Electric Power System Innovations in the Era of Restructuring

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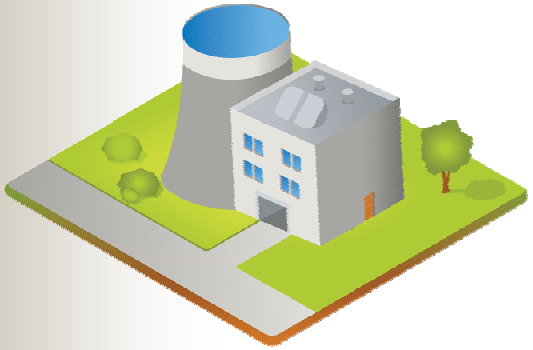
Outline

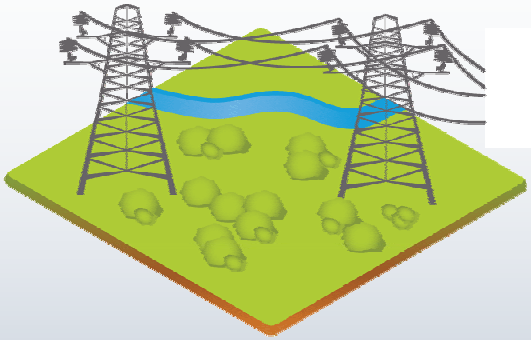
- Challenges of Electricity Restructuring and Privatization
- Innovation in Electricity Infrastructure
  - Supply Adequacy and Economics: Renewable Energy and Distributed Generation
  - Transmission Expansion and Security: Self-Healing and Distribution Automation
  - Energy Efficiency and Smart Grid: Price Response, Consumption Reduction, Capacity Market
- Electricity Infrastructure of Tomorrow

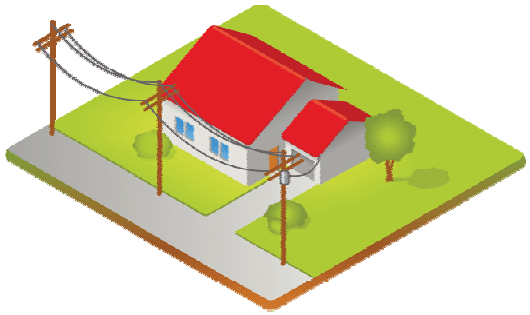
The Interconnection

- Edison designed the entire electrical system down to the wall outlet and in 1881 established the first power company
- In the 1930s, isolated power systems melded into interconnected systems
- In the 1950s and 1960s, isolated systems were converted to large regional pools
  - bulk delivery over long distances
  - originated at large generating plants
- With economies of scale, prices declined and demands increased

Electric Grid







Generation	Transmission	Distribution
17,000 plants with 994 GW	160,000 miles	Over 1,000,000 miles
65% of monthly bill	5% of average customer monthly bill	30% of average customer monthly bill
Employs approx. 120,000 people nationwide	Employs approx. 45,000 people nationwide	Employs approx. 400,000 people nationwide

