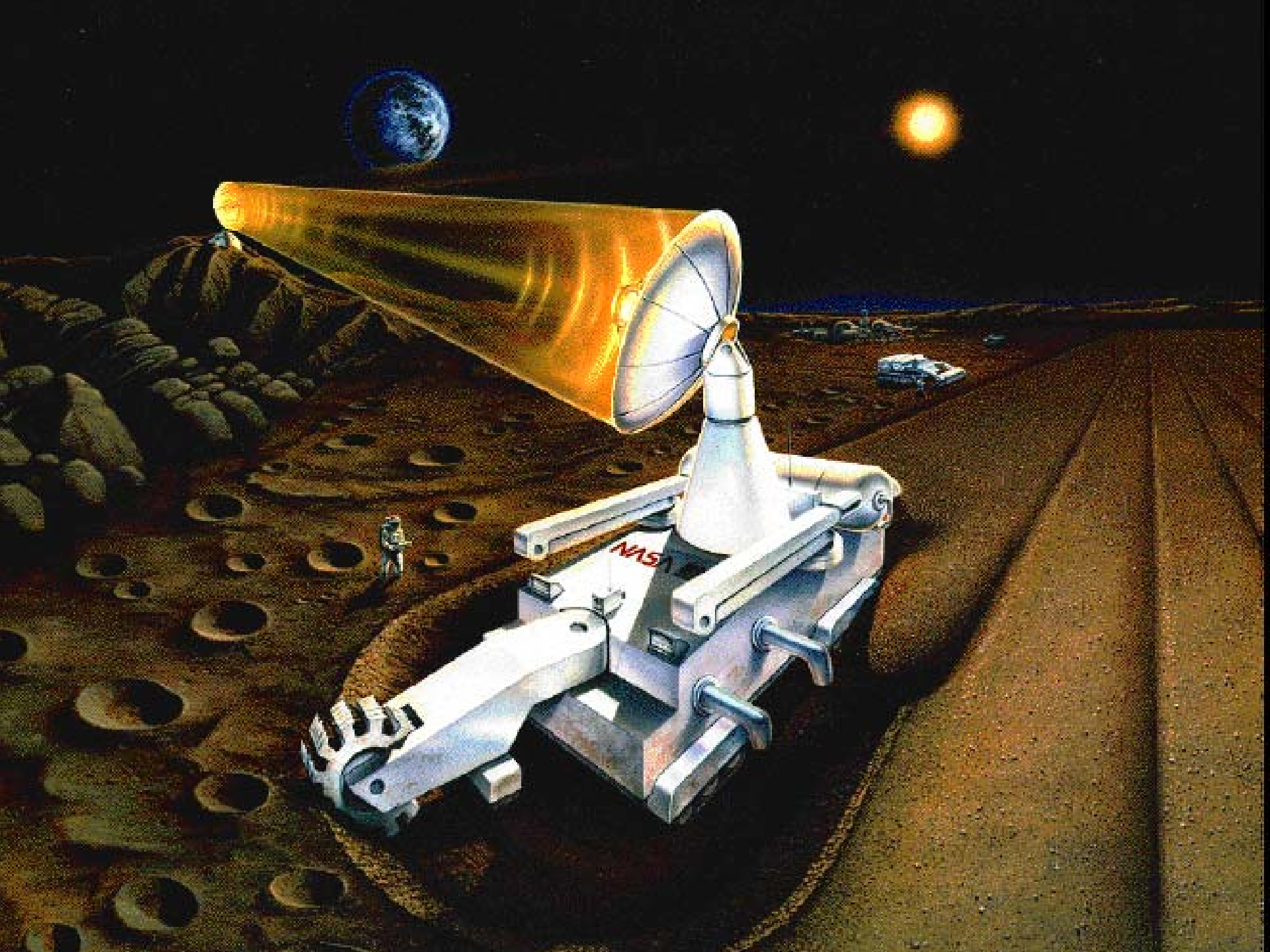
