

# Activities and Plans in the US

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W2AGZ Technologies  
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3TU Workshop

SUPERCONDUCTORS IN  
THE POWER GRID

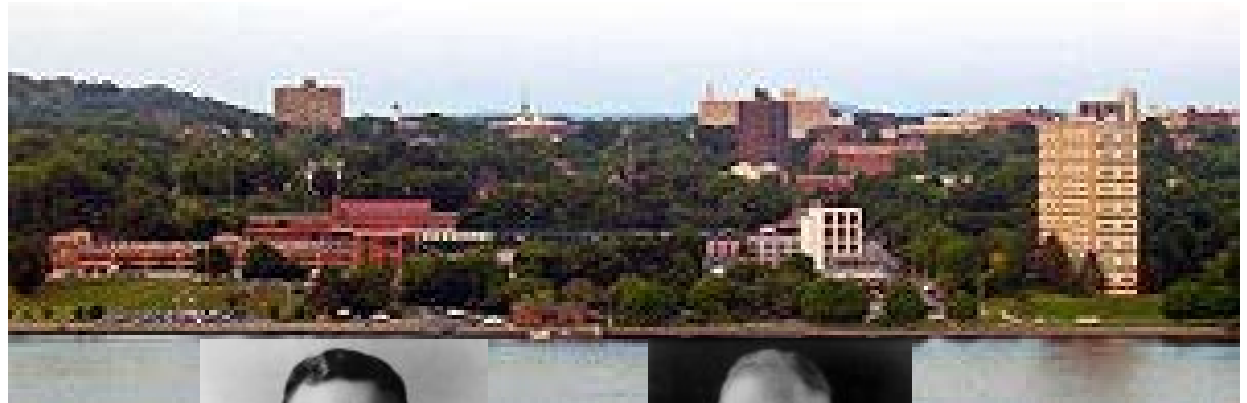
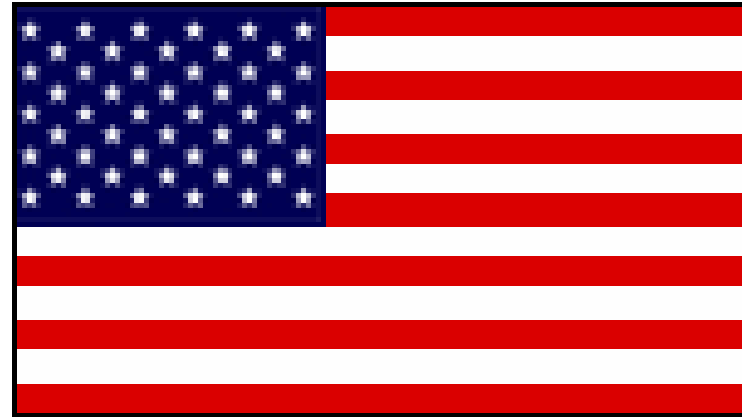
UNIVERSITY OF TWENTE

Thursday 19 - Friday 20 November 2009  
Conference Hotel Drienerburgh  
University of Twente, Enschede

“A Sober Assessment of Opportunities and Realities”

[http://www.w2agz.com/BD\\_3TUW09.htm](http://www.w2agz.com/BD_3TUW09.htm)

# New Holland & The Hudson Valley



Barents Baltus (1659) > Baltus Barents van Kleeck (?)(1702) > Poughkeepsie

**US**

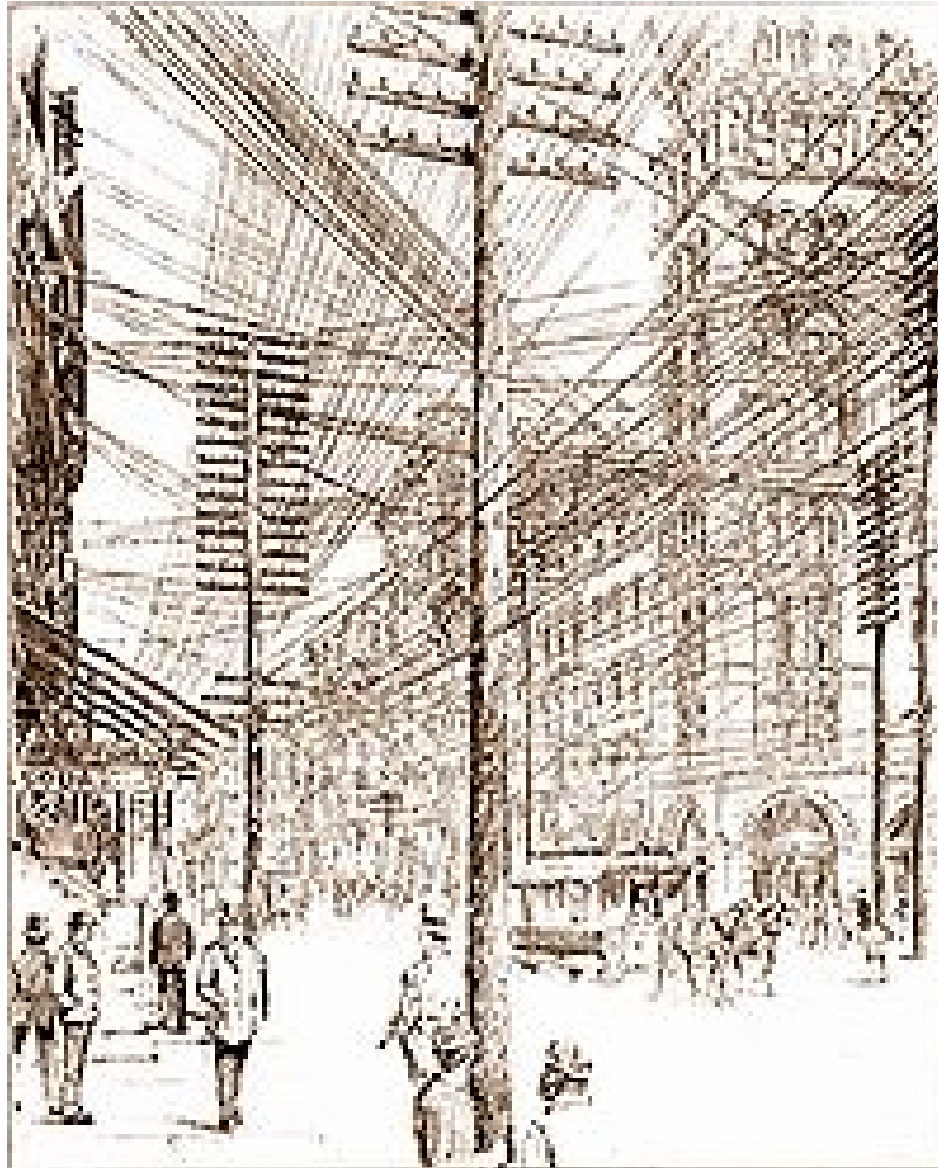
# **Electric Power 101**

- Electricity Today -  
The Crown Jewel of the US Economy

- **~\$2 trillion total asset value**
- **\$344 billion annual revenues**
- **142 million customers**
- **3273 utilities**

*Without electric power the \$14.3 trillion  
U.S. economy would come to a halt*

# NYC circa 1890s

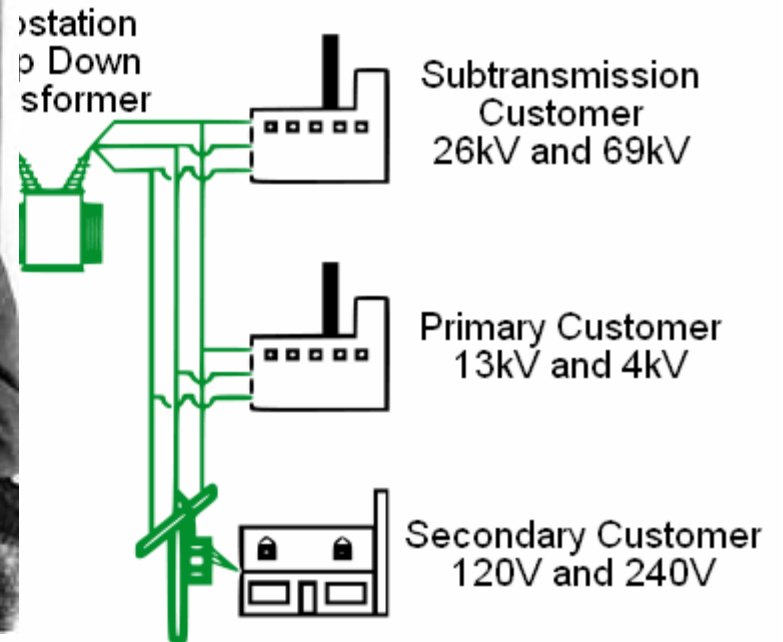
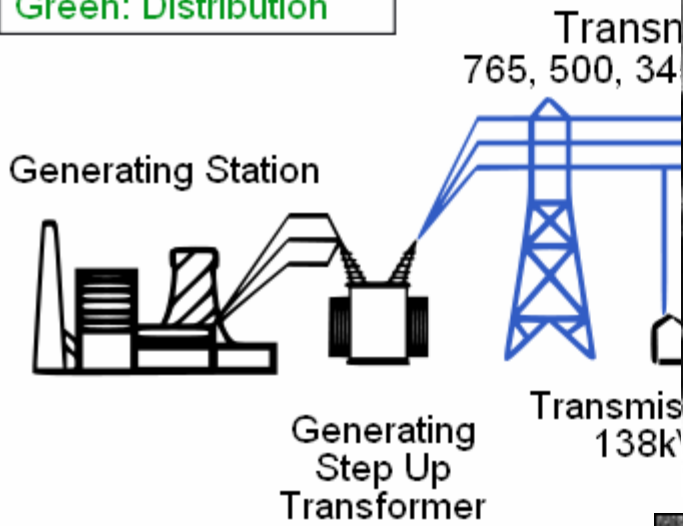


