A Power Grid for the Hydrogen Economy: A Continental Energy SuperGrid

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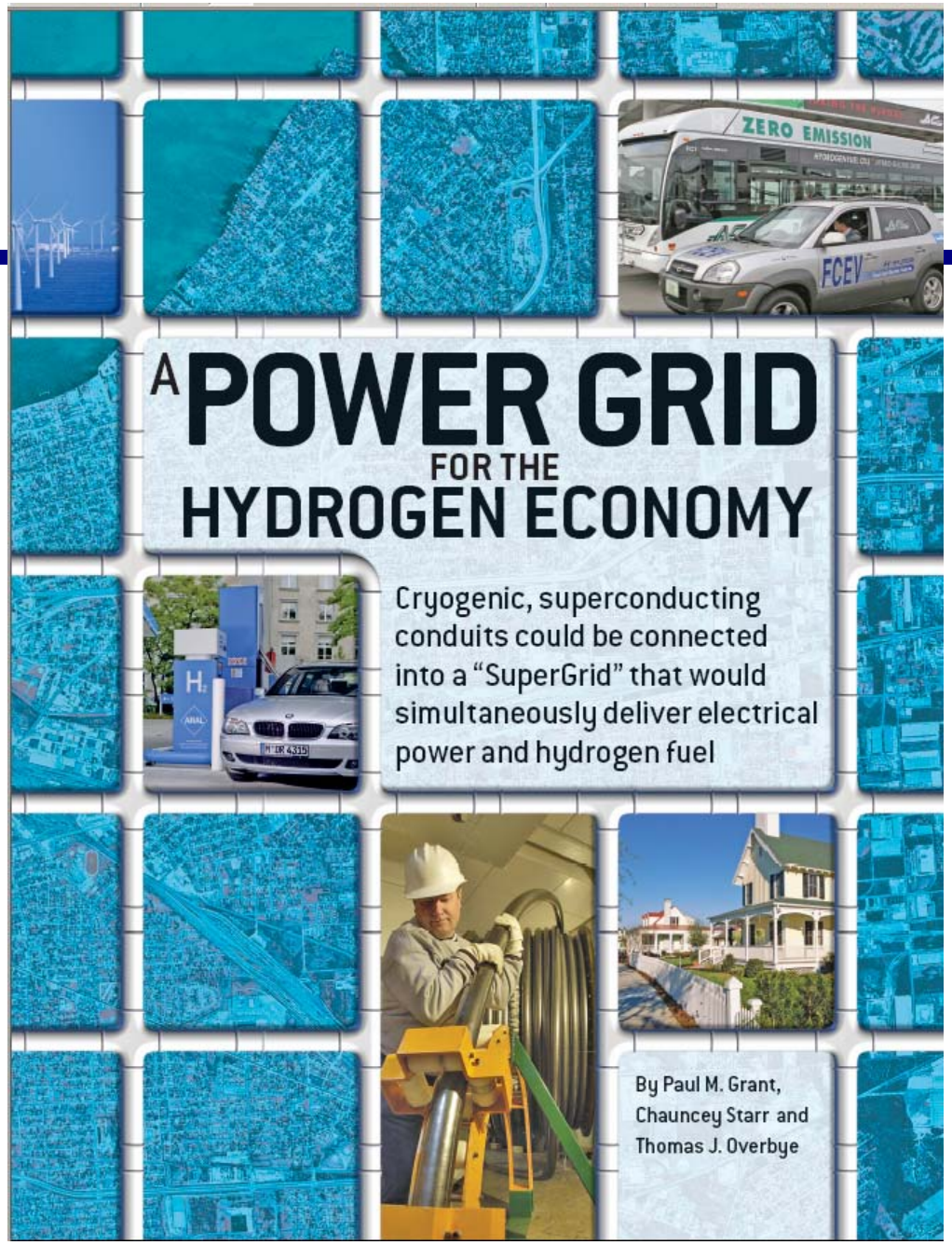
Presentation is based in part on an article from the July 2006 issue of *Scientific American*



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SuperGrid Overview

- Continental Energy SuperGrid (SuperGrid) is a visionary concept proposed by Chauncey Starr, founder and emeritus president of EPRI, in 2001 to meet our long-term energy needs (> 2025)
- UIUC has sponsored workshops in Nov 2002 (SG1) and Oct 2004 (SG2) to consider the concept

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SuperGrid Overview

- Main idea is to use a network of underground, DC superconductors to augment the existing electric grid to transfer large amounts of energy from remote, sustainable resources
  - energy flow of electricity and hydrogen
  - Electricity or hydrogen could replace gas for transportation
- SG1 concluded idea was technically feasible, SG2 developed research plan