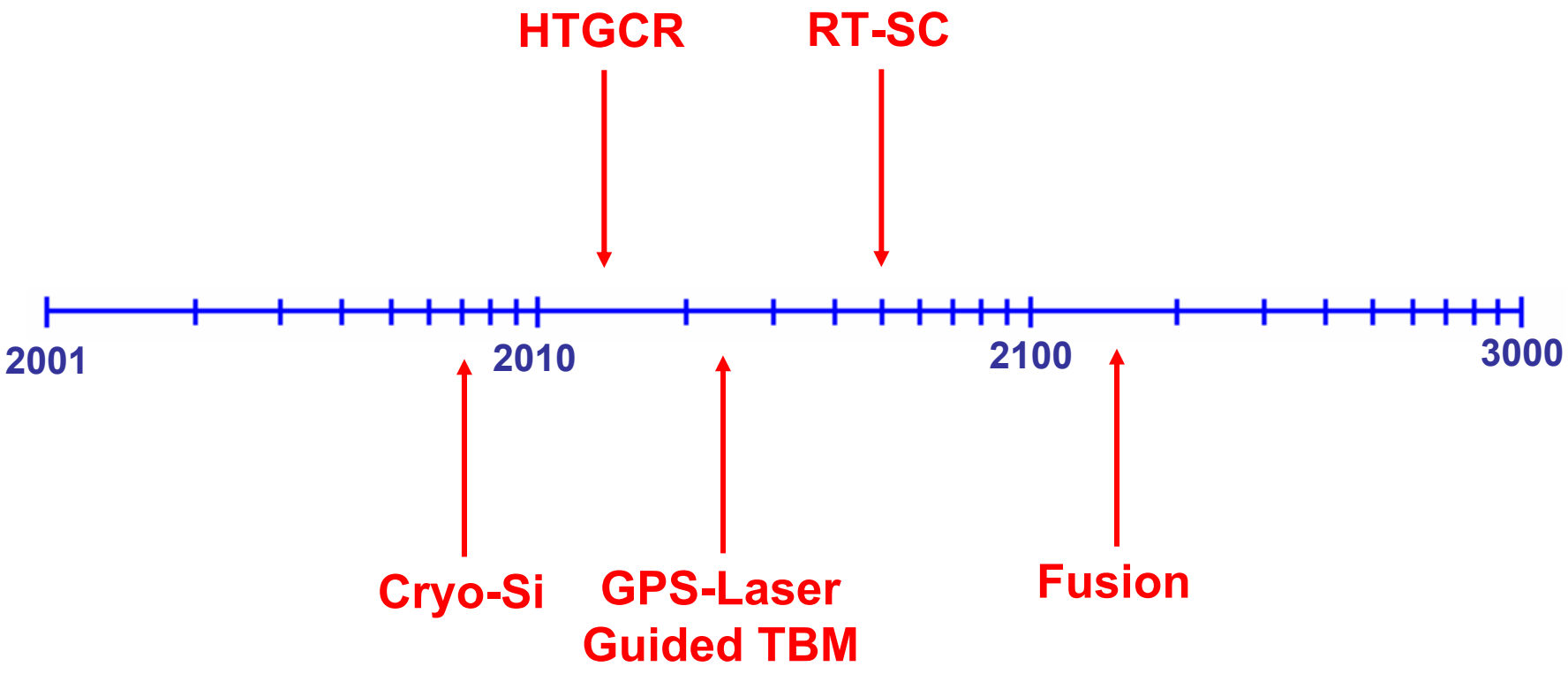
Back to the Moon