# Fathers of American Electric Power

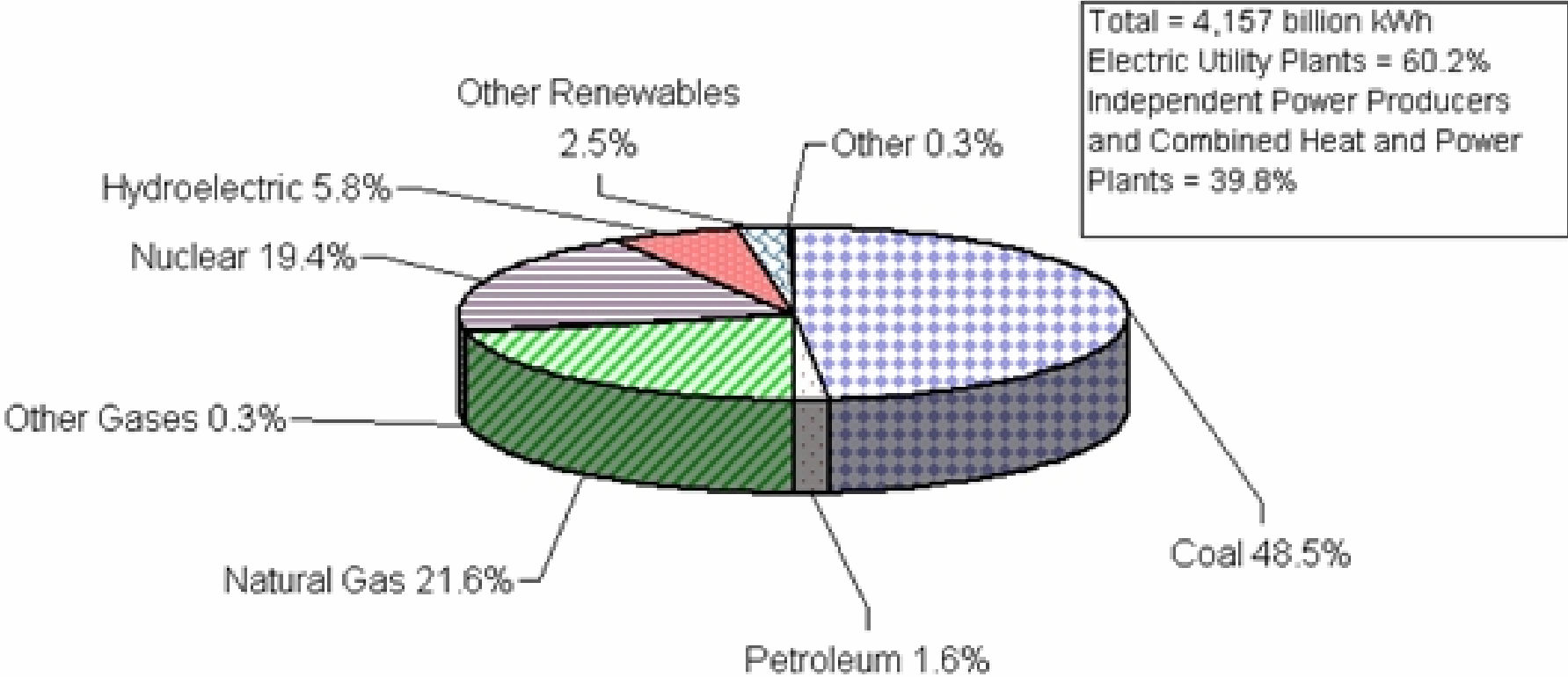


# The US Electrical System

Color Key:  
Black: Generation  
Blue: Transmission  
Green: Distribution



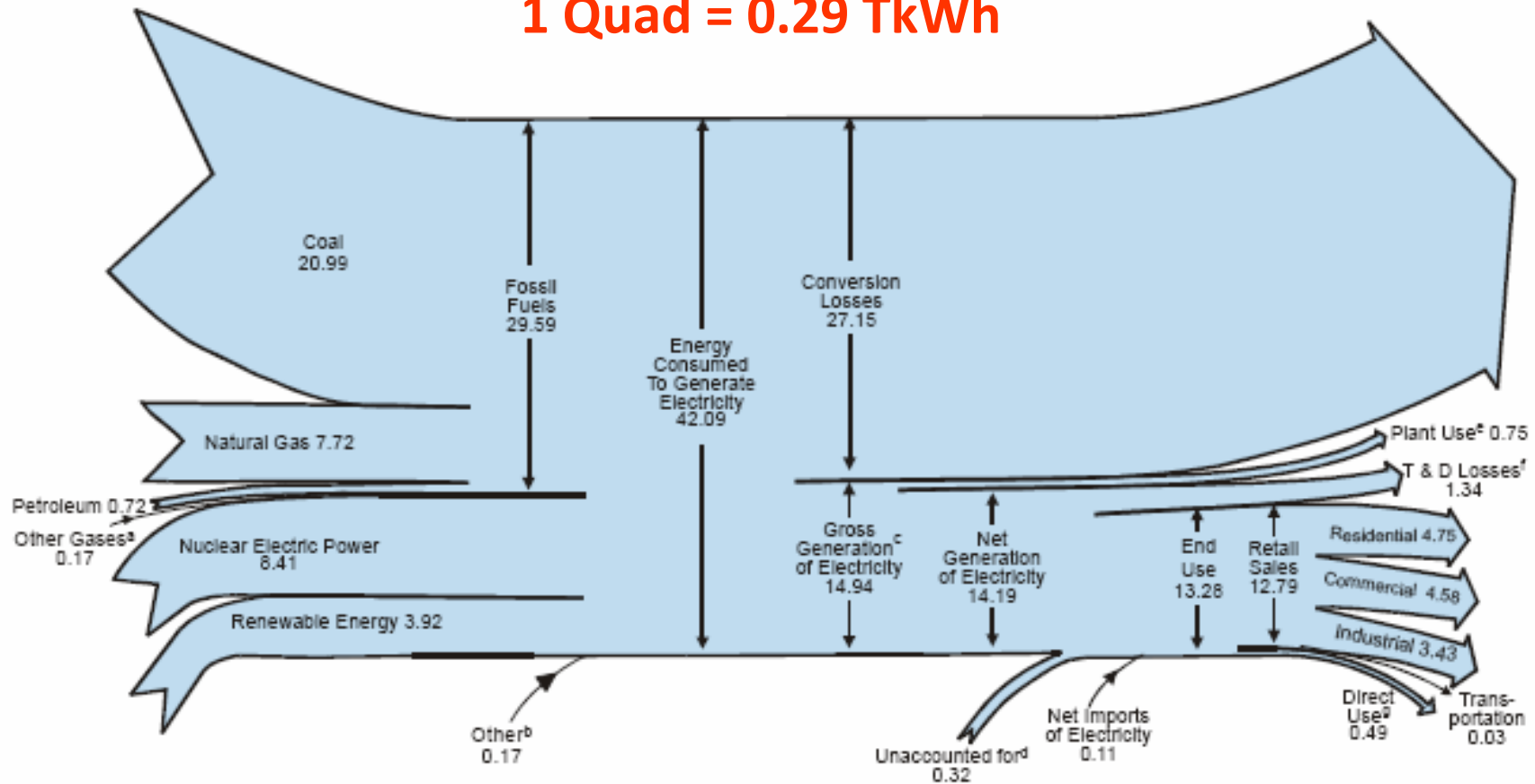
# US Electricity Generation Sources





# US Electricity Flow - 2007

1 Quad = 0.29 TkWh



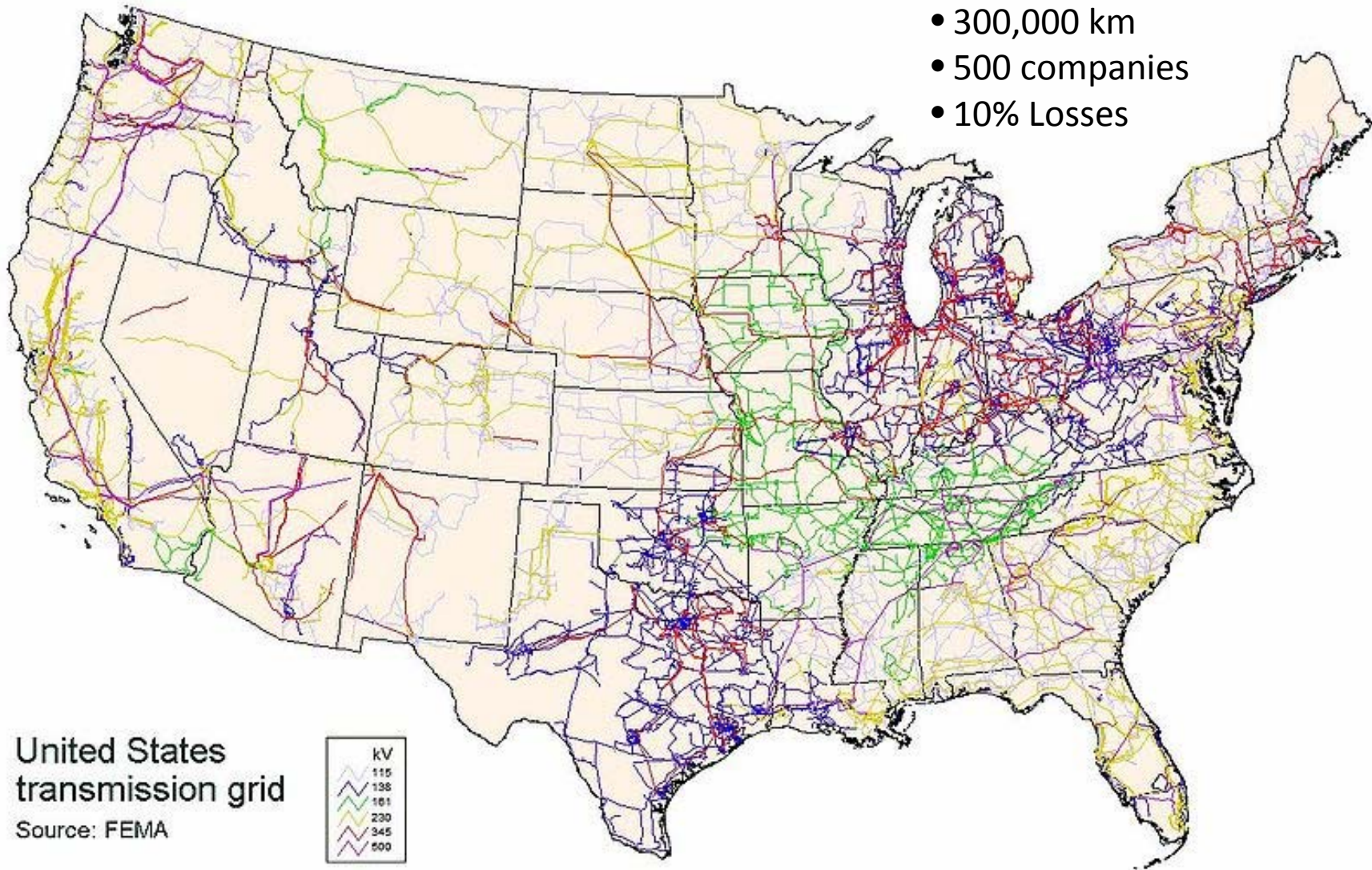
US Generation Capacity = 1.1 TW

Gross Generation = 4.33 GkWh

$(T\&D\ Losses)/(End\ Use) = 10\%$

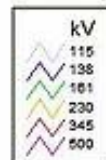
# The US Transmission Grid(s)

- 300,000 km
- 500 companies
- 10% Losses



United States  
transmission grid

Source: FEMA



# North American HVDC



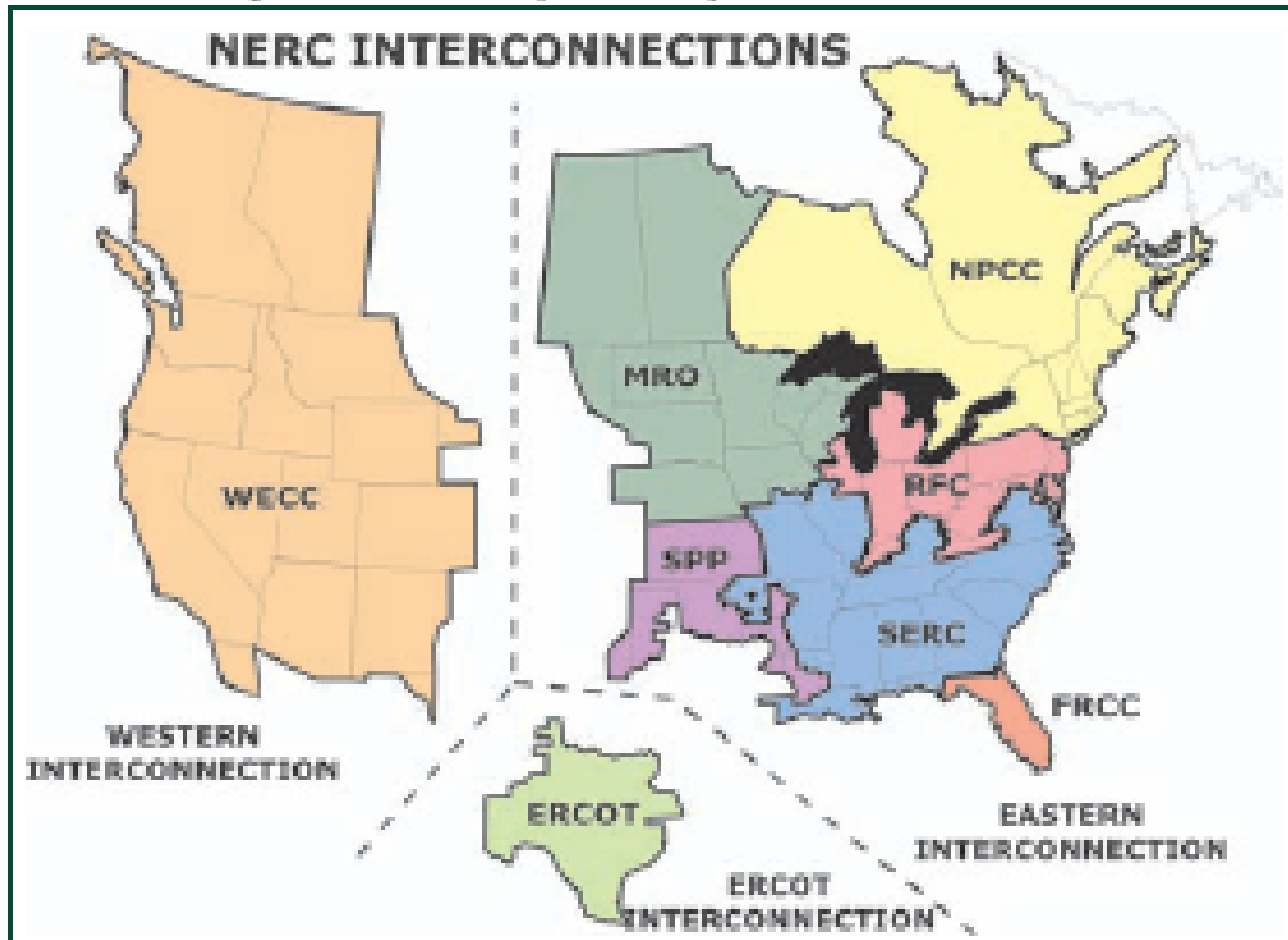
# Pacific Intertie

- HVDC, +/- 500 kV, 3.1 kA, 3.1 GW
- 1,362 km
- ~50% of LA Power Consumption
- Converter/Inverter Losses ~ 5%
- Ohmic Losses ~ 10%



Celilo I/C Station  
“A Mountain of Silicon”

# NERC Interconnects



Source: DOE 2006 National Electric Transmission Study

# The Grid:

A Journey Through the Heart of Our Electrified World

By Phillip F. Schewe  
Joseph Henry Press, 2007 (Buy It!)