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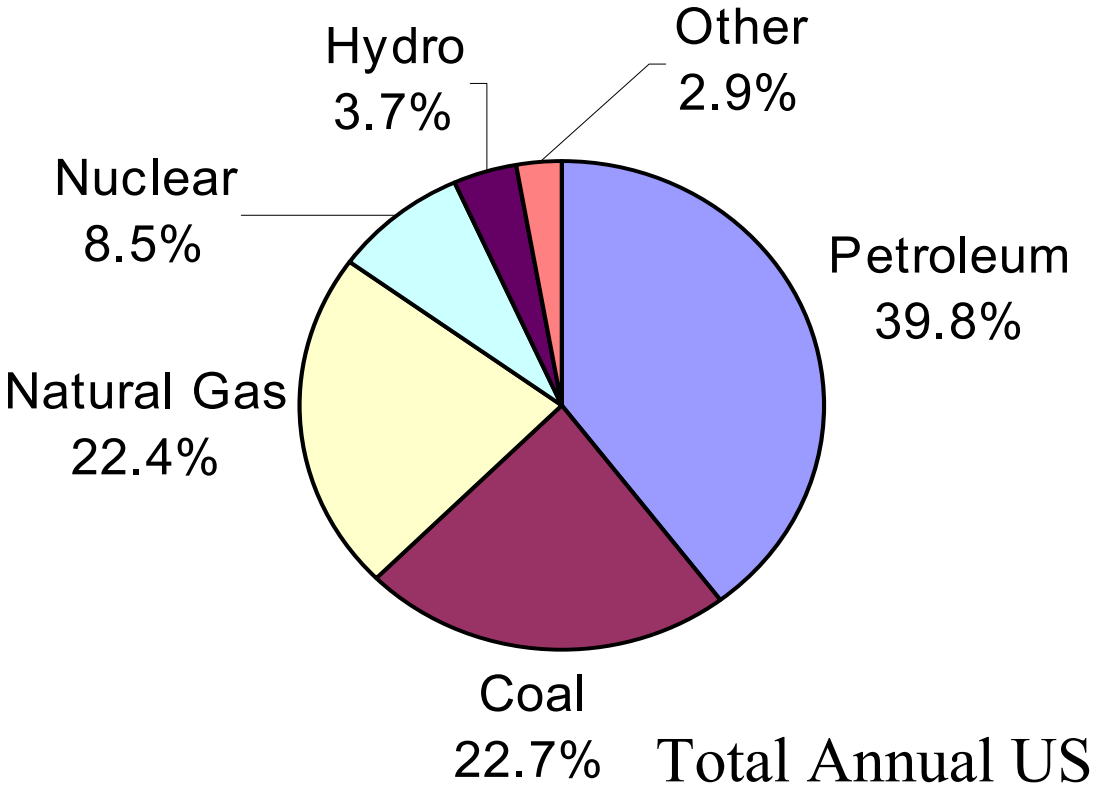
Understanding the Need: U.S. Current Energy Usage by Source



Total for 2004 is 100 Quad (Quadrillion Btu), of which 39 Quad was consumed as electricity and 27 Quad for transportation

Total Annual US Energy for 2004: $870 Billion, with the 2005 value at about $1 Trillion

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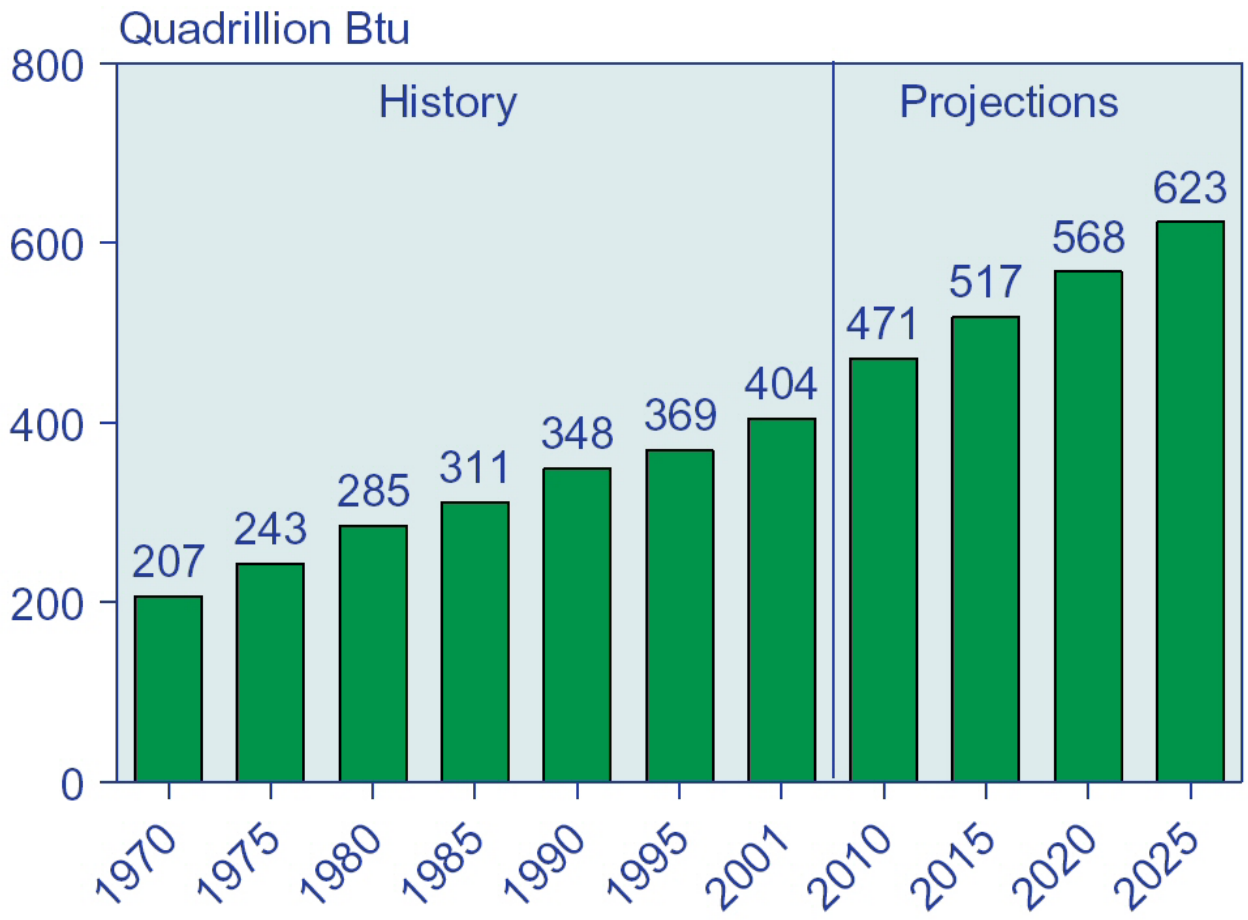
Worldwide Energy Usage – Historical and Projected (EIA)



Total energy consumption could double or even triple in 30 to 50 years.

US will be about 127 Quad by 2025.