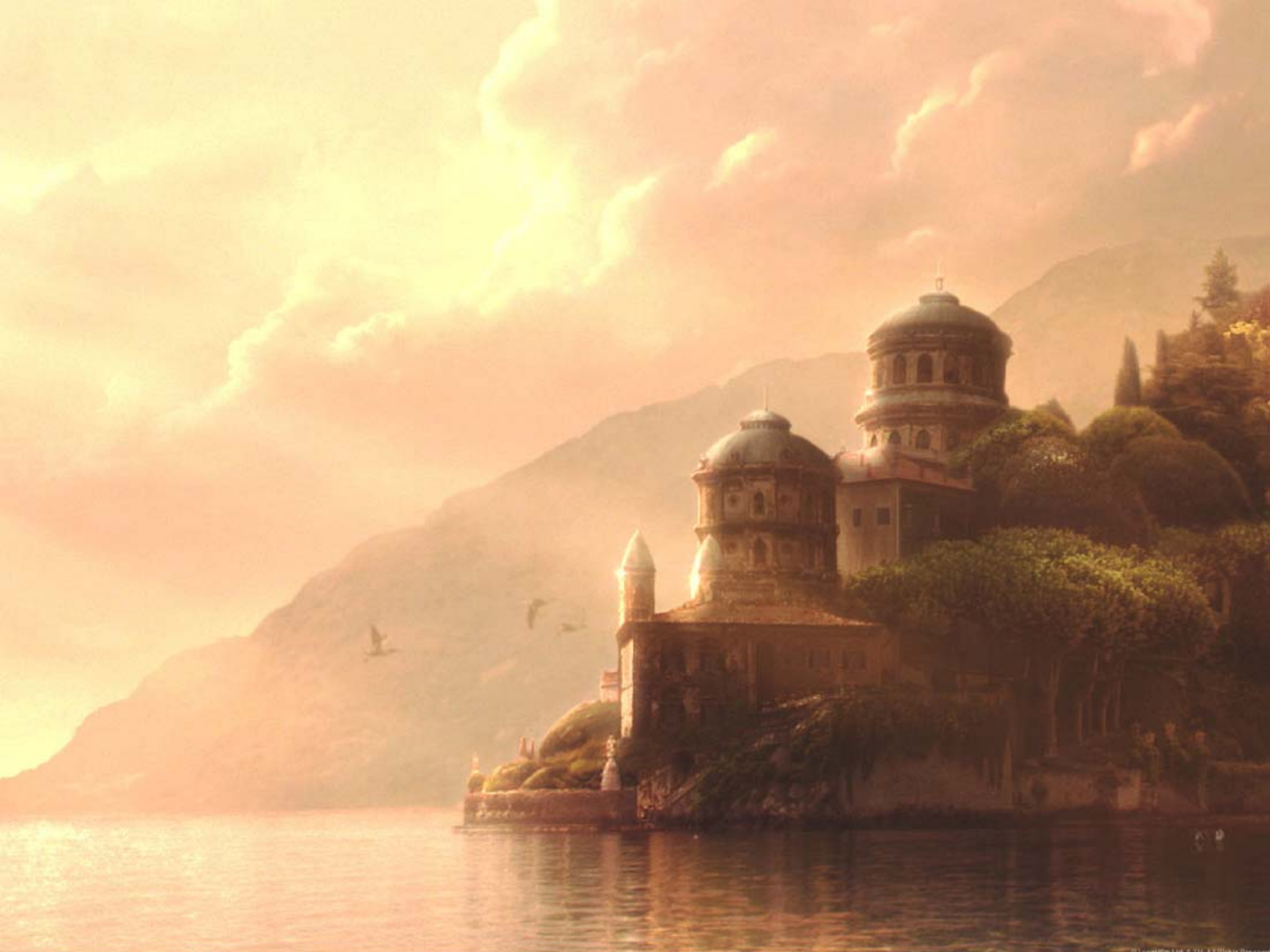


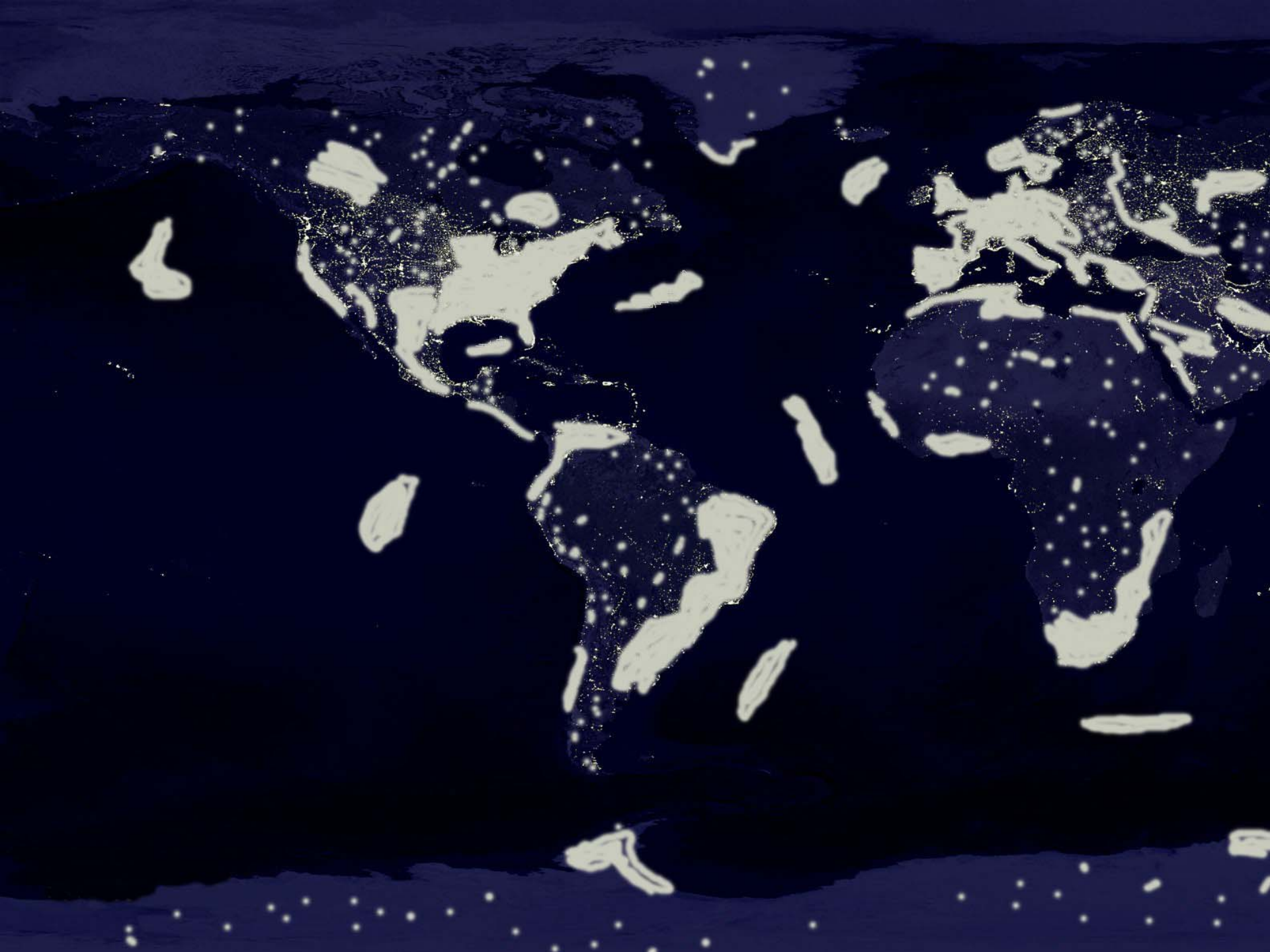

NASA

The 1000 Year Slide Rule

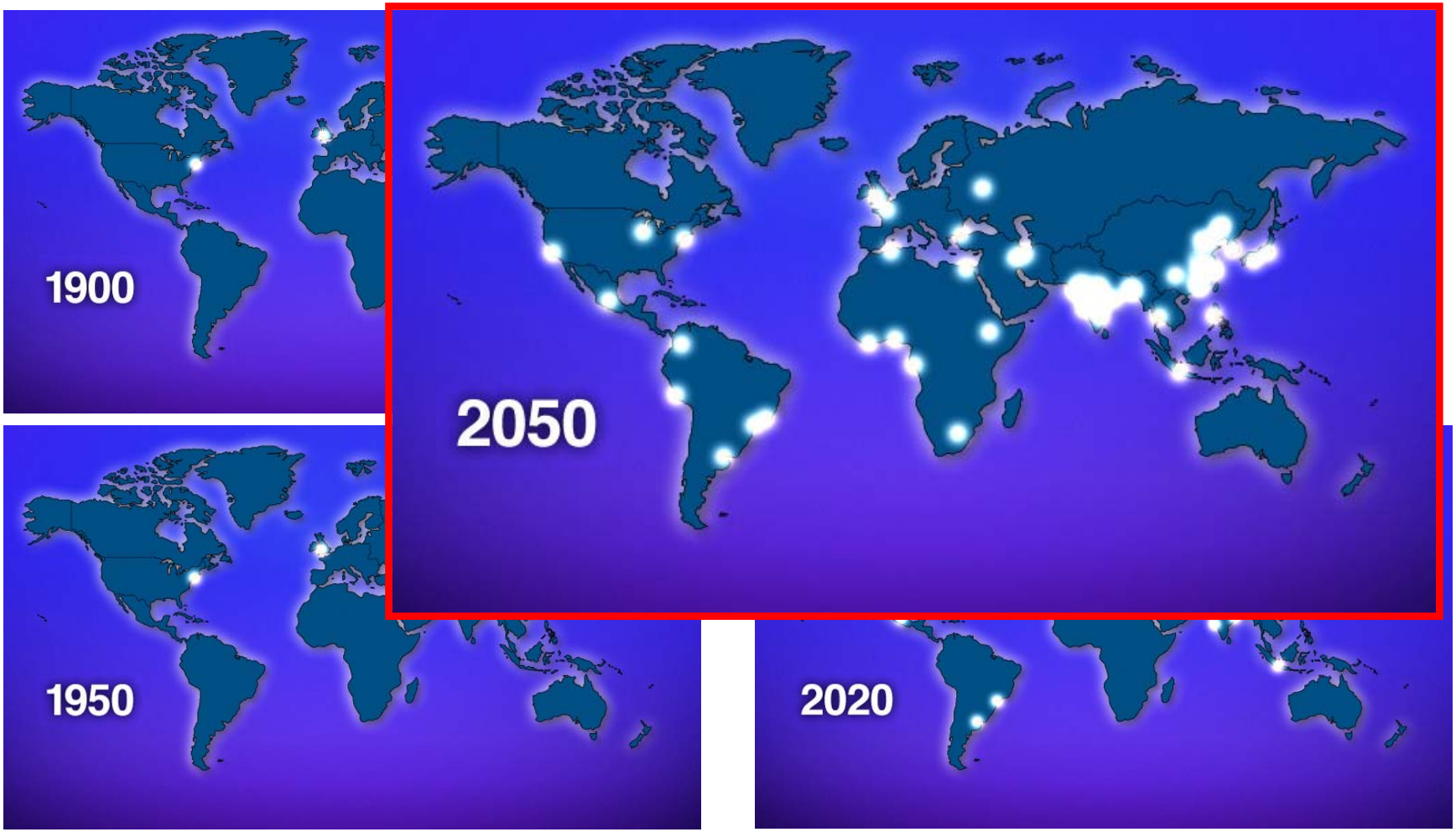