Reviewed by Paul M. Grant:

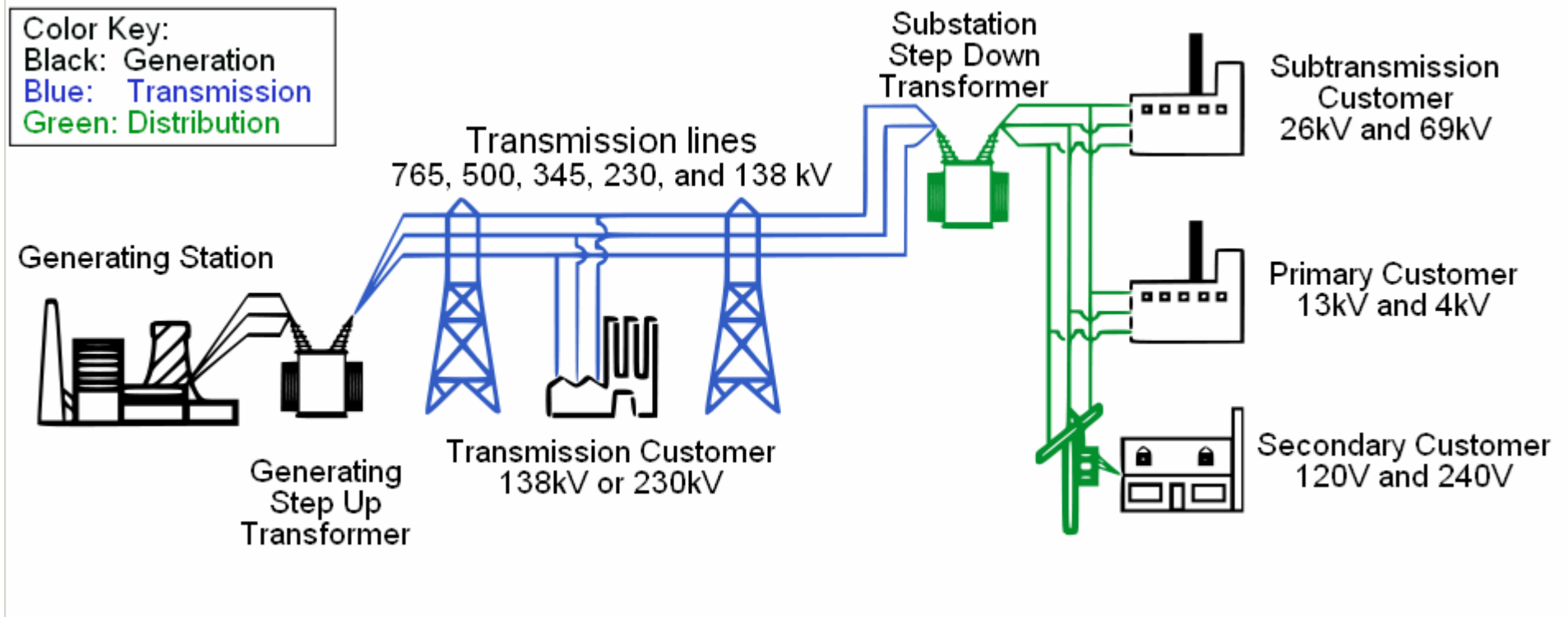
**Plugged into the matrix**

*The rise and potential fall of the US electricity grid*

Nature 447, 145 (2007)

<http://www.w2agz.com/Publications/Book%20Reviews/06%20%282007%29%20Plugged%20Into%20the%20Matrix.pdf>

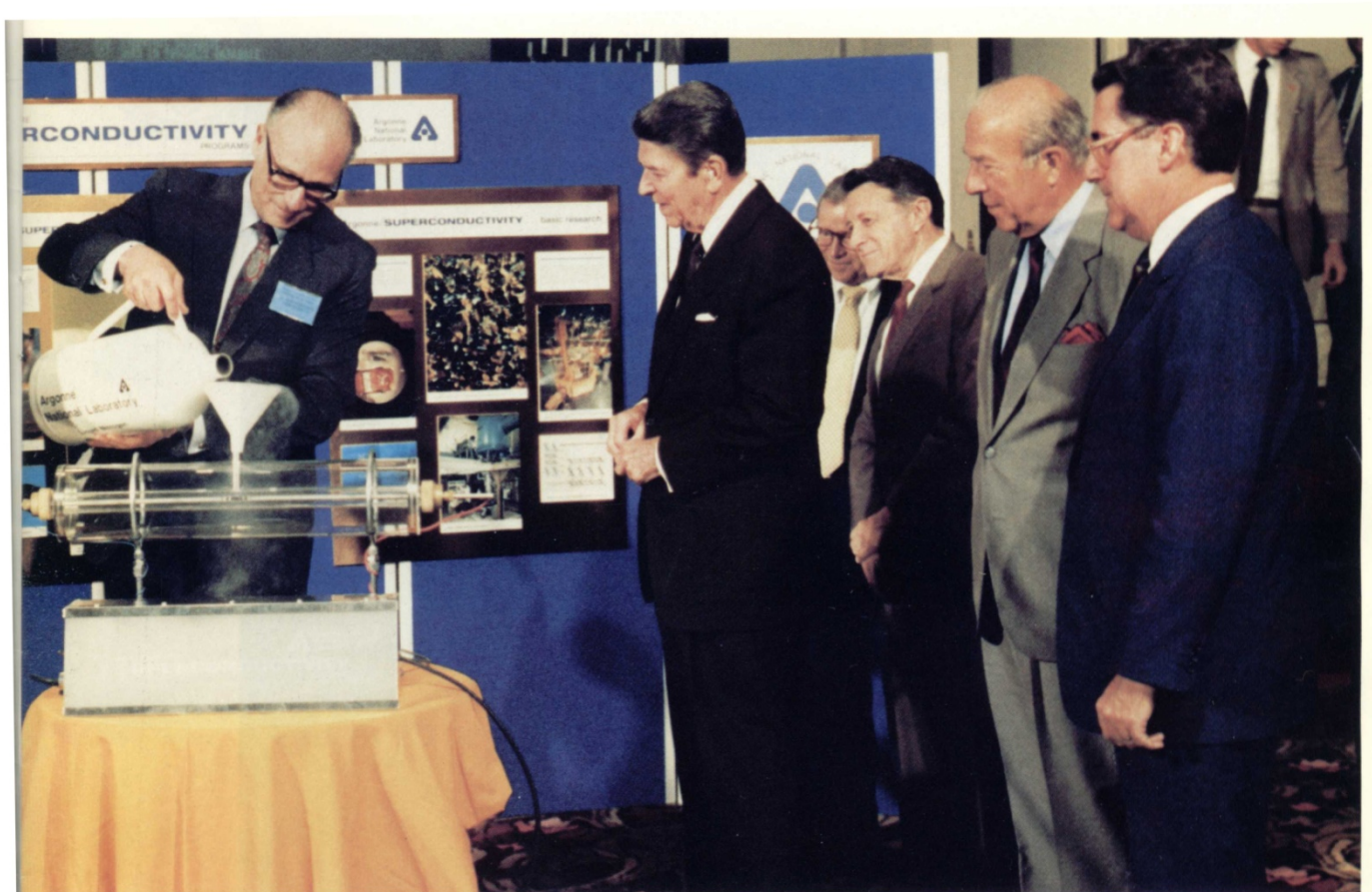
# Where Can We Use Superconductivity?



**Potentially Everywhere**

...maybe

# Superconductivity Act of 1988



*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.*

**DOE Program: ~ 20 Years @ ~ \$50 M/yr = \$1 B**



# HTSC Utility Market

In the utility/energy market, the applications that appear to value performance attributes of HTS most are Fault Current Limiters and Synchronous Condensers.

10 More Years!

Utility/Energy Market - Importance of Performance Attributes						
	Small & Light	High Power Density	Low Impedance	High Efficiency	High Field	Overall
Power Cable	●	●	●	●	○	●
Synchronous Condenser	●	●	●	●	●	●
Fault Current Limiter*	●	●	●	●	○	●
Industrial Motor	●	●	●	●	●	●
Utility Generator	○	○	●	●	●	●
Wind Generator	●	●	●	●	●	●
Transformer	●	●	●	●	○	●

Source: NCI Analysis, see Appendix: Value Propositions

\* Fault current limiters also rely on the inherent quench properties of HTS.



# HTS Cables...



Footprint  
conventional cables



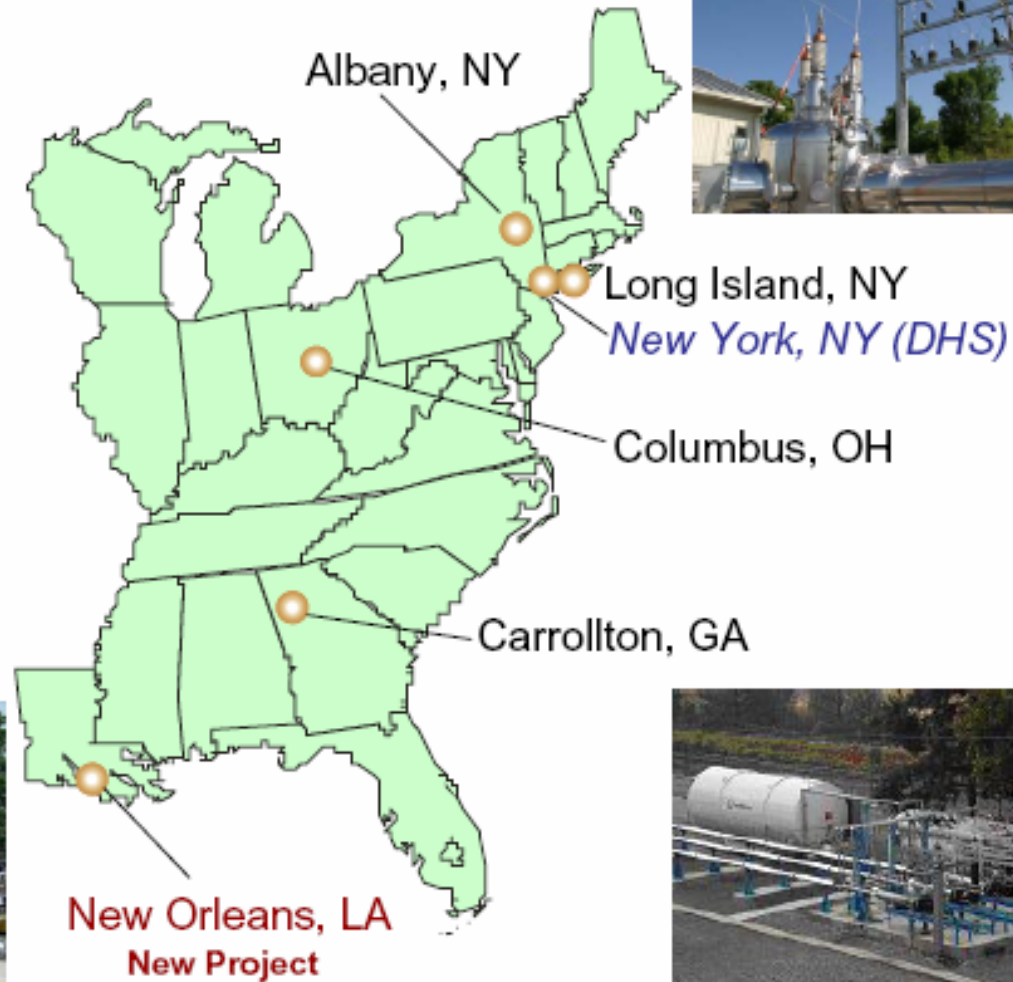
Long Island Power Authority HTS  
Cable Project (September 2006)

... are made by using conventional  
stranding techniques

...require no special training  
for installation since  
conventional pulling and  
rigging equipment are used