Vertically Integrated Utility

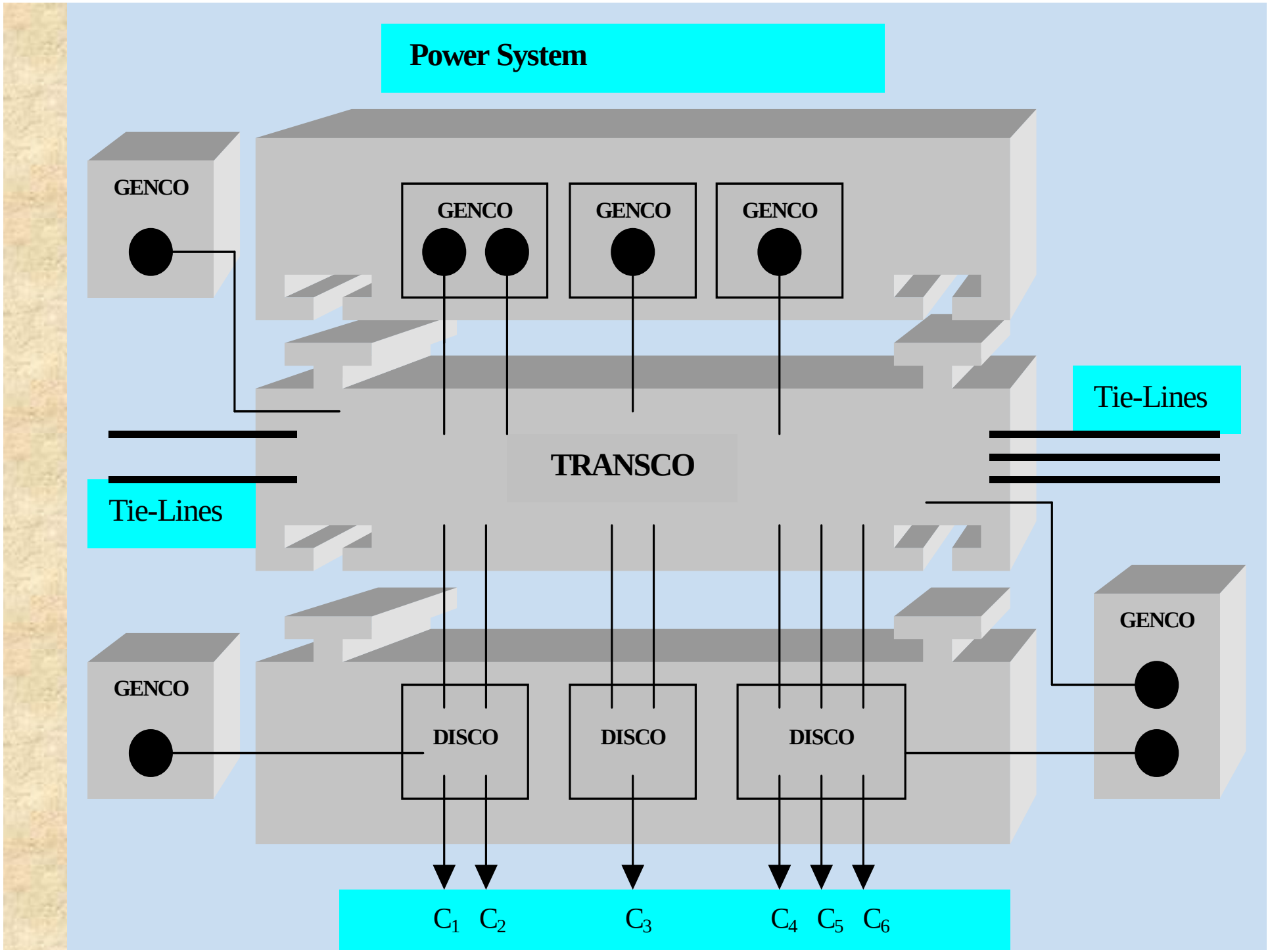
- Vertically integrated company established exclusive franchise within a service territory
  - Regulated prices that guaranteed a fair rate of return on invested capital
- A long period characterized by increasingly centralized power generation, declining average costs, and stable prices was upset by energy supply disruptions and high capital costs of 1970s
- These developments prompted price increases and sparked consumer advocacy for cheaper and more reliable service that was coincident with a growing environmental awareness