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The Need for Change in Our Energy Infrastructure

- Global oil production is probably going to peak in the not too distant future, perhaps in 2020-2025
  - after the peak consumption will fall off quite quickly, with a corresponding rise in prices
- Production of natural gas is expected to peak shortly thereafter
- SuperGrid addresses issue of how to replace this energy, and need for an enhanced energy infrastructure

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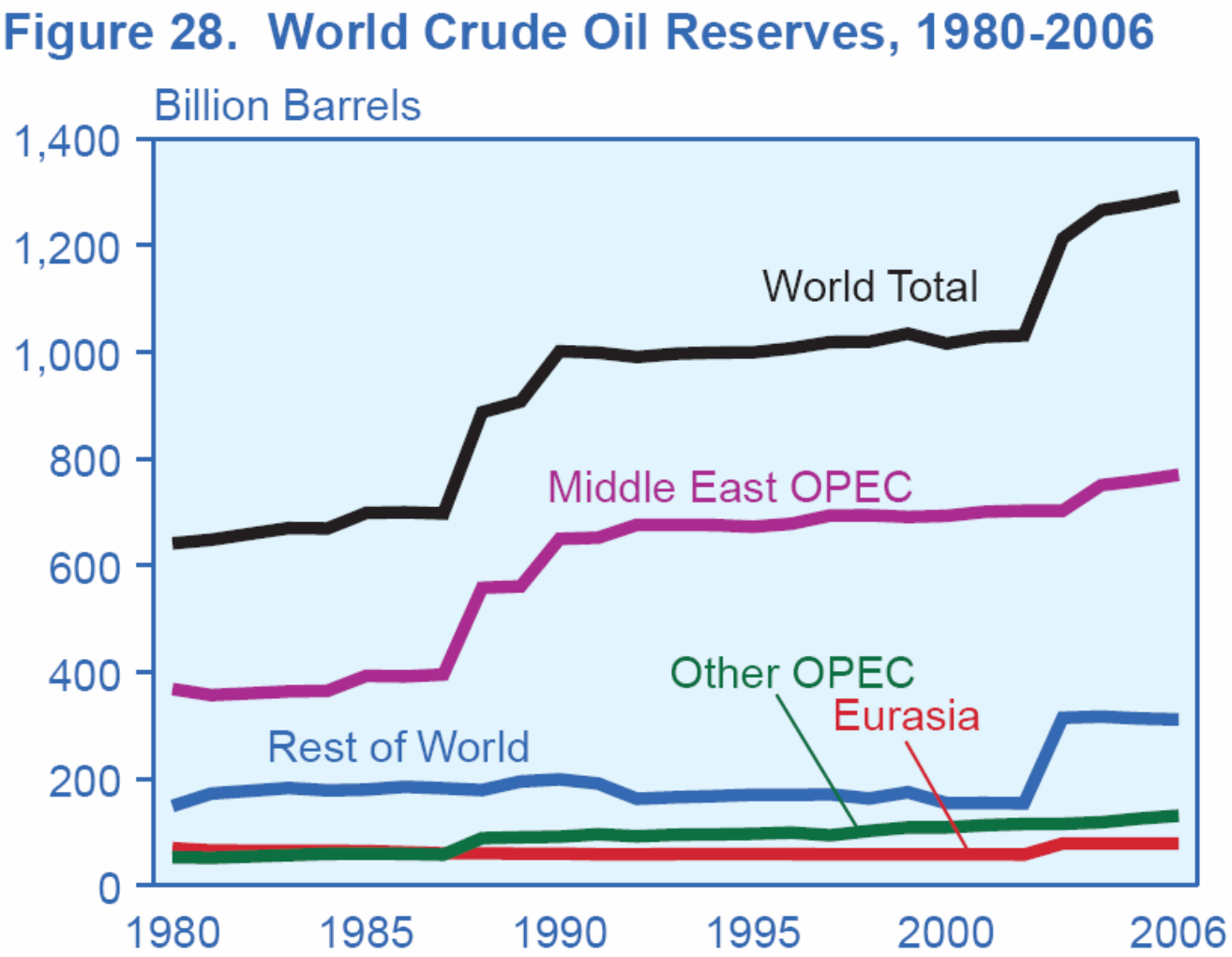
Worldwide Crude Oil Reserves Have Increased