R.M. QUARRIE

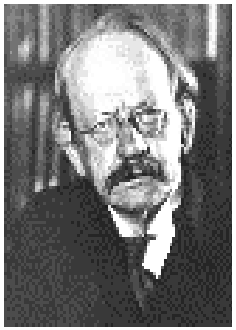


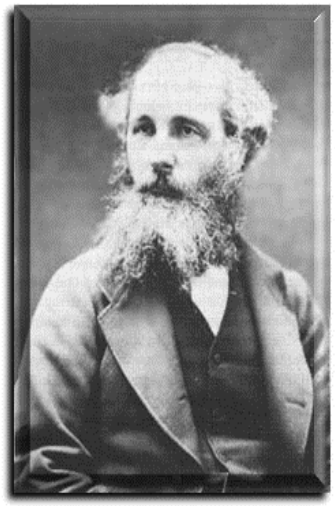


Mega-Cities



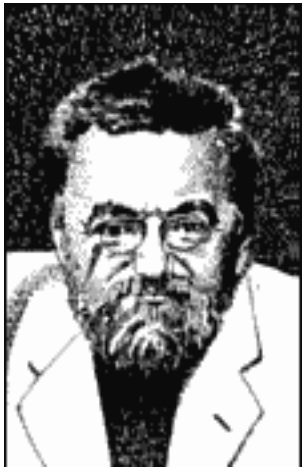