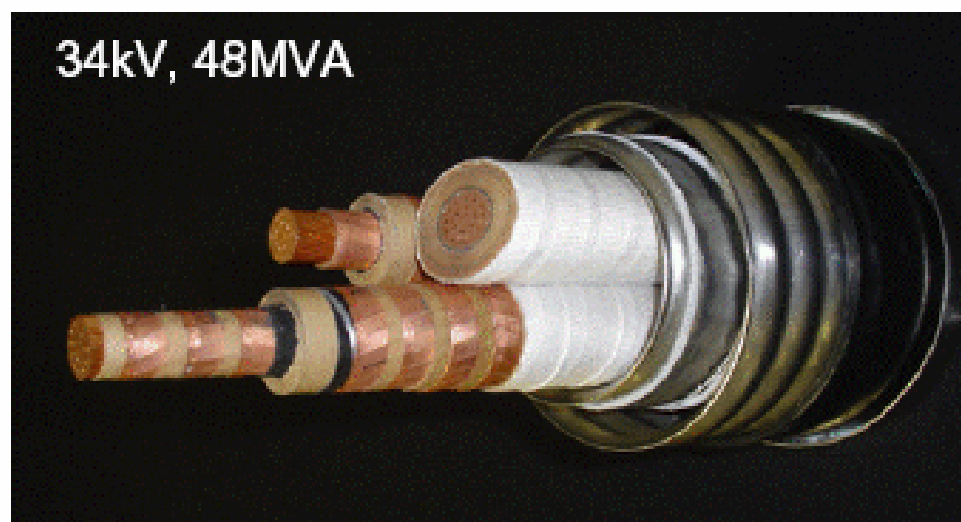


# U.S. HTS Cable Installations



# Albany HTS Cable Project

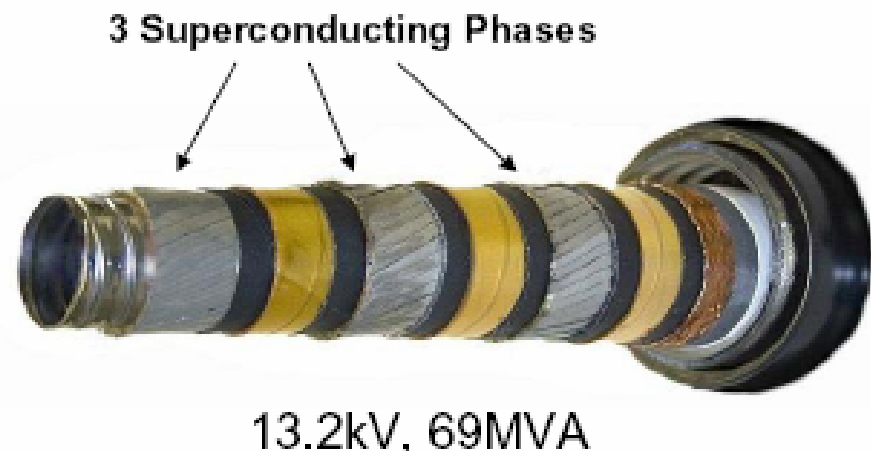
- Demonstration of technical and commercial viability of underground HTS cable operation between two National Grid substations
  - 350m long - 34.5kV - 800A<sub>rms</sub> - 48MVA
- Cable was energized on July 20, 2006 and serves the equivalent of 25,000 homes
- 2006 installation connects two lengths of 1G cable totaling 350 meters with the world's first HTS cable-to-cable joint, required for long cable runs
- Cable operated for more than 9 months (>6,720 hours) before taken-off-line
- In Fall '07, a 30 m section will be replaced with a 2G cable - world's first use of 2G in any utility device



Cable configuration: 3 phases in 1 common cryostat

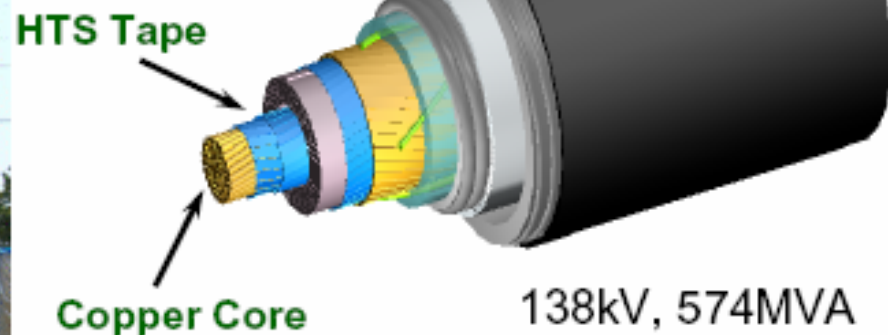
# Columbus HTS Cable Project

- 200-meter, 3-phase HTS power cable at an American Electric Power substation in Columbus, OH
- Cable was energized August 8, 2006 and serves the equivalent of 36,000 homes
- New “triax” cable design – all 3 phases in one cable and uses  $\frac{1}{2}$  the amount of HTS wire compared to other designs
- Cable has operated successfully for more than 1 year



# Long Island HTS Cable Project

- World's first transmission voltage in-grid HTS power cable
  - Design Voltage/Current – 138kV/2400A ~ 574MVA
  - Design Fault Current – 51,000A @ 12 line cycles (200ms)
- Will serve the equivalent of 300,000 homes when energized  
Length ~ 600m (world's longest HTS cable)
- Installation/Commissioning – Fall 2007



# New Project: New Orleans HTS Cable

## Problem:

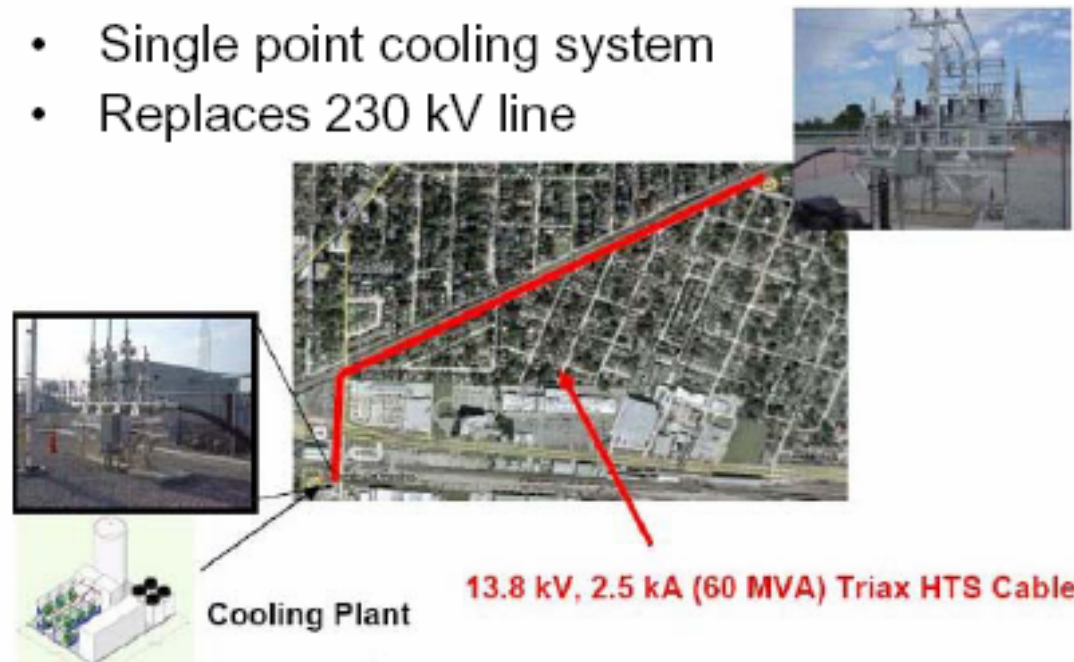
- Load growth in urban area
- Saturated 13 kV distribution
- 230/13 substation to north & south of area
- Need new substation at mid-point

## Challenges:

- Overhead rights of way for 230 or 13 kV very difficult or impossible
- Small footprint available for new substation dictates gas insulated substation 230 kV equipment or expensive station expansion
- 230 kV solution: placing transformer in dense residential area
- 13 kV conventional: Voltage drop, power quality

## Solution:

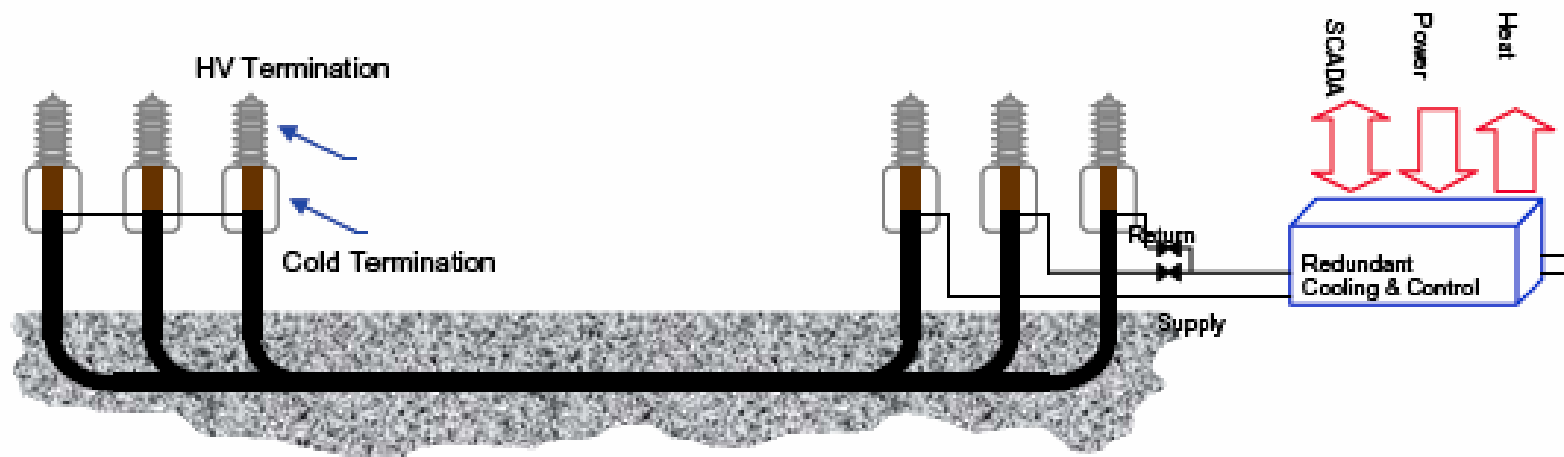
- 13 kV, 1.1 mile HTS cable to transmit 60 MVA into small footprint substation
- 2 splices; three sections
- No transformers needed
- Single point cooling system
- Replaces 230 kV line



# New Project: “LIPA 2A” HTS Cable

## LIPA 2A Project Scope:

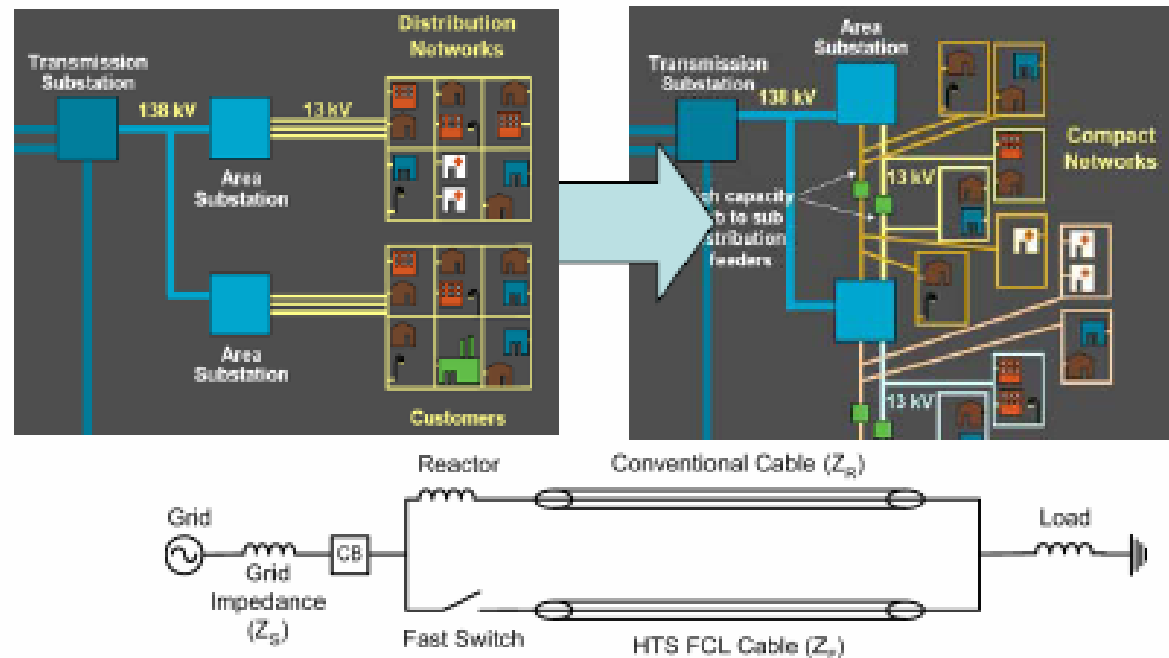
- Demonstrate cost effective 2G cable at transmission voltage
- Introduce repairable cryostat and cable joint
- Develop low cost, reliable, and efficient refrigeration system
- Demonstrate inherent fault current limiting capability at transmission voltage