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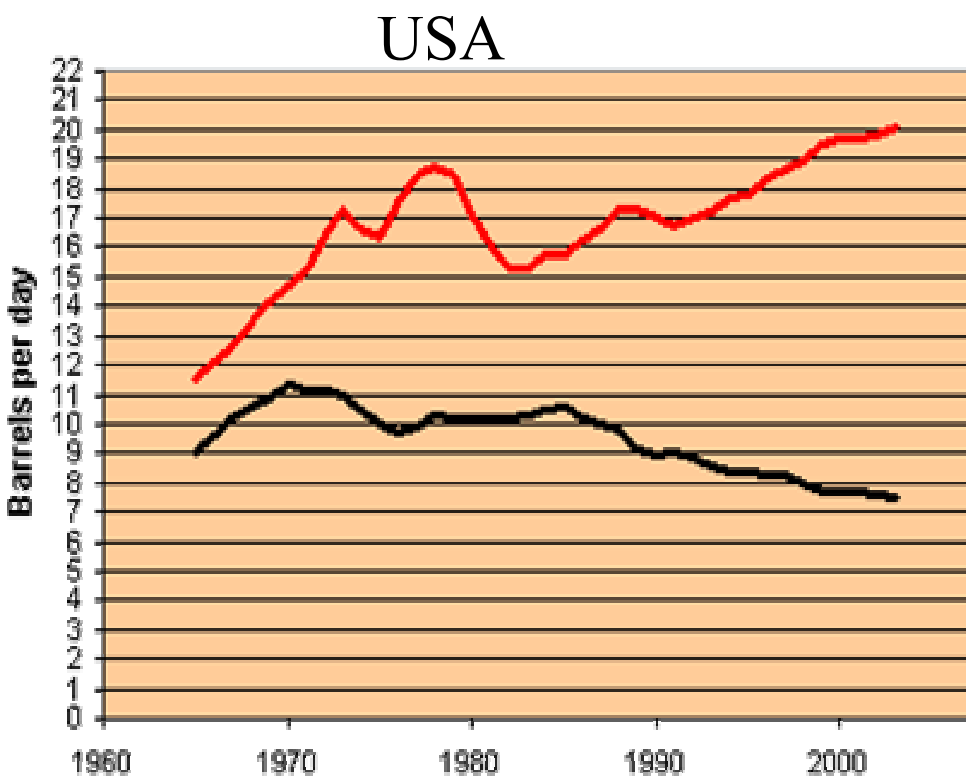
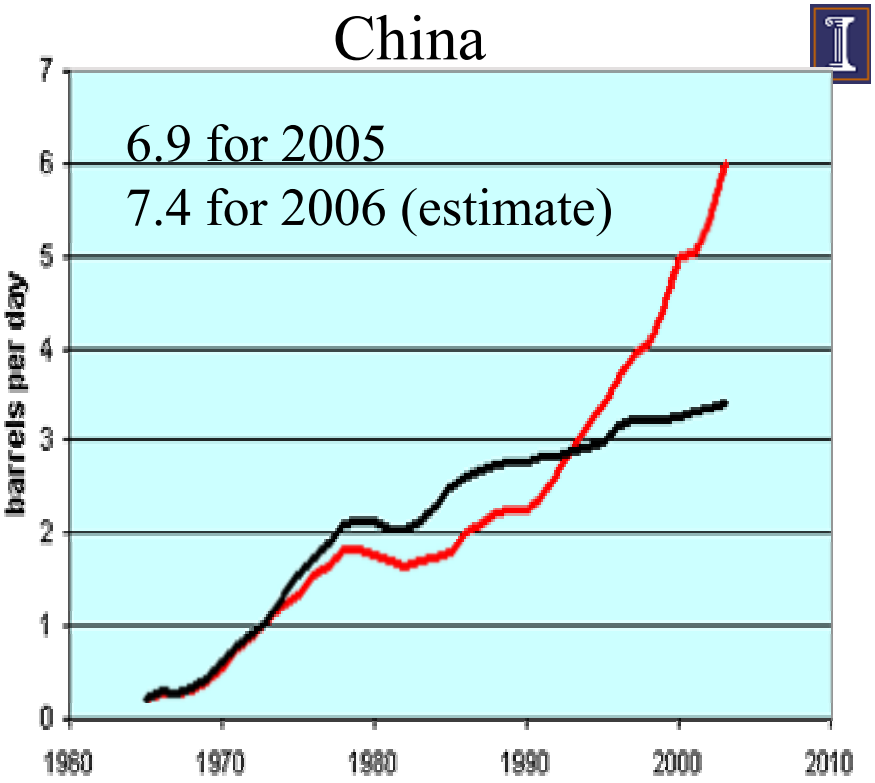
But so has Petroleum Demand (units are millions of barrels per day)





Red is consumption, black is production; Worldwide demand is 83.8 in 2005 (30.6 billion barrels per year), up from 78.0 in 2002.

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How Will We Get Even 27 Quad of New Energy?

- We have limited choices for replacing our existing petroleum/natural gas fuel source
  - Hydro: 2.7 quad, same as 1971, no growth
  - Solar: 0.06 quad, same as 1990, expensive
  - Wind: 0.14 quad, growing at 25%/year, needs lots of land
  - Ethanol: 0.3 quad max by 2015 (7.5 billion gallons – not enough land for corn)
  - Geothermal: 0.3 quad, same as 1990, few locations

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Sources for Additional Energy

- Coal – Lots of energy available, but with high carbon emissions
- Nuclear – Lots of energy available, but waste disposal is an issue
- EIA says by 2025 we'll get 8 more quads from petroleum, 4 from natural gas, 8 from coal.
- Hydrogen and electricity are not primary energy sources

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Transitioning Energy Usage to Reduce Fossil Fuel Consumption

- Pluggable hybrid electric cars (PHEVs), and perhaps eventually hydrogen fueled vehicles could make a major dent in transportation
  - Ethanol and other bio fuels can also play role
- Geothermal heat pumps, and also hydrogen could do the same for heating
- Percent of total energy consumed as electricity has increased from 20% in 1965 to 40% in 2005, with percentage continuing to rise

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Energy Transportation

- The new sources of energy will tend to be remote from where the energy is consumed
  - Primarily nuclear and wind with some new coal generation
- A major challenge to changing energy sources is transforming the energy infrastructure to deliver the energy from more distant sources to the urban load centers