Fathers of Electricity



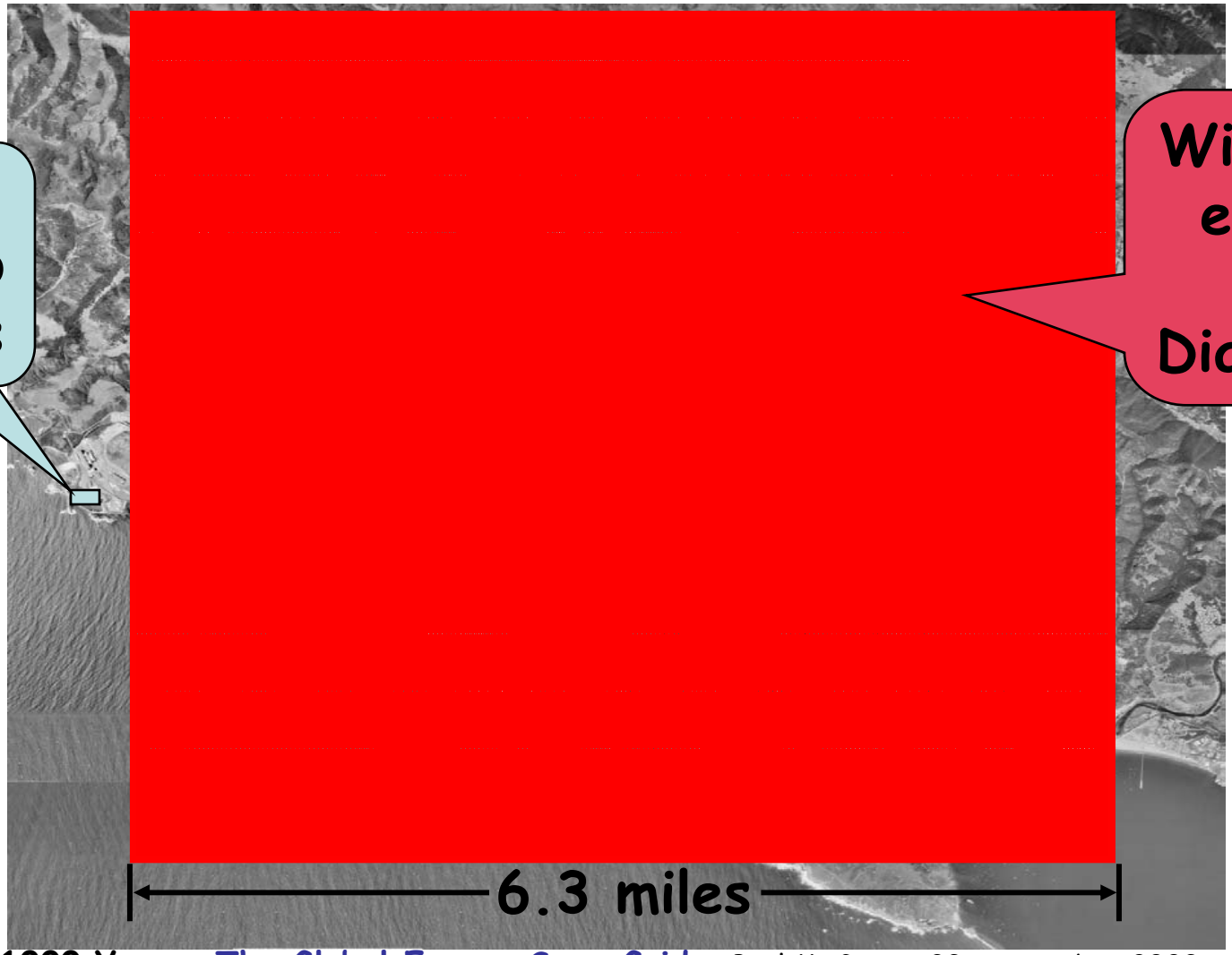


Discoverers

Practitioners



Diablo Canyon



1100
1 MW
Towers,
1000 ft
apart

EPRI