Natural Monopoly

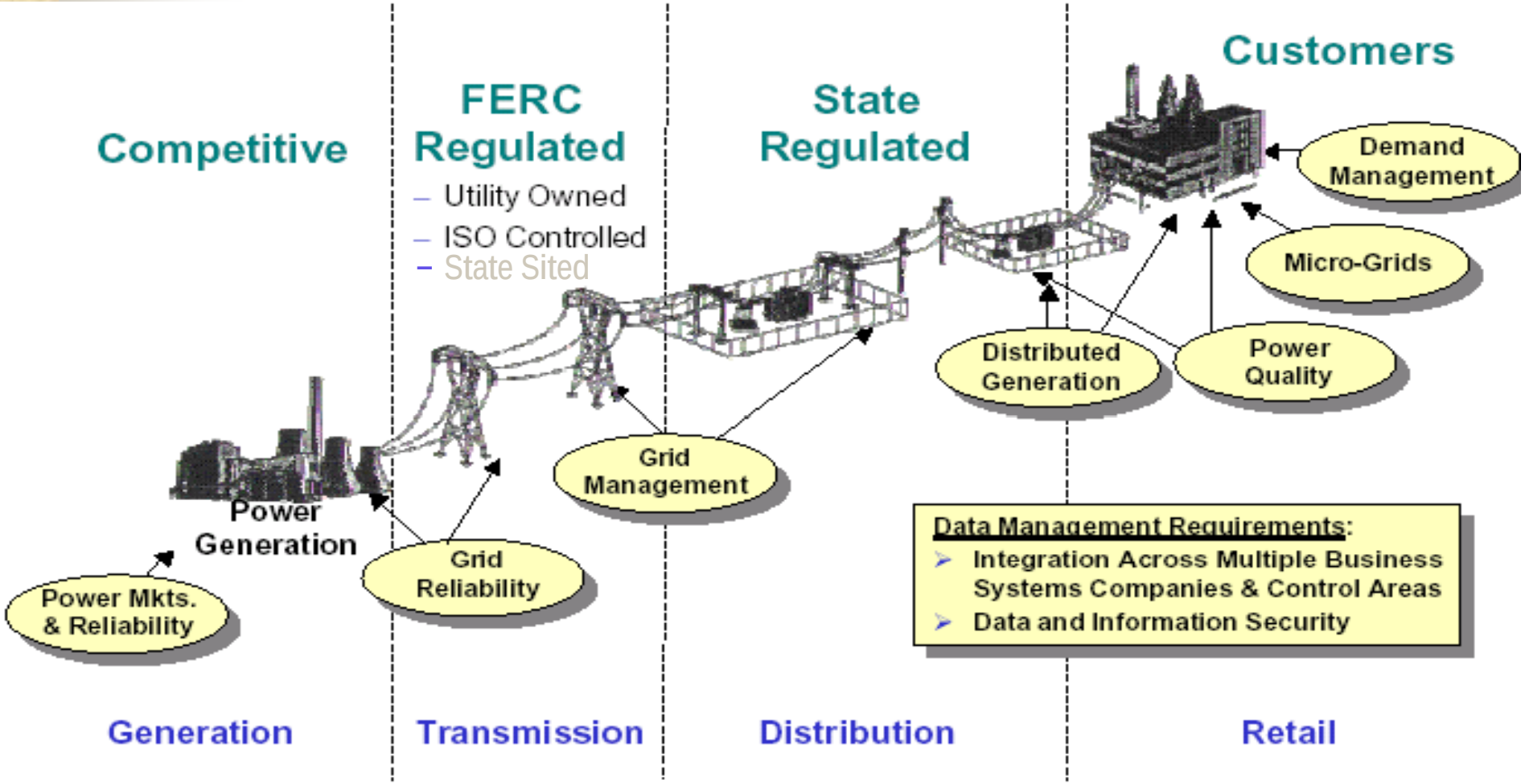
- Electricity service was considered to be a natural monopoly.
  - A service provider is equipped to serve customers more efficiently
- Electricity industry as a natural monopoly
  - Capital intensive: generating plants, transmission network, and distribution network
  - Efficiency: the larger the generating capacity, the more efficient
  - Regulation: public utility commissions regulated customer prices

Natural Monopoly No More…….

- Higher fuel costs and environmental concerns required more diversified generation portfolios
- Emergence of new technologies challenged the natural monopoly
  - Efficiency
    - size is not the only determining factor (combined-cycle units)
  - Generation, Transmission, and distribution
    - distributed generation (locally installed wind, photovoltaic)
    - superconductors (massive transmission)


Power System
GENCO
GENCO
GENCO
GENCO
Tie-Lines
TRANSCO
Tie-Lines
GENCO
GENCO
DISCO
DISCO
DISCO
C1 C2 C3 C4 C5 C6