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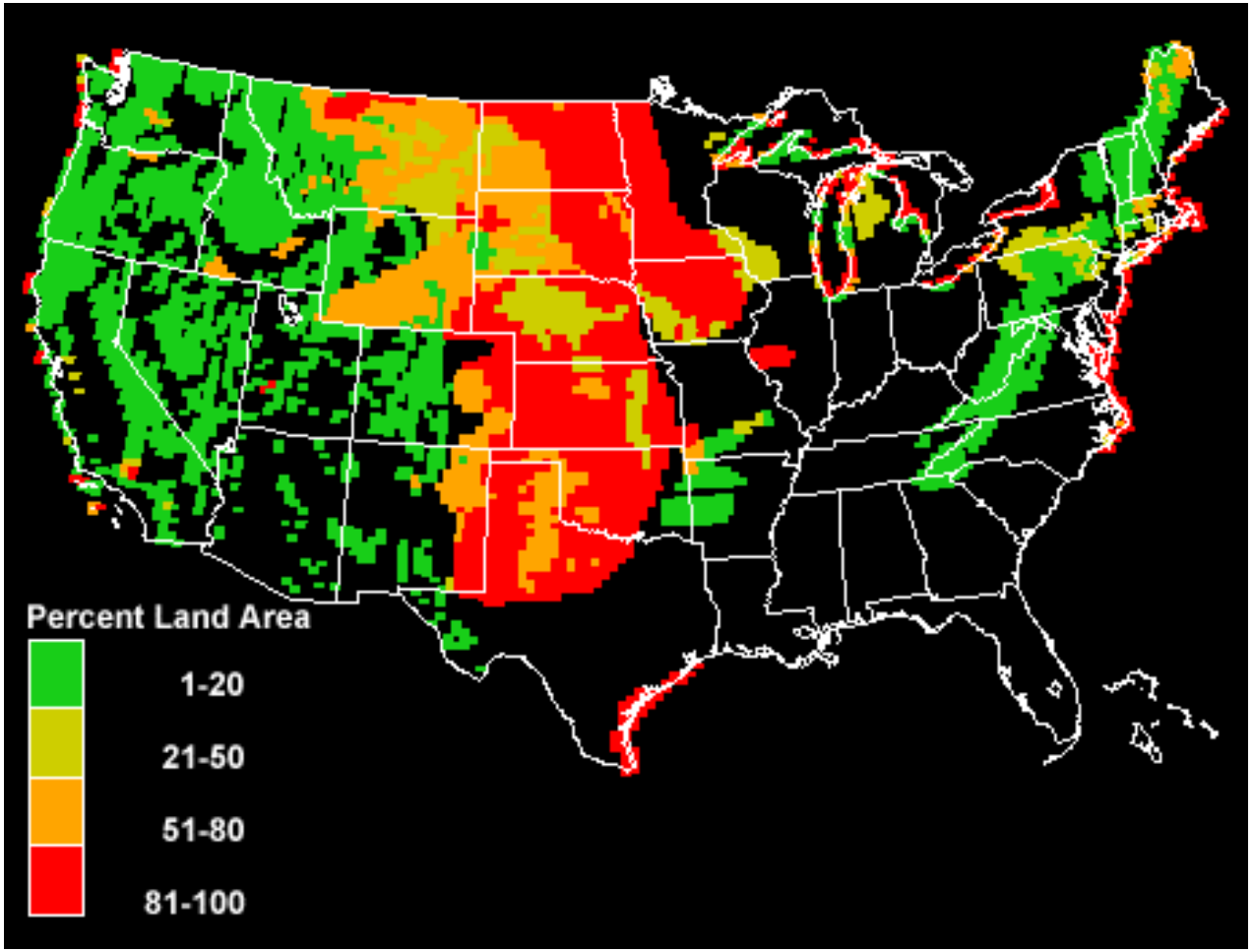
Potential Wind Resources are Not Located by Major Load Areas



Wind power density is on the order of 10 MW per square mile

Replacing one 1000 MW nuclear plant requires 200 square miles of turbines!

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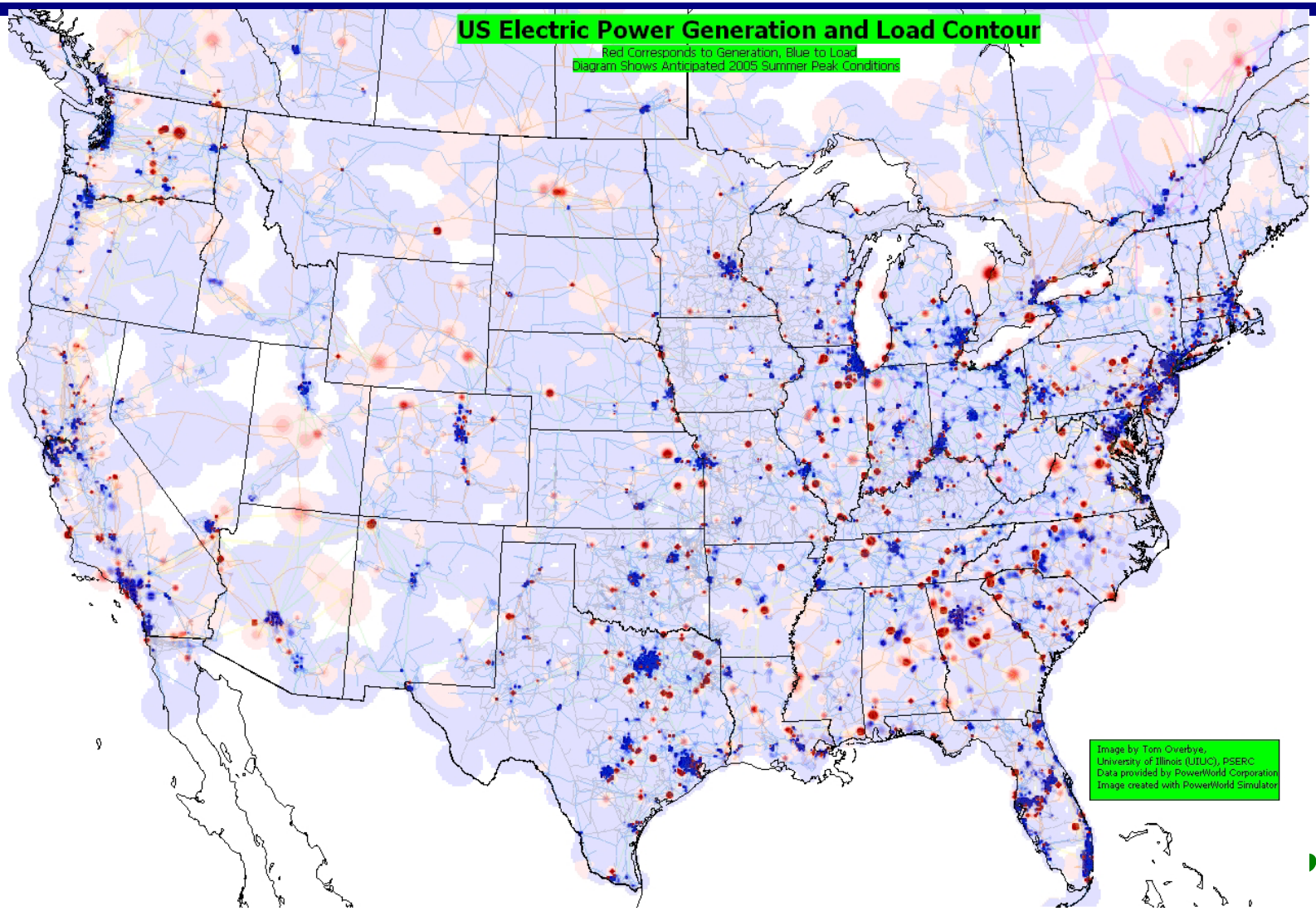
Existing Power Grid is Not Designed for Much Long Distance Power Transfer