# New Project: “Project Hydra”

- 13 kV, 4000 A HTS cables with fault current limiter (FCL) between substations in the Manhattan power grid allow Area Substations to share excess capacity in emergencies
- Technology Demonstration by FY08
- Integrated System Test and Demonstration by FY10



## **2007 DOE Awards for 2G HTS Fault Current Limiters (FCL)**

- SuperPower 138 kV FCL at AEP (DOE: \$5.8M)
  - Features matrix design consisting of parallel 2G HTS elements and conventional coils
  - Team includes: Sumitomo; Nissan; BOC Group; and ORNL
- AMSC-Siemens 115 kV FCL at Southern California Edison (DOE \$12.7M)
  - Features Siemens proprietary low-inductance coil technology
  - Team includes: U. of Houston; Nexans; and LANL
- SC Power Systems 138 kV FCL at Con Edison (DOE \$11M)
  - Features 2G HTS coil and DC power supply in a saturable reactor in series with AC line
  - Team includes: LANL; Air Products; Cryo-Industries of America; Southern California Edison; Delta Star Inc.; and Trithor GmbH

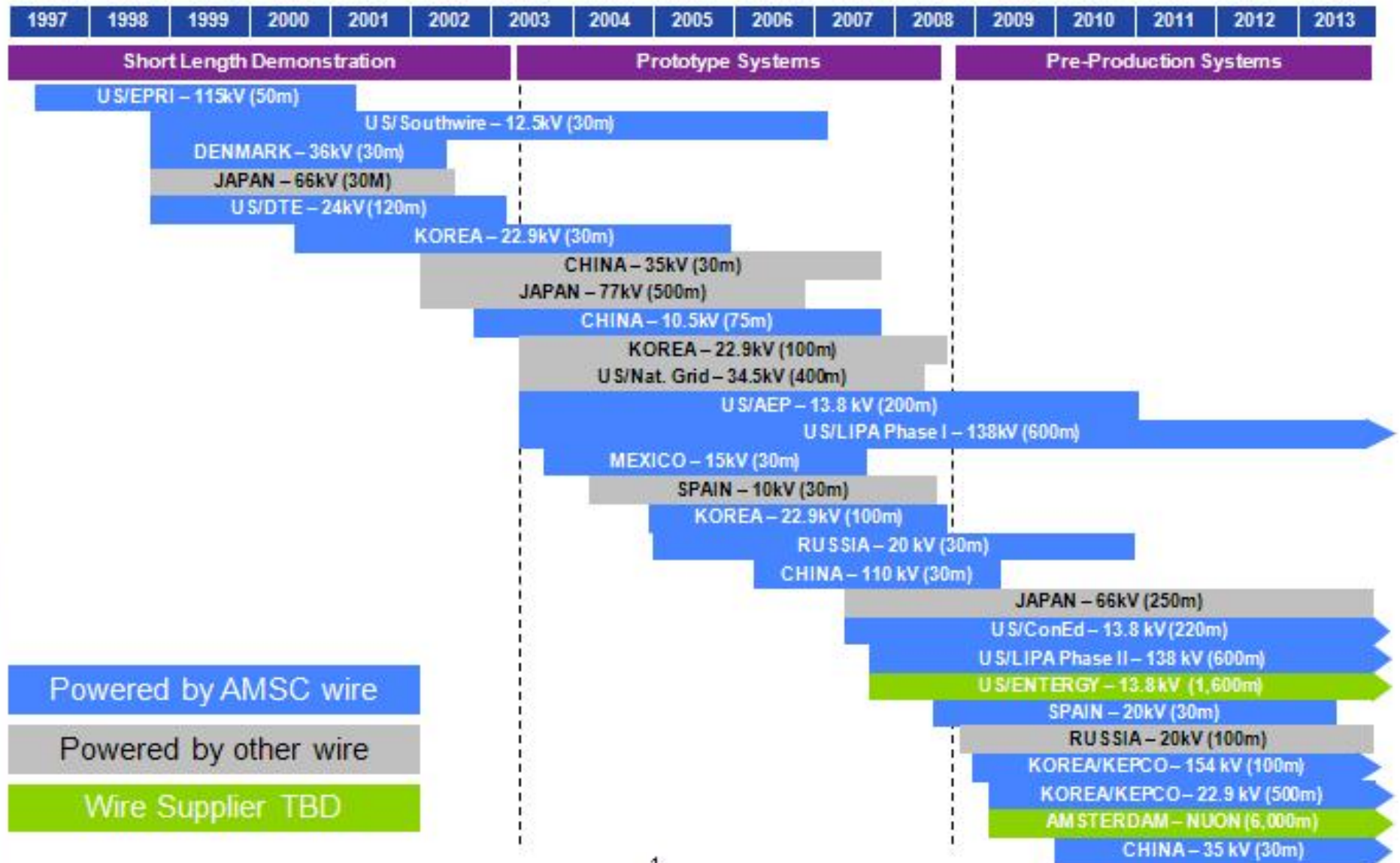
# 2010 DOE OED&ER Budget Request

Dollars in Thousands

	FY 2008 Appropriation	FY 2009 Appropriation	FY 2009 Additional Appropriation	FY 2010 Request
<b>Research and Development</b>				
Clean Energy Transmission and Reliability	-	-	-	42,000
Smart Grid Research and Development	-	-	-	67,000
Energy Storage	-	-	-	15,000
Cyber Security for Energy Delivery Systems	-	-	-	50,000
High Temperature Superconductivity	27,148	23,796	-	?
Visualization and Controls	24,373	24,373	-	-
Energy Storage and Power Electronics	6,552	6,552	-	-
Renewable and Distributed Systems Integration	24,753	30,000	-	-
<b>Subtotal, Research and Development</b>	<b>82,826</b>	<b>84,721</b>	-	<b>174,000</b>
Operations and Analysis	11,451	11,451	-	-
Permitting, Siting, and Analysis	-	-	-	6,400
Infrastructure Security and Energy Restoration	-	-	-	6,188
Program Direction	17,603	21,180	-	21,420
Congressionally Directed Activities	24,290	19,648	-	-
American Recovery and Reinvestment Act	-	-	4,500,000	-
<b>TOTAL, Electricity Delivery and Energy Reliability</b>	<b>136,170</b>	<b>137,000</b>	<b>4,500,000</b>	<b>208,008</b>