Electric Power Infrastructure

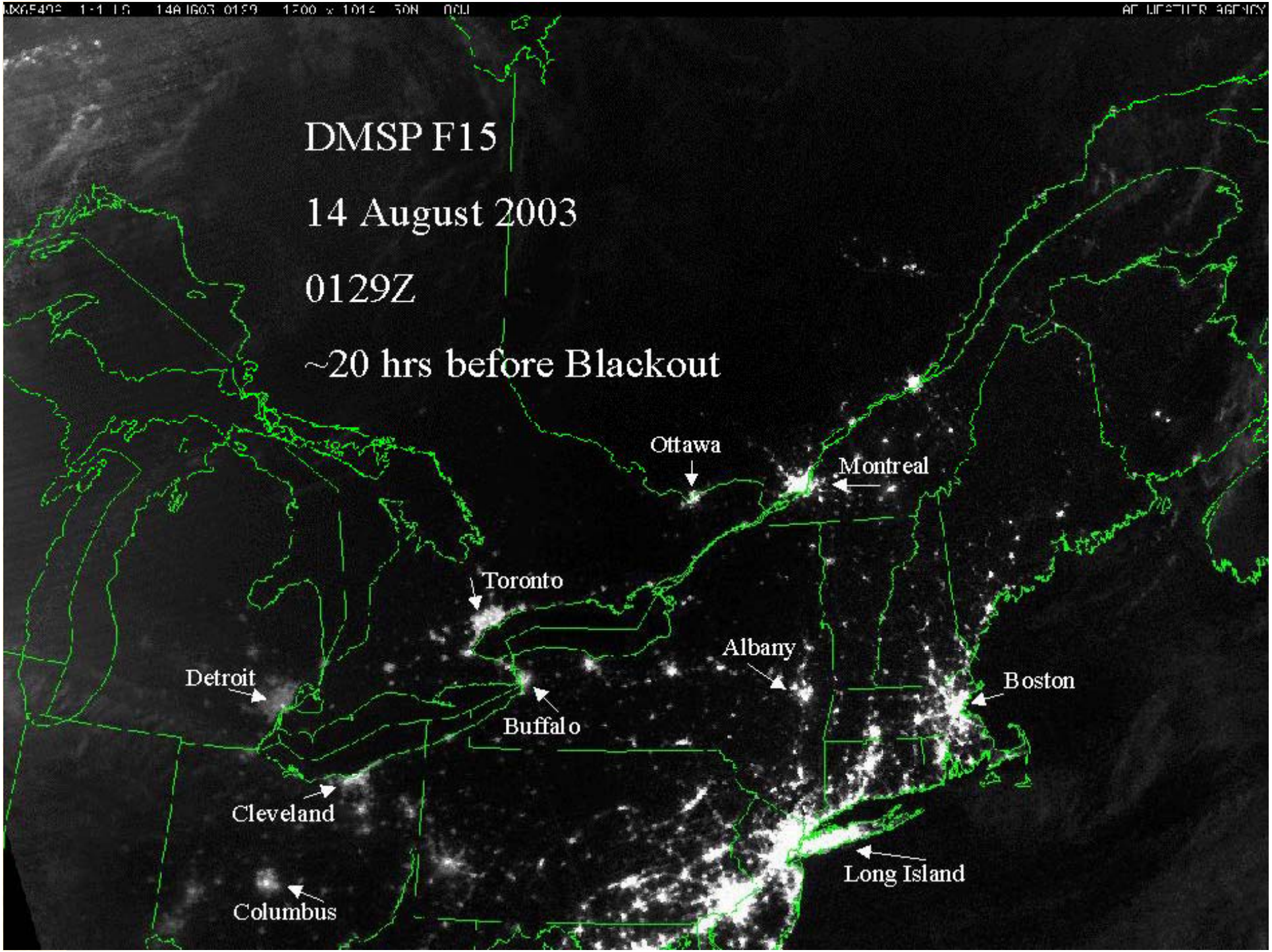


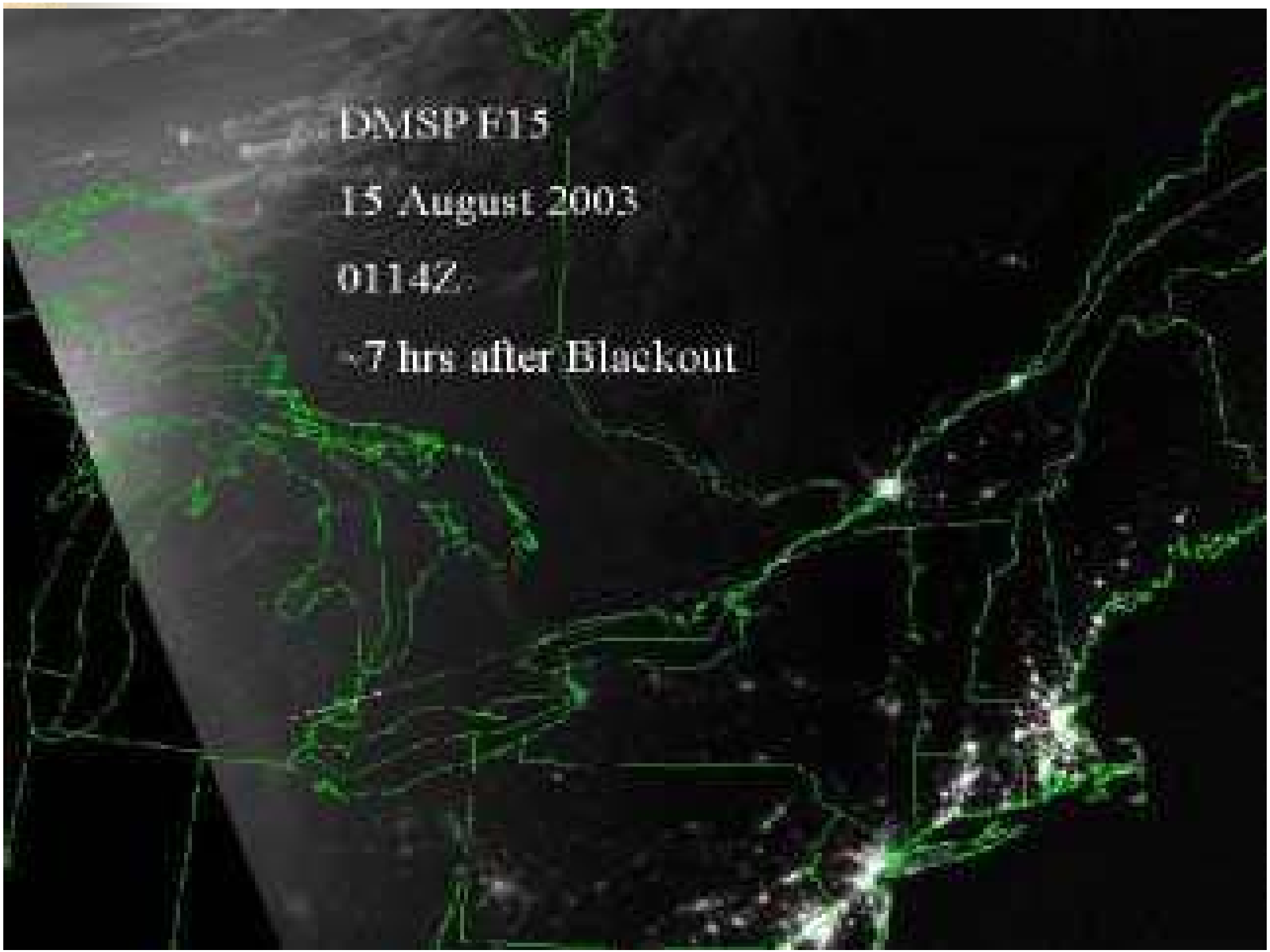
Power System Challenges

- Competition has increased the stress on power delivery system
  - The quest for the lowest cost power delivery has led to an explosion of power transactions
- Power system was not designed for the fast pace of competition
  - Power system is largely based on the 1950s technology
  - Strain on the aging system is beginning to show in digital era