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The Existing U.S. Transmission Grid is Often Heavily Loaded

- North American transmission grid is one of the largest and most complex man-made objects ever created
- But the existing grid is becoming increasingly constrained
  - not designed for bulk, inter-regional power transfers
  - building new, high voltage transmission lines is VERY difficult particularly when new right-of-ways are needed

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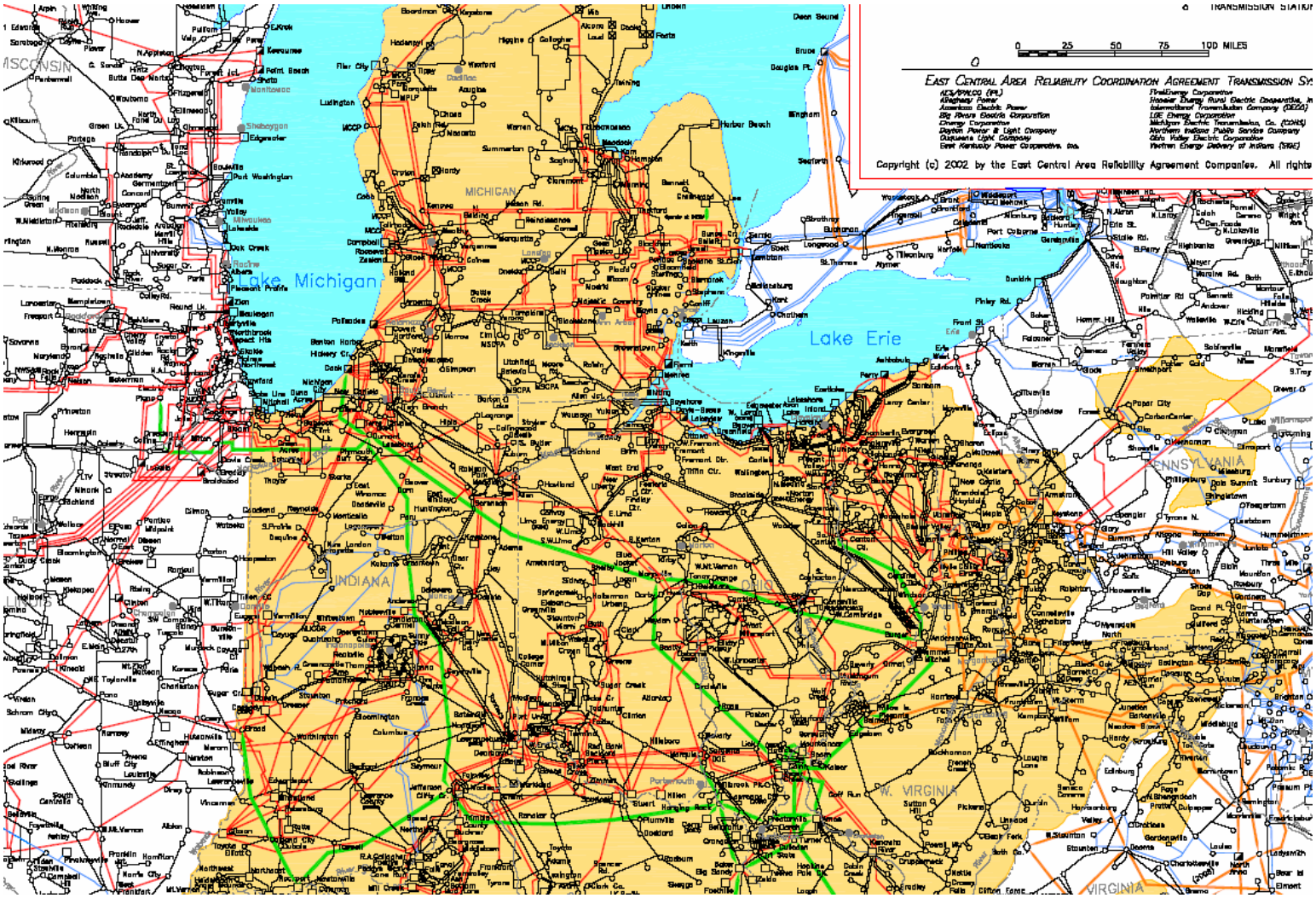
High Voltage Transmission Grid



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National Energy Supergrid

- National Energy Supergrid is an idea developed in 2001 by Chauncey Starr to supplement the existing electric grid using underground superconducting dc electric cables
  - one promising material is magnesium diboride (MgB_2), which is superconducting at 39K
  - superconducting material allows for very high power densities