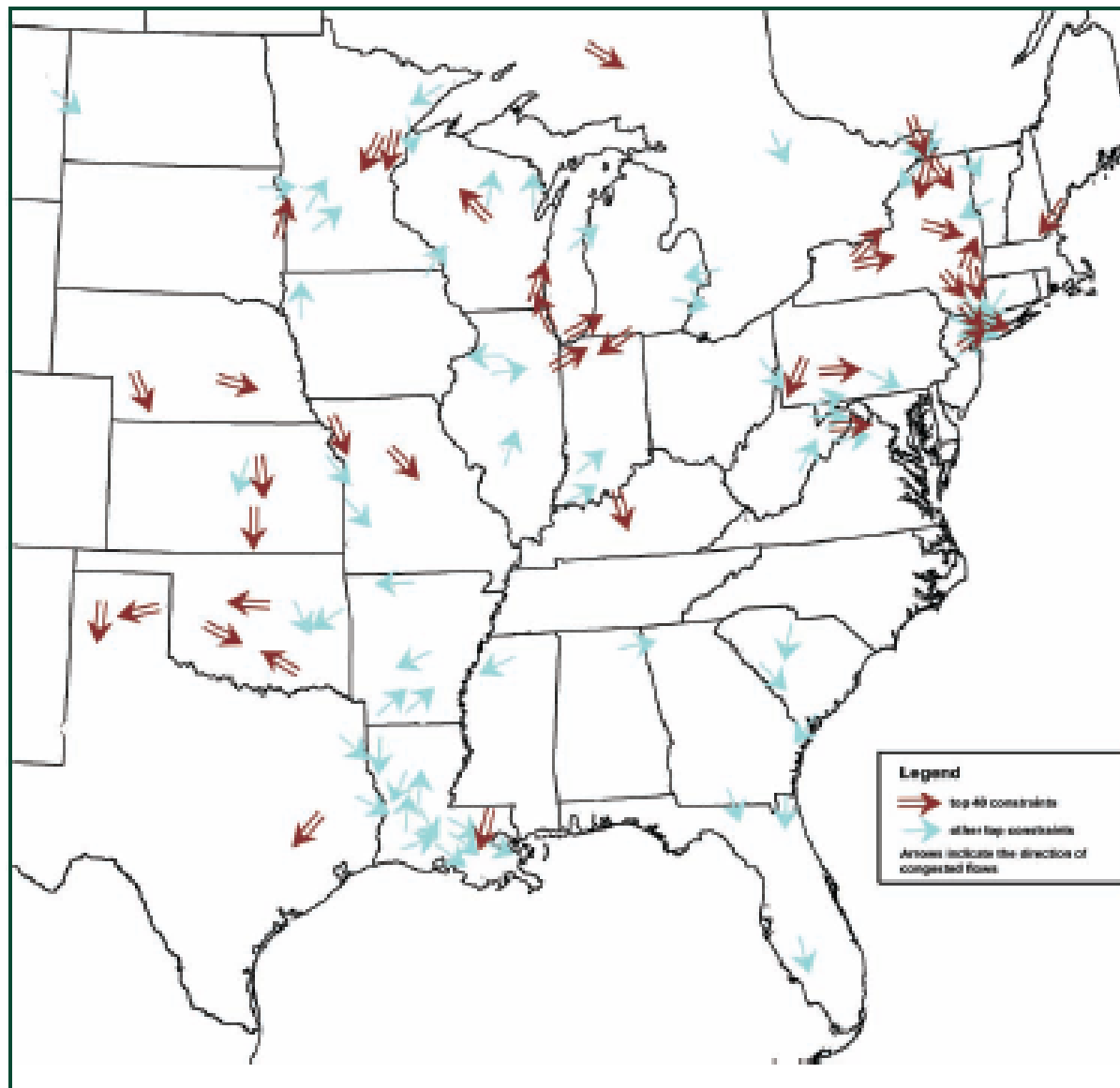
# Wiring the World with Copper Oxides



# HTSC Power Technology is Here

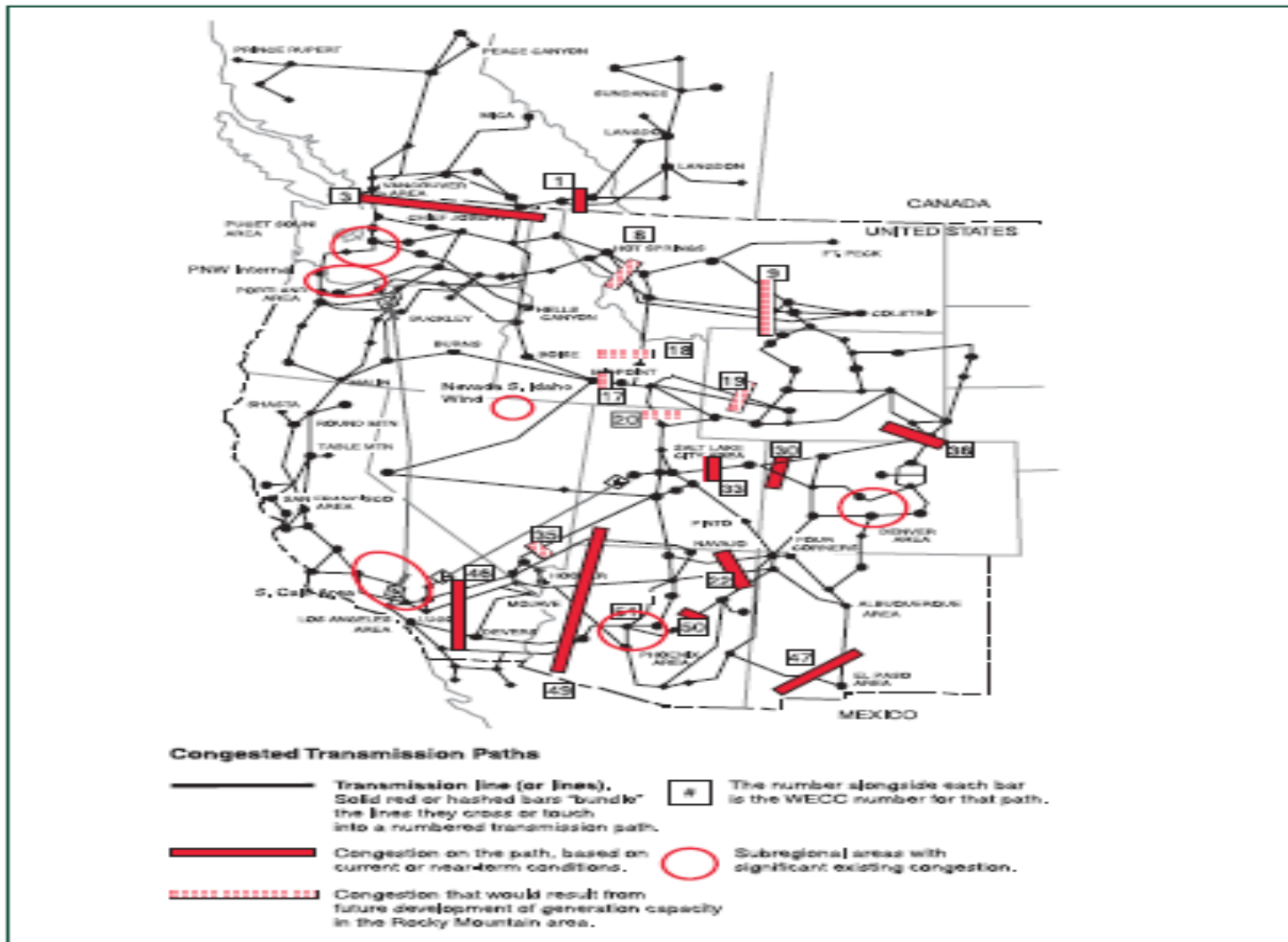
- ...and it works!
  - ...perhaps still a little pricey, though
- ...so where's the demand?
- ...what needs to be fixed?
- ...why isn't it being used?
  - ...would it help if the wire/tape were free?

# Projected 2008 Congested Paths in the Eastern Interconnection



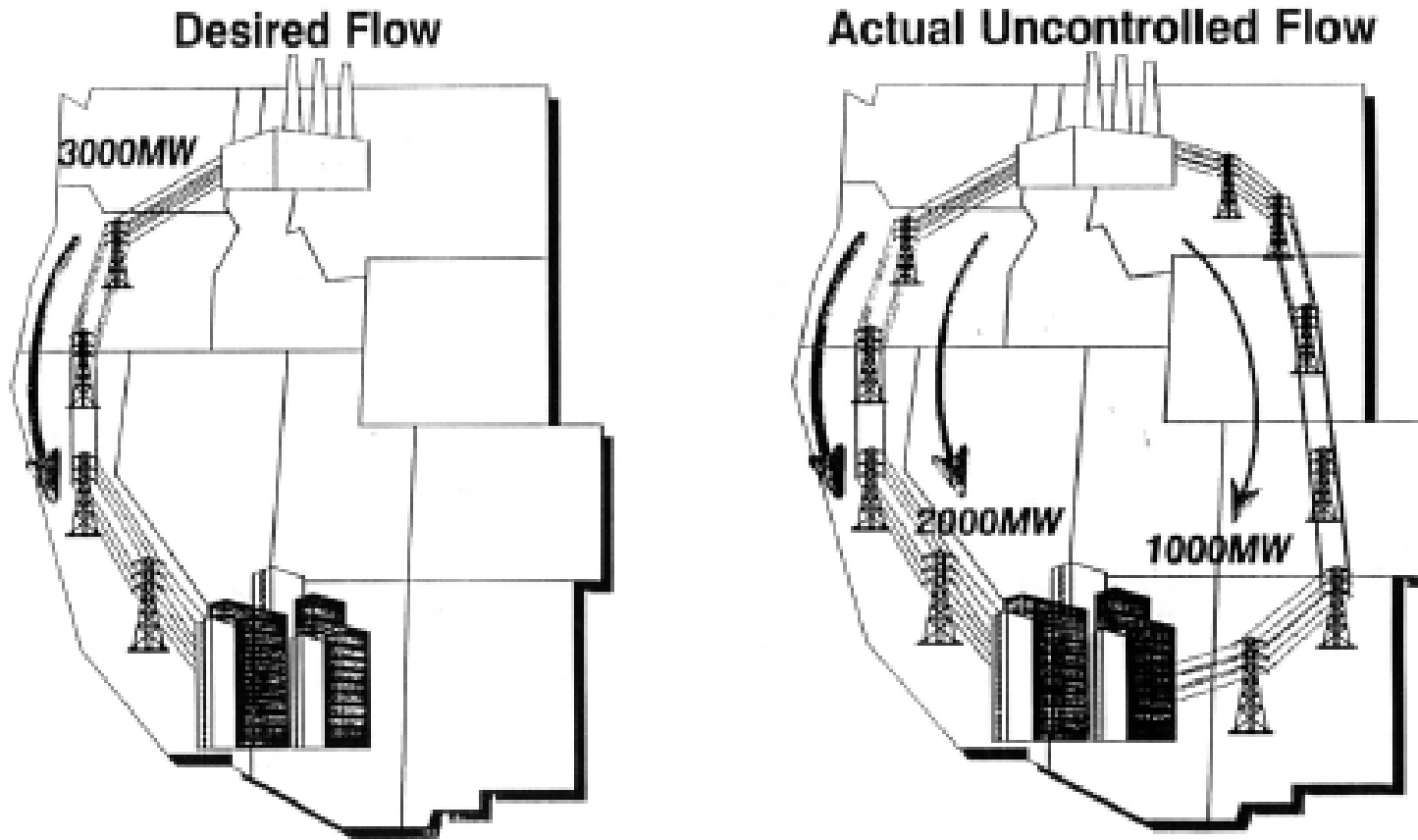
Source: DOE 2006 National Electric Transmission Study

# Western Interconnection



Source: DOE 2006 National Electric Transmission Study

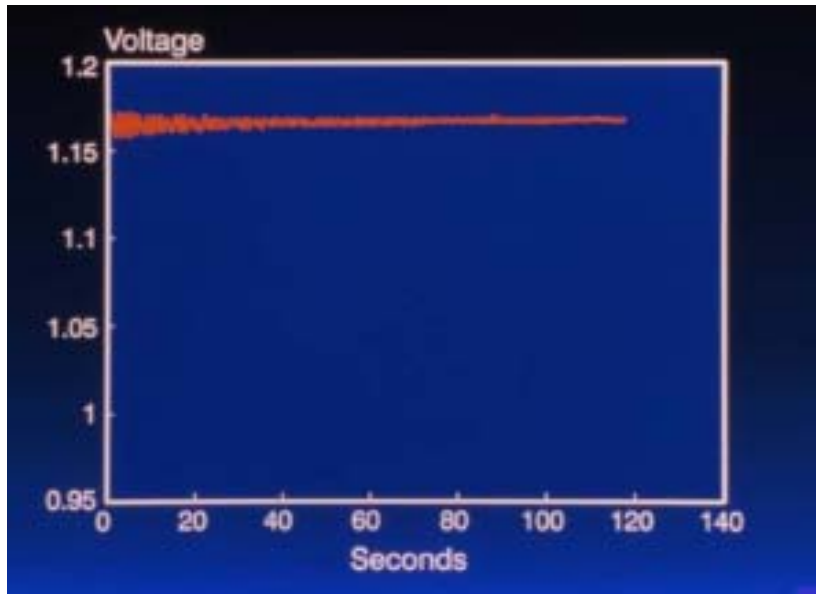
# Real-Life Power Flows



Can we defeat (macroscopically) Kirchhoff's Laws?

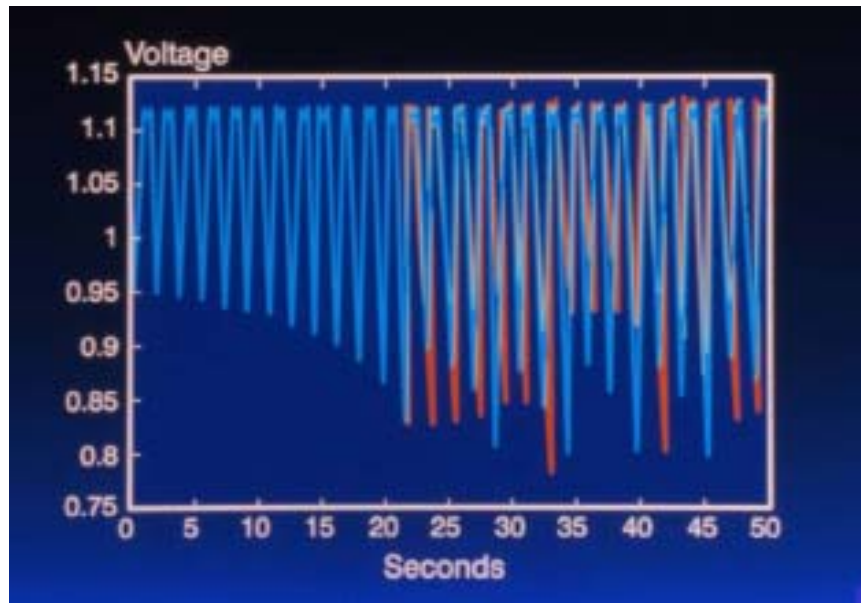


# Chaos on the Grid

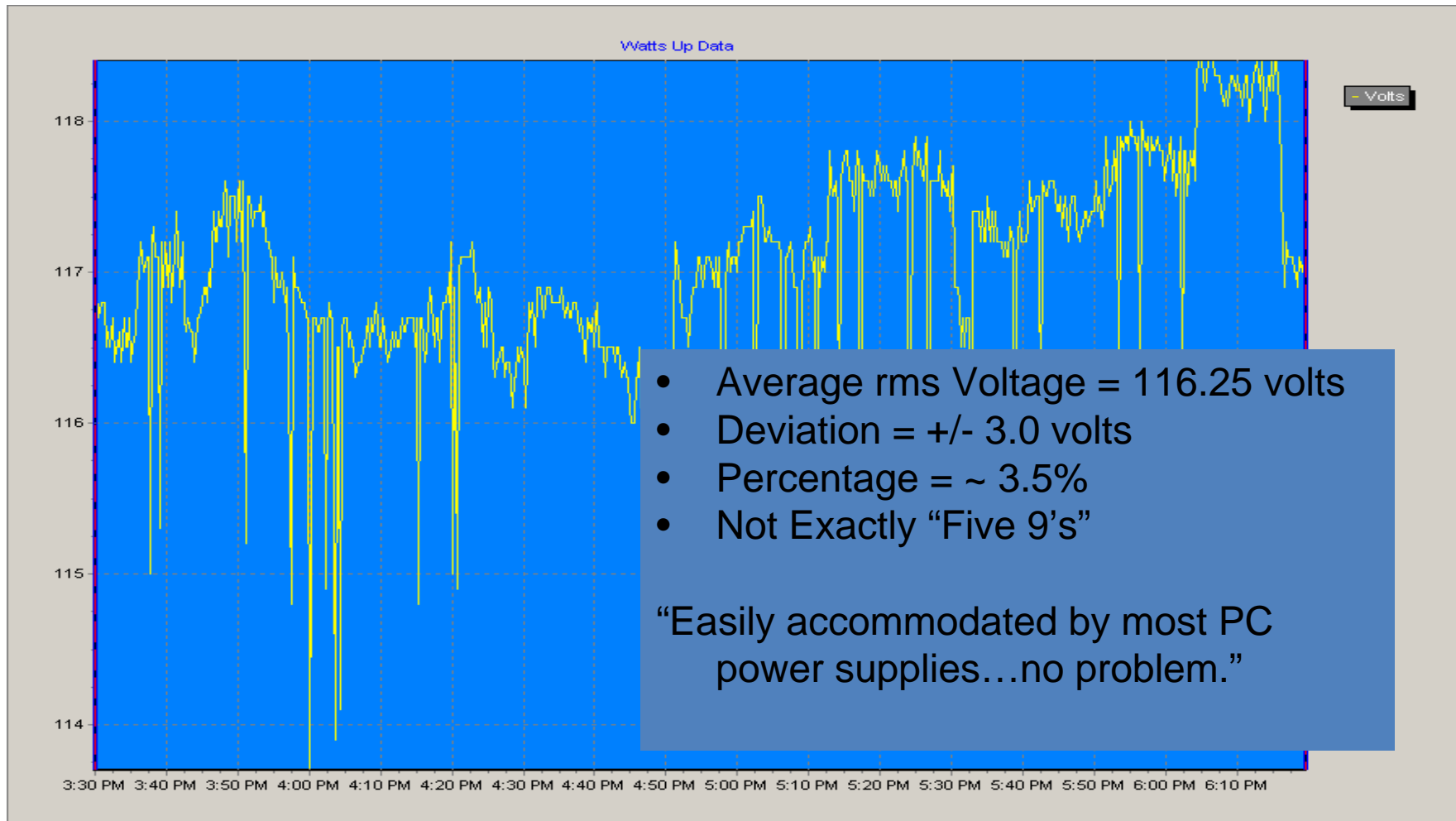


Business as usual

Business when a crowbar is thrown across the lines



# How many 9's?



07/25/04 3:30-6:00 PM, Sunday, SJ, CA 95120--W2AGZ Server Voltage

# Blackouts

Texas '03

Detroit '00

Northern California '01

San Francisco '00

Delaware '99

New Orleans '99

Chicago '99

New York '99

Northeast '03

West Coast '96

Atlanta '99



# The Big Blackout

## Northeast 8/14/03



# As Night Falls...



# The Party Begins...



...and Continues...