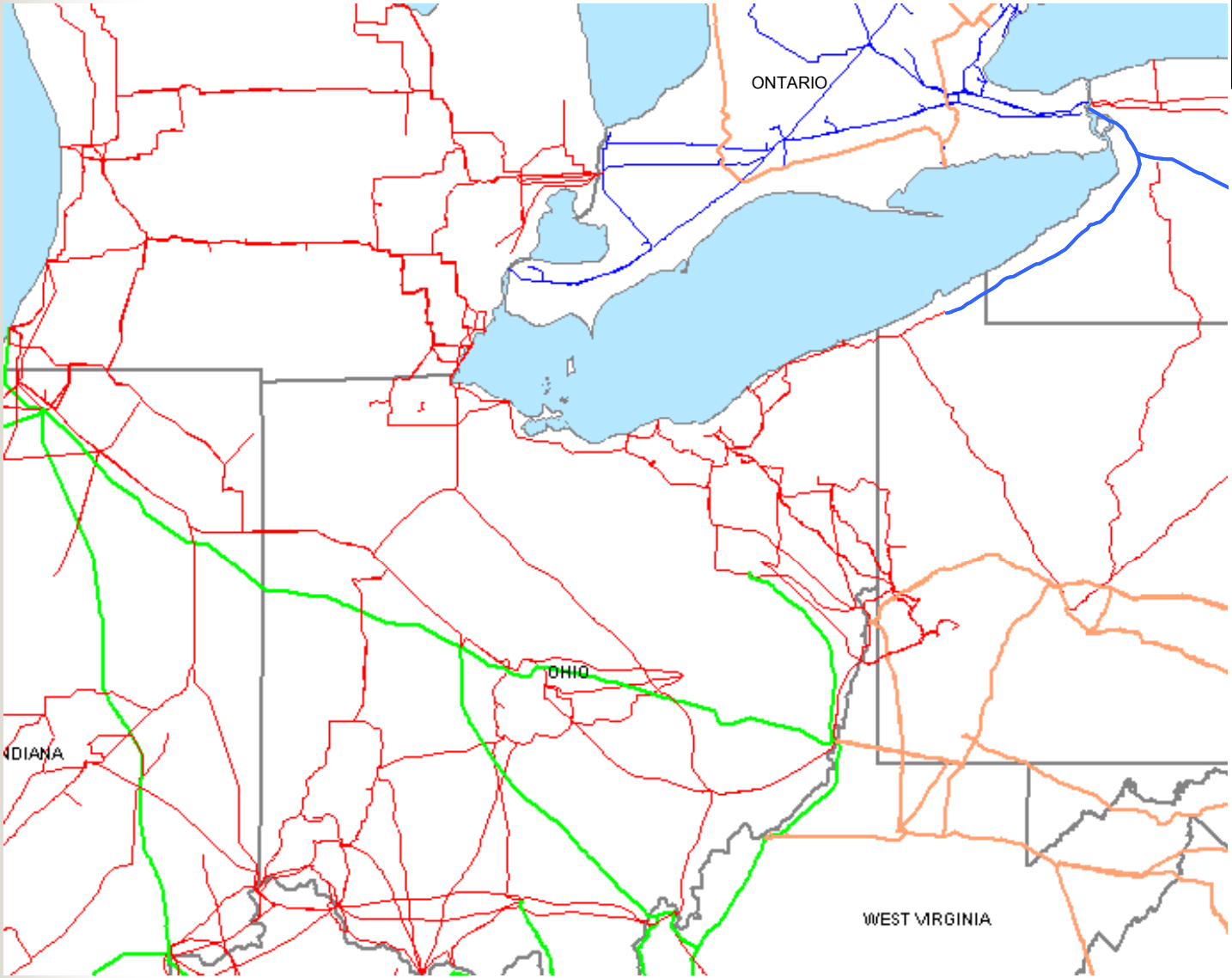
Power Grid – Trends and Drivers

2006		2030
• 4% renewable (non-hydro) • 7% hydro • 19% nuclear • 20% natural gas • 49% coal	Changing Supply Mix	• Renewables increasing • Nuclear • Fossil fuels decreasing • Energy storage increasing • Carbon constrained future
• 1,000 GW capacity • Constrained regions-reliability concerns	Demand Requirements	• Load curves – increased peaking • Balancing with energy storage • More electrically sensitive equipment • Higher power quality demand • Transition to plug-in hybrids
• 140 control areas • 350,000 miles transmission lines • 10 million DG units	Complexity of Grid	• More transmission lines needed • Highly interconnected structure • More on-site generation • Wide-area monitoring and real-time control
• Aging Infrastructure • Vulnerabilities – cyber • Age of Workforce	Vulnerability of Energy Infrastructure	• Increased interdependencies • Material and resource limitations • Increased use of IT, communications, and controls • Multi-discipline workers


DMSP F15
14 August 2003
0129Z
~20 hrs before Blackout
Ottawa
Montreal
Toronto
Albany
Boston
Detroit
Buffalo
Cleveland
Long Island
Columbus


DMSP F15
15 August 2003
0114Z
~7 hrs after Blackout

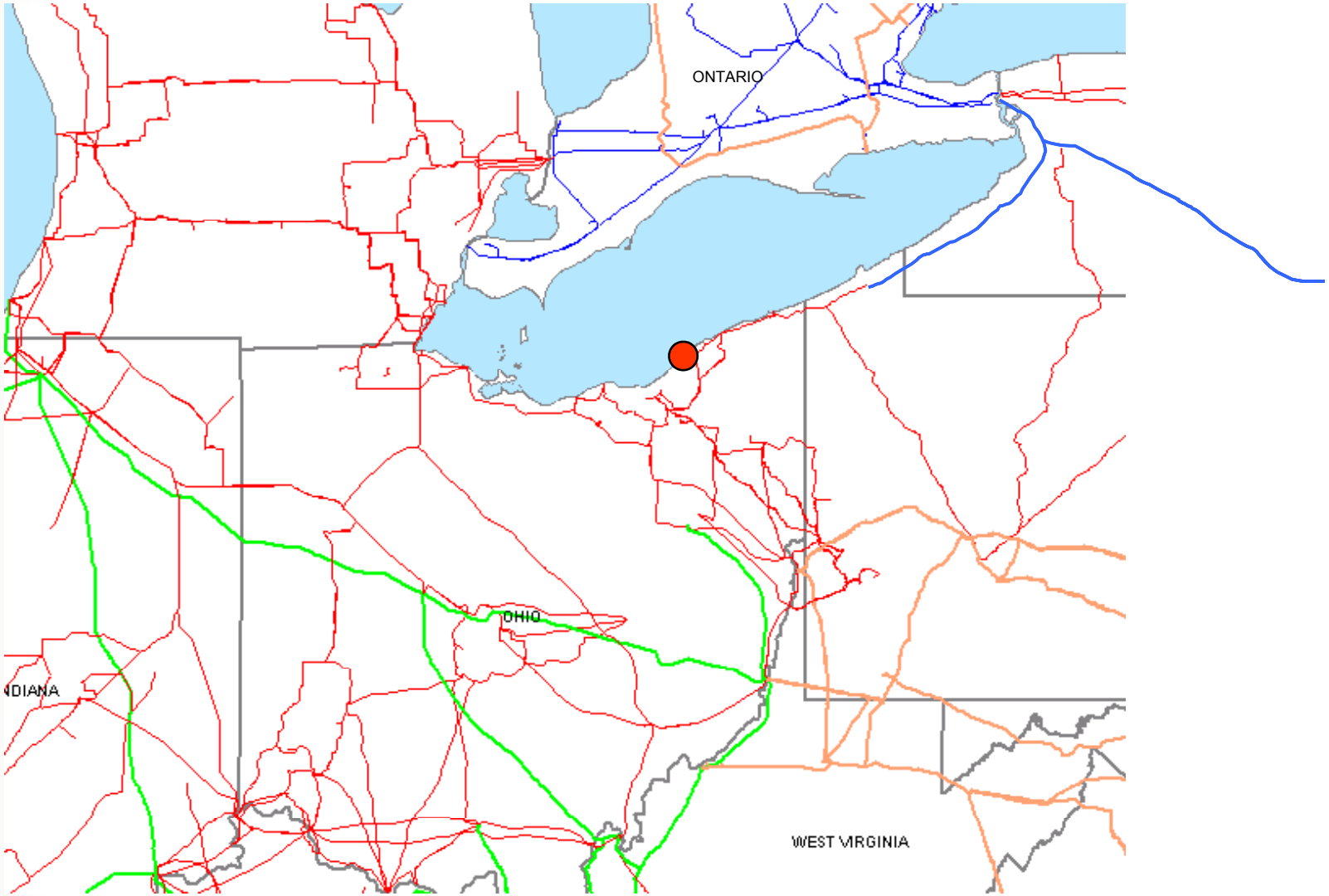
Outage Sequence of Events

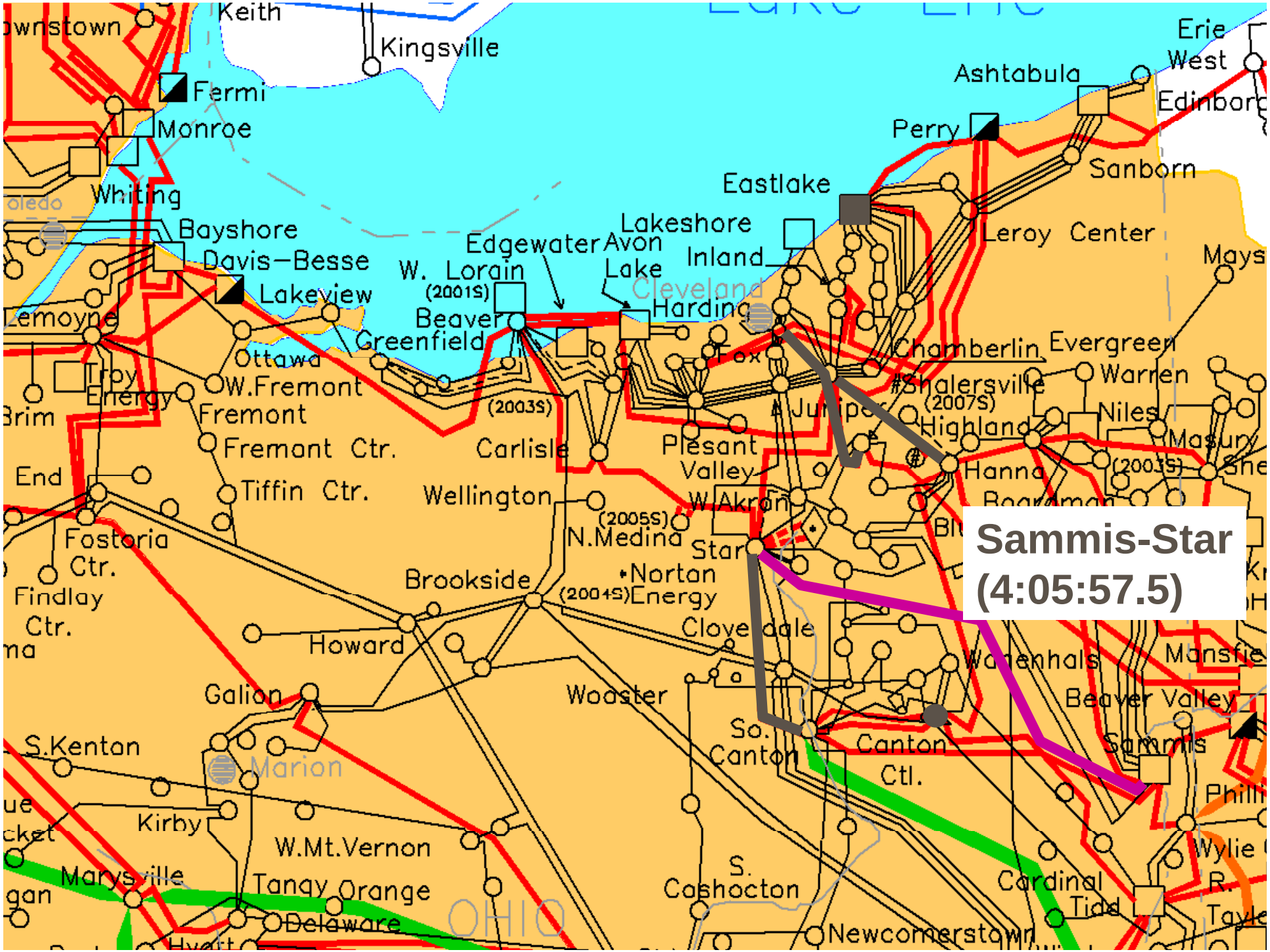


Transmission Lines