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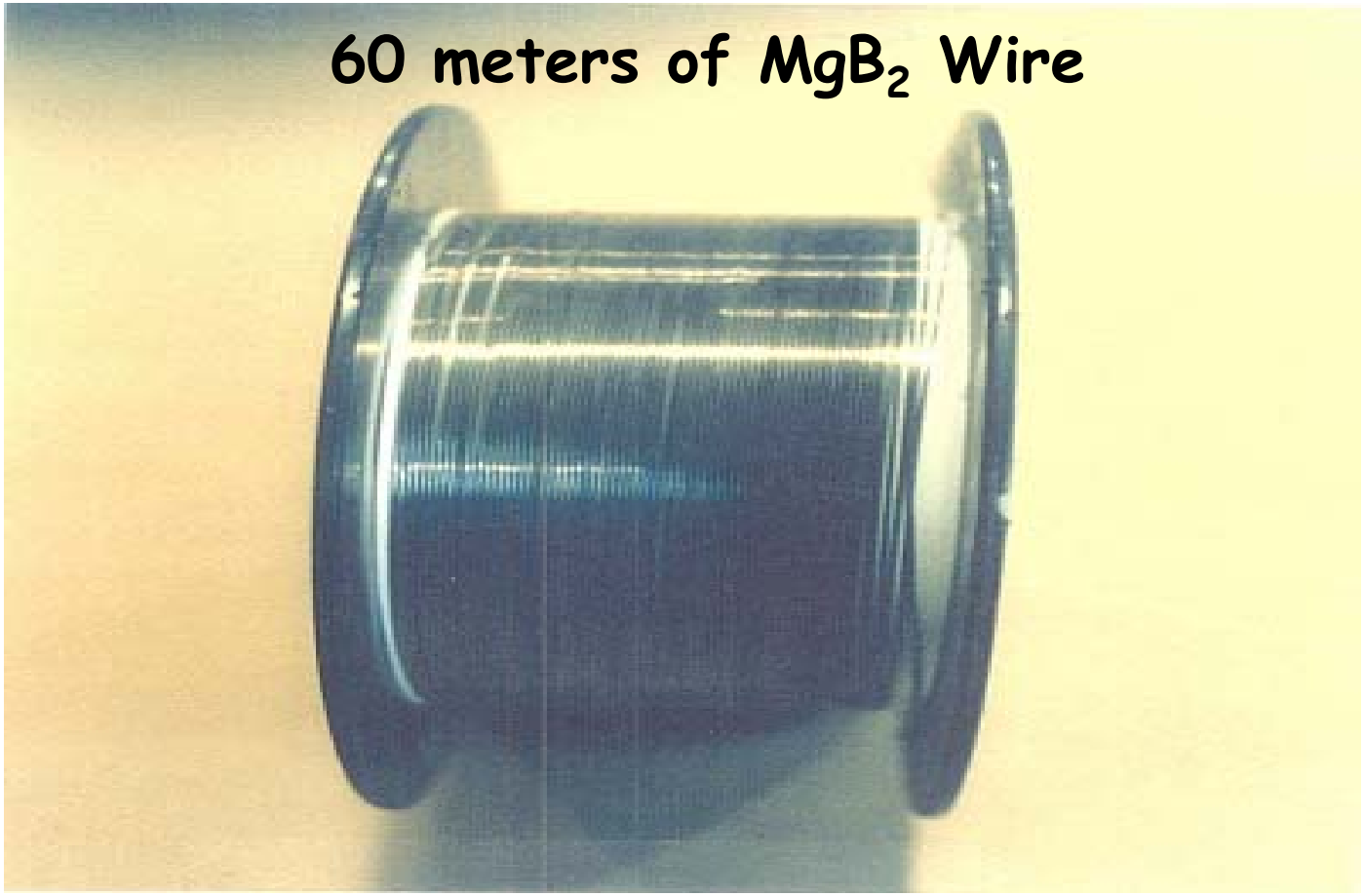
Cheap MgB_2 Wire Here Now!



Current density is 25,000 A/cm^2 at 21K; typical values for regular wires are about 150 A/cm^2

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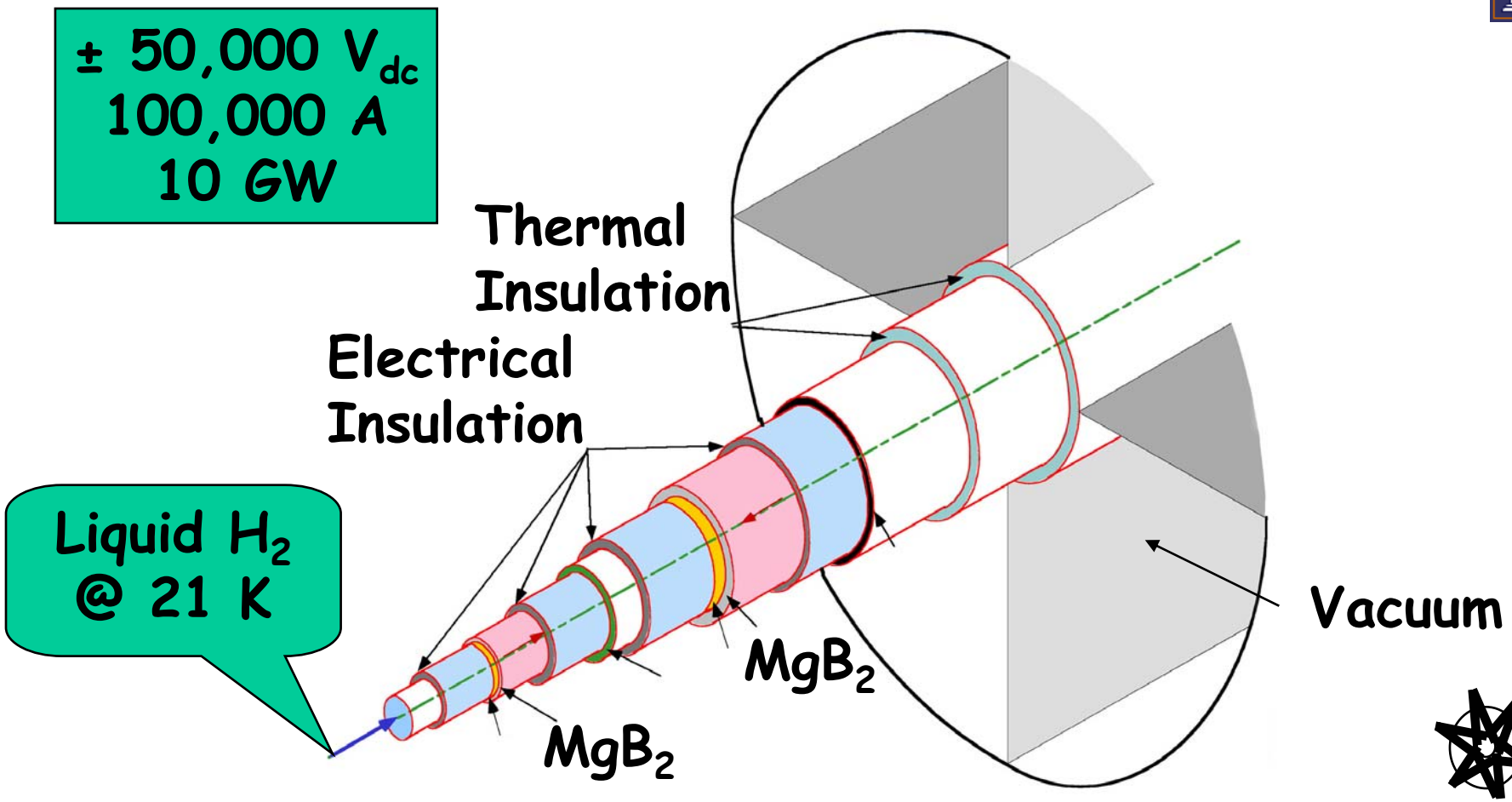
The Energy Pipeline – Less than One Meter in Diameter!