Mary Altaffer / AP

# It Gets Better...



David Friedman / MSNBC.com



and Better...



George Widman / AP

# The Morning After



Gregory Bull / AP

# Viva New York!



# Can “New” Transmission Technology Help?

- Yes, but probably not superconductivity in a big way, at least for a while.
- More likely, “smart” grid stuff will come first
  - HVDC cables and lines
  - FACTS to increase present corridor capacity by 30%
  - IT and communications plus an “OS/360” to more effectively and efficiently management power flows



## EMPIRE CONNECTION

### Specifications

#### 2-1000 MW HVDC Bipolar Circuits

- Circuit 1: 130 miles, *Greene County* → Bronx County
- Circuit 2: 140 miles, *Albany County* → New York County
- Each Circuit: +/- 500 kV, 1000 A Bipolar (2 cables ea.)

### Financials

#### \$750 M (\$400 M "VC", \$350 M "Futures")

- Loan Payment (4%, 40 yrs, 750 M\$) = 35 M\$/yr
- Labor, Overhead, Maintenance = 5 M\$/yr
- Tariff = 0.5 ¢/kWh
- Profit (NOI) @ 50% Capacity = 4 M\$/yr
- Profit (NOI) @ Full Capacity = 48 M\$/yr



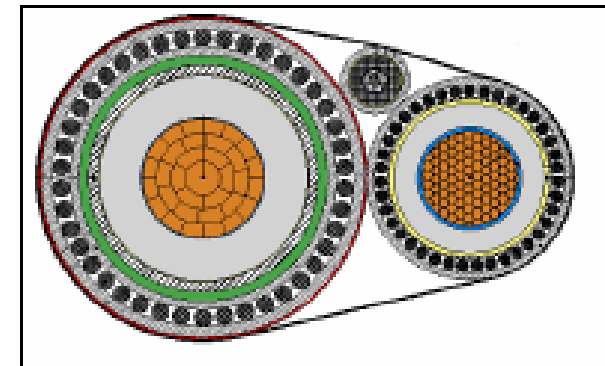
Wire C/P = 100 \$/kA×m

HTSC Cost = \$87 M

***Why didn't it go forward?***

# NEPTUNE

Regional Transmission System™



HVDC Cable Cross-Section

## Pirelli (Prysmian) Energy Cables

\$190 M

### Sayerville, NJ → Levittown LI, NY

- 600 MW (+/- 250 kV, 1200 A)
- 65 miles (105 km)
- \$400 M
- 2007

#### Financials

40 yrs @ 4%: \$ 20M  
 LOM: 1 M  
 NOI (100%): 5 M

T	C/P	Cost (\$M)
77 K	\$/kA×m	
Cu	7	1.8
HTSC	100	25.1

# So Where's the "Gold Rush" to Superconductivity?

- What's the analogy to the Erie Canal, Railroads, REA, TVA, Interstate Highways that opened the country to economic development?
  - Capacity? Possibly
  - Reliability? Maybe
  - Power Quality? Nah

# THE TRES AMIGAS PROJECT

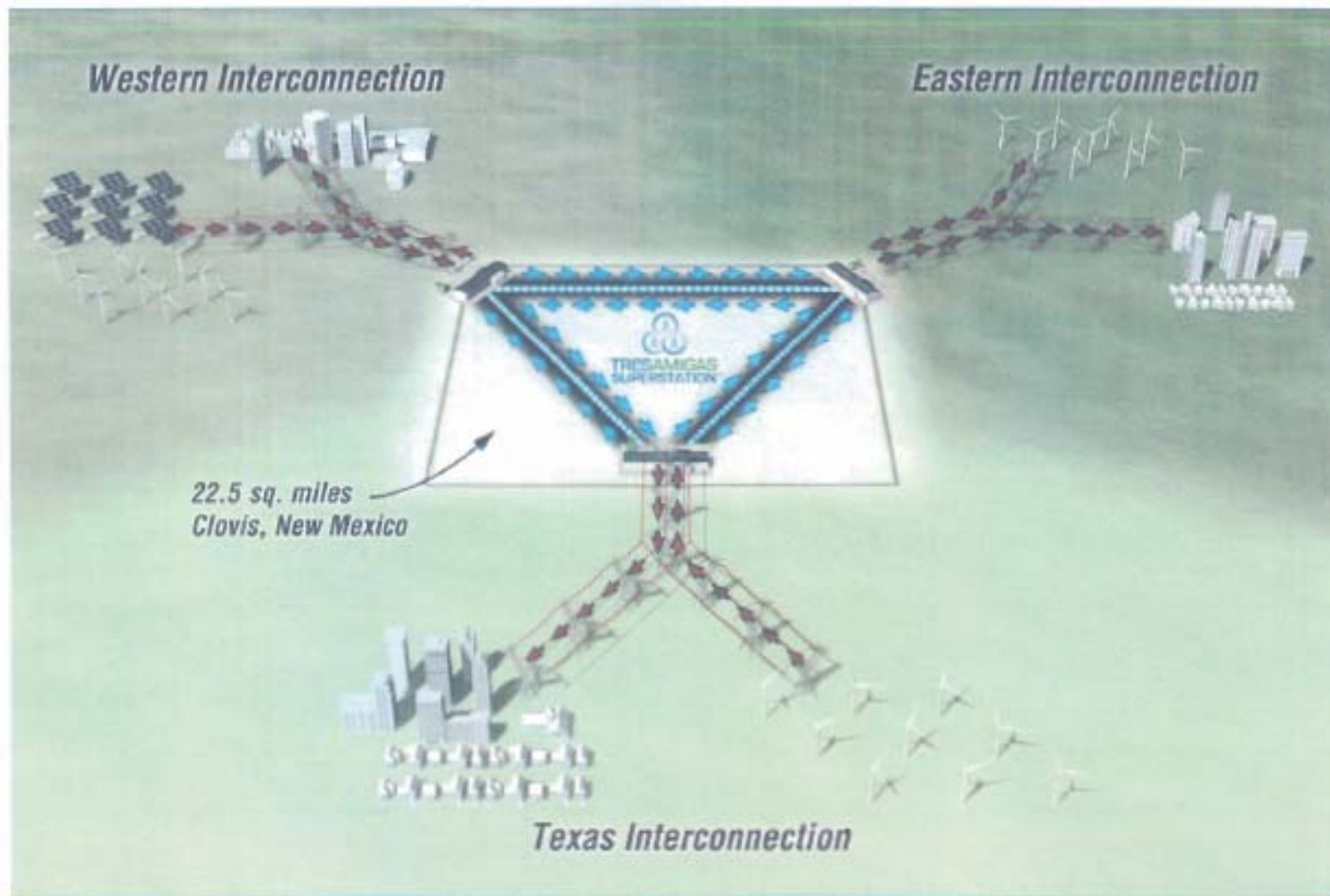
*October 2009*

- Tres Amigas Super Station (TASS) will be the first system to unite the three U.S. power grids
- Able to carry gigawatts of renewable power from region to region
- Centrally located in Clovis, New Mexico
- Will utilize the latest advances in energy technologies, including superconductor power cables, voltage source converters and large-scale energy storage systems
- Will form the nation's first renewable energy market hub





# Tres Amigas Super Station



# The Tres Amigas SuperStation

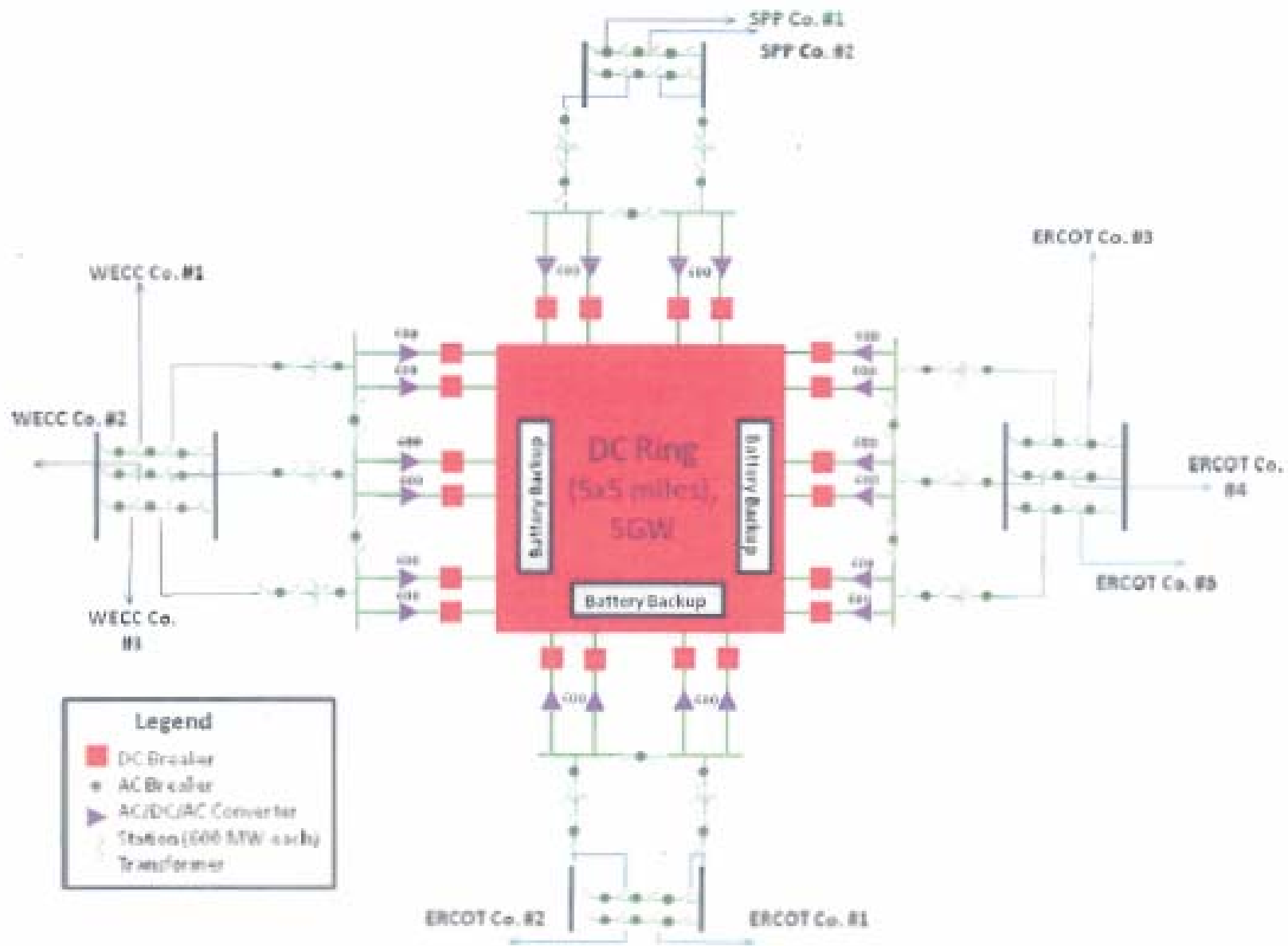


**Transmission Lines from Western Interconnection**

**Transmission Lines from Eastern Interconnection**



**Transmission Lines from ERCOT**  
One or more transmission lines from the Texas Interconnection (see the U.S. Grid Interconnections box) connect to this HVDC terminal.



### **The latest proven technology in converters - Voltage Sourced Converter (VSC) technology will be used**

- VSC control systems determine both power levels and direction and are able to vary power levels from +100 percent to -100 percent incrementally (as desired). VSCs do this without any converter function interruption (IE, switching to AC) or equipment interruption (switching shunt banks or filters)
- Unlike traditional converter technology, VSC design supports the multi-terminal ring design goals of Tres Amigas and can be scalable
- The VSC converters make power control flow changes rapidly and accurately
- Dispatch control is significantly improved and simplified thereby improving the performance and efficiency of the interconnected AC networks

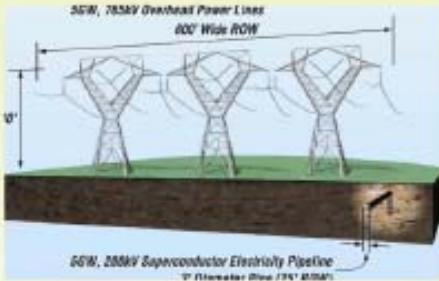
### DC Superconductor Ring

Key to the Tres Amigas SuperStation is an underground pipeline of direct current (DC) superconductor cables less than three feet in diameter capable of carrying more than 5,000,000,000 watts (5 gigawatts) of electricity with no electrical losses; enough electricity to power 2.5 million homes. Superconductor cables:

**Enhance efficiency:** When the station is running at full power, the superconductor pipeline can save as much as 60,000,000 kW-Hrs of energy annually compared with conventional transmission technology. That's equivalent to the electricity usage of 30,000 homes and a 40,000 ton reduction in CO2 emissions.

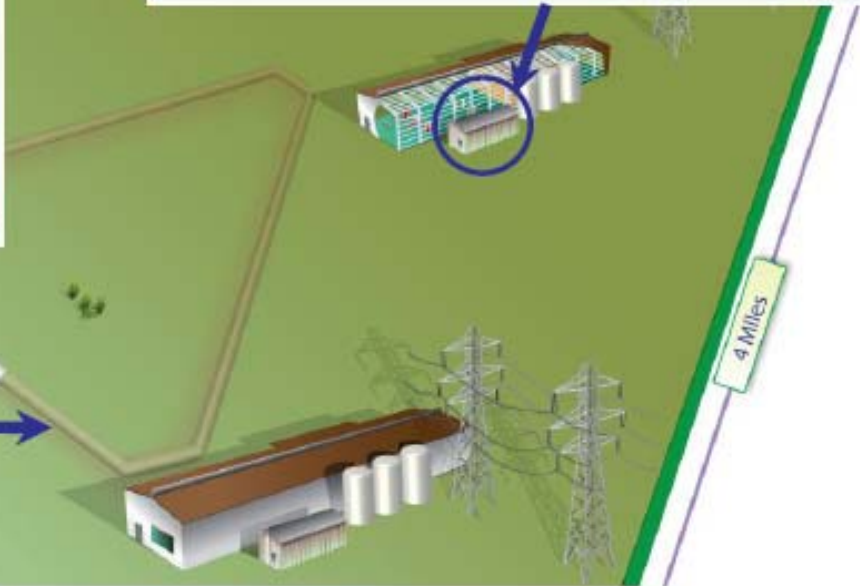
**Are out of sight:** A single, underground superconductor pipeline can carry as much power as three, 765kV AC overhead transmission lines (see figure).

**Increase power security:** Unlike overhead lines, underground cables are virtually immune to weather-related outages, the most common cause of power disruptions. Similarly, underground placement makes them less subject to vandalism and other forms of willful attack.



### Energy Storage Battery

Each HVDC terminal is equipped with an advanced battery system to provide both back up to the renewable energy purchased by Tres Amigas to run the facility and to provide what are termed "ancillary services" support to the connecting AC systems.



### What are Superconductors?

A superconductor is a perfect conductor of electricity; it carries direct current with 100% efficiency. When properly cooled, superconductor wires provide significant advantages over conventional copper and aluminum wires because they can transmit 150 times more electricity than conventional wires of the same size.



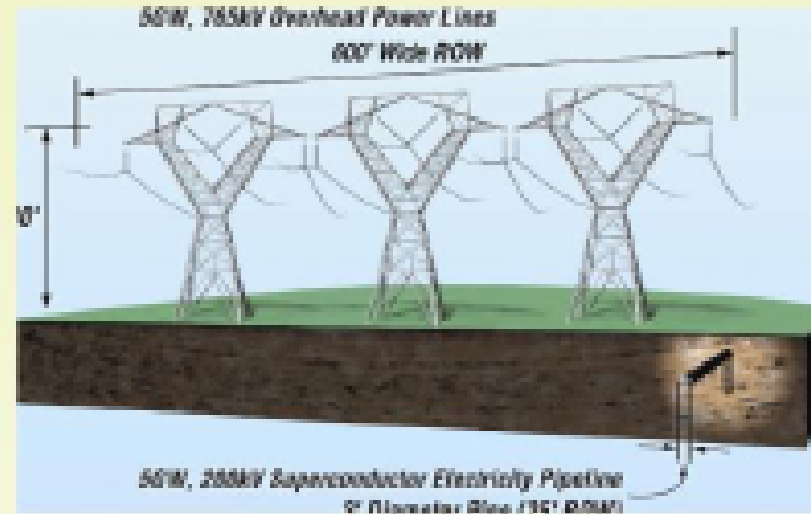
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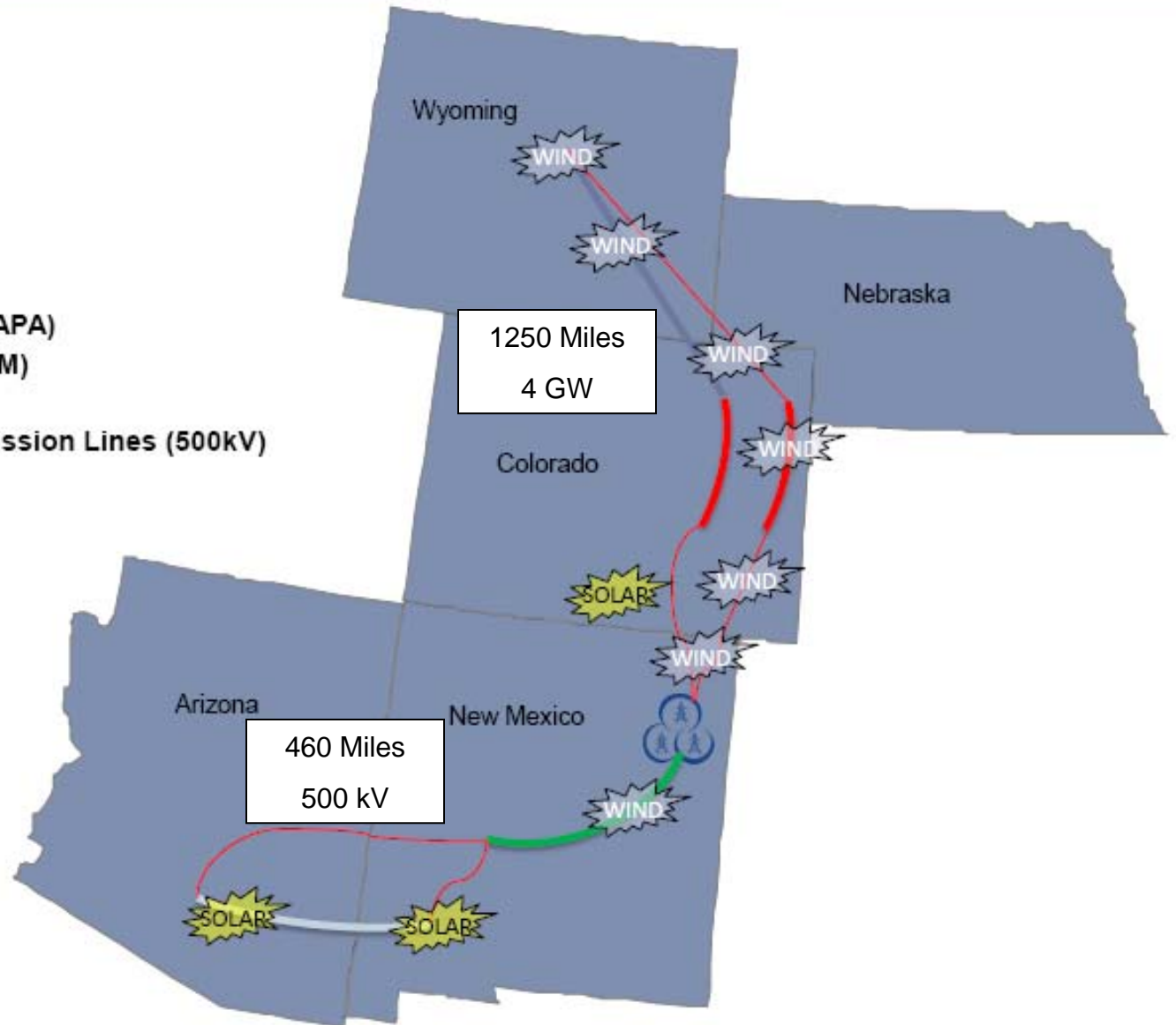
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# Potential Beneficiaries in WECC



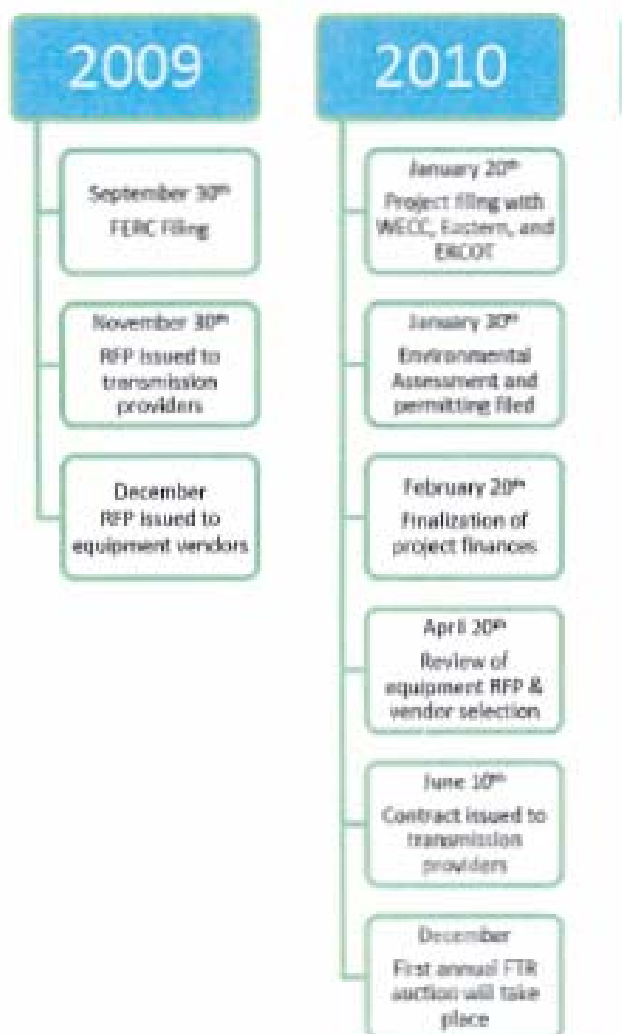
- WCI (TE/WIA/WAPA)
- FFTP (Tri-State/Xcel/WAPA)
- NM Wind Collector (PNM)
- SunZia
- HPX Proposed Transmission Lines (500kV)





# Milestones

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"Superconduct-ress"



# Mr. Electric Utility Good Ol' Boy

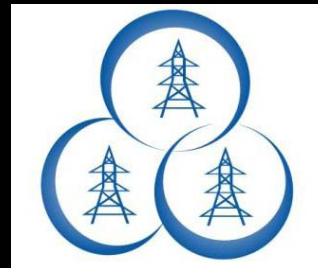
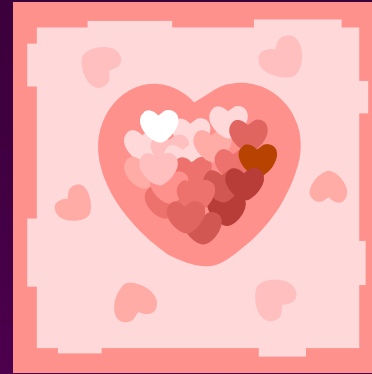


# Miss Same Old Technology



# Together Forever?





Meet

**Phillip G. Harris**