Diablo Canyon

1967: SC Cable Proposed!

538 PROCEEDINGS OF THE IEEE, VOL. 55, NO. 4, APRIL 1967

Superconducting Lines for the Transmission of Large Amounts of Electrical Power over Great Distances

R. L. GARWIN AND J. MATISOO

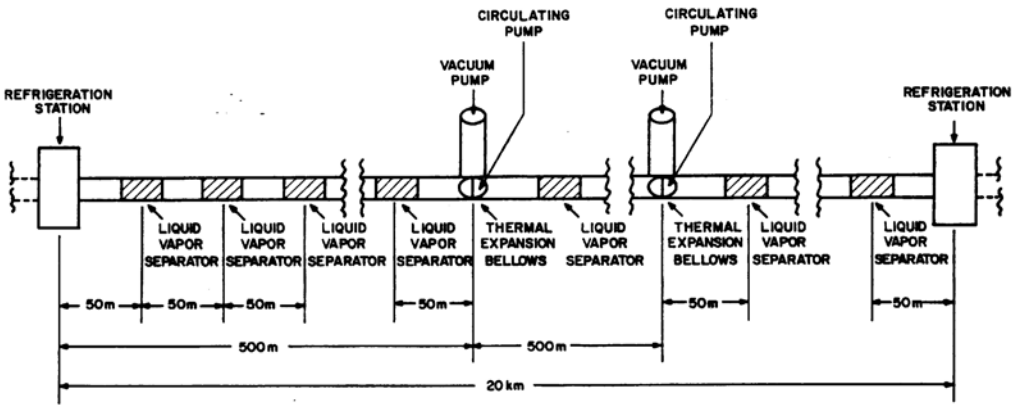


Fig. 2. A 20-km module of the 1000-km, 100-GW line.

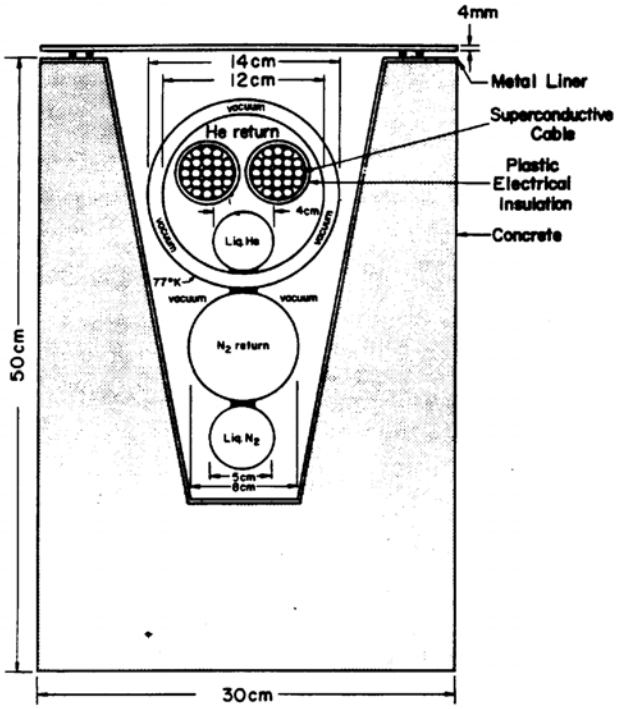


Fig. 1. Cross section of the 100-GW line.

100 GW dc, 1000 km !

Distribution

10 MW Community Substation

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dc XFMR

Reversible Fuel Cell

H_2 Storage

End Use

Streetside Service
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100 A @ +/- 25 Vdc

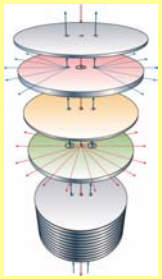
H_2 @ 200 K, 100 psi

PLC @ 5 MHz

H_2 Heat Exchanger for AC

H_2 for Heat/Hot H_2O

Household Fuel Cell



Inv/Conv for Electricity

H_2 Storage for Auto

Energy Intensity Factoids

Grant Household Power Requirements

Watts	Avg	Peak
Elect	2000	4000
Therm	4000	8000

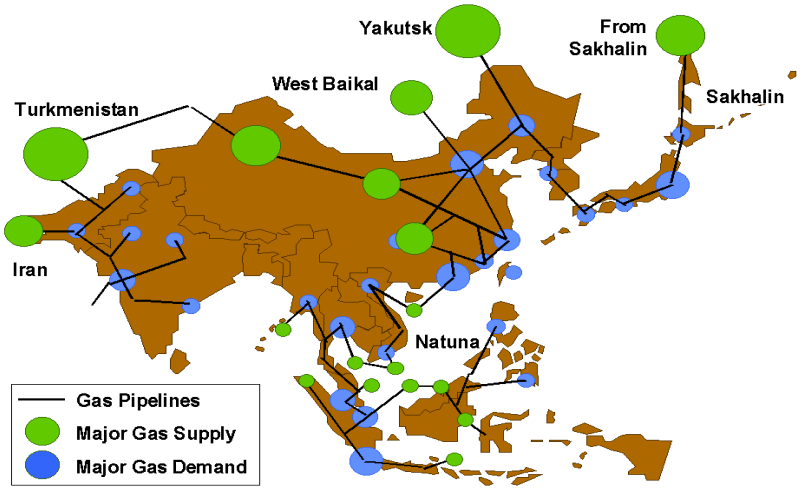
Does not include 3 automobiles!

Peak Power for 250,000 GHE's

Electrical: 1000 MW

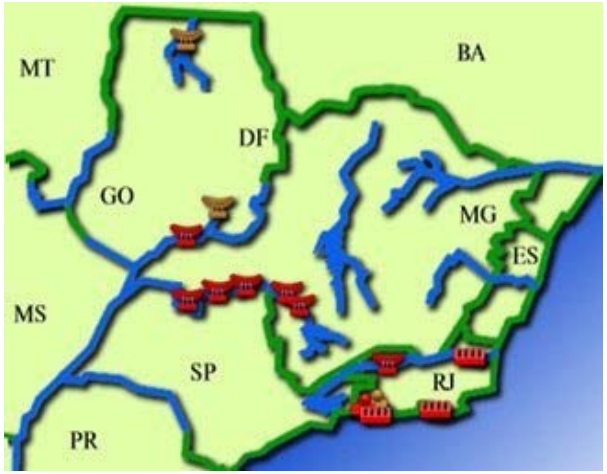
Thermal: 2000 MW

Global Electrification



EPRI

More Examples: South America



The 1000 Year Slide Rule