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Power Flows

- If we use a hollow tube of superconducting material, with an inside radius of 10 cm, the thickness would only need to be 0.125 cm to carry 100,000 Amps!
- The inside of this tube could carry the equivalent of about 500 MW of "hydrogen" power if the hydrogen flow rate is 4 M/sec
- Larger inside radius would allow more chemical power flow

Hydrogen and Electricity

- Hydrogen and electricity can be interchanged with fairly high levels of efficiency
  - hydrogen to electricity via a fuel cell
  - electricity to hydrogen via high pressure electrolysis
- Hydrogen has an advantage that it can be more easily stored, but electricity is easier to control and transport

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SuperCable H_2 Has Tremendous Energy 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

Each 500 km segment of the SuperGrid could store the equivalent energy as 1 Raccoon Mountain

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SuperGrid Hydrogen/Electricity Synergies

- Since hydrogen can be stored, much of the needed hydrogen could be created by electrolysis when the price of electricity is low for later usage
  - this addition of a large amount of flexible electric load would allow much greater usage of weather dependent generation sources such as wind

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Original Proposal Called for Undergrounding the SuperGrid

- Undergrounding the supercable in a micro tunnel could reduce public and political opposition to construction
- Costs for microtunneling are decreasing, with larger decreases possible with a large project like the SuperGrid
  - Current costs for a 4 foot tunnel are about $500 per foot ($2.5 million per mile)

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Environmentally the SuperGrid is Seen as Fundamentally "Green"

- While nuclear continues to be controversial, the SuperGrid is seen as being environmentally friendly since it replaces less friendly technologies

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SuperGrid is Technologically Feasible but Still Requires R&D

- SuperGrid level power injections (5-10GW) are 2-3 times levels of Pacific Intertie
  - Implications on existing grid need to be considered
- Controlling 100,000 amps at 50kV is not trivial
- Cooling cables to begin/resume operation can take days

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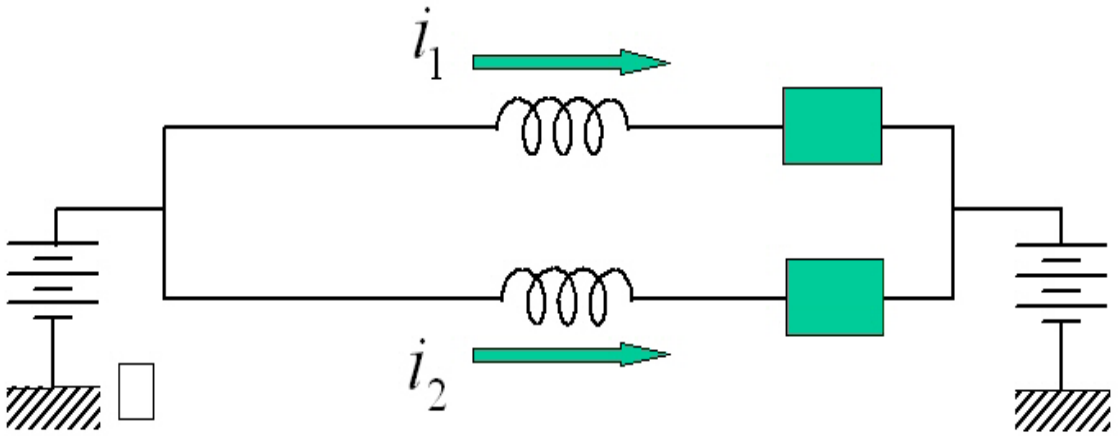
Supercable Networks would be Difficult to Control

From a current perspective DC lines can be thought of as RL circuits. Current is easy to control in traditional HVDC networks because of the low L/R time constants (< 0.05 seconds). But in a supercable, with R going to zero, time constants could be quite long, making current control difficult.



When a parallel line is added its current will ramp VERY slowly!

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Moving Forward

- No technological show stoppers but lots of R&D
- Public needs to understand infrastructure implications of going to a “hydrogen economy”
  - Really it is an electric/hydrogen economy
- Initial SuperGrid research should be
  - Economic study comparing to HVDC
  - Electric grid study showing potential benefits

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Questions?

Additional information is available at

http://www.supergrid.uiuc.edu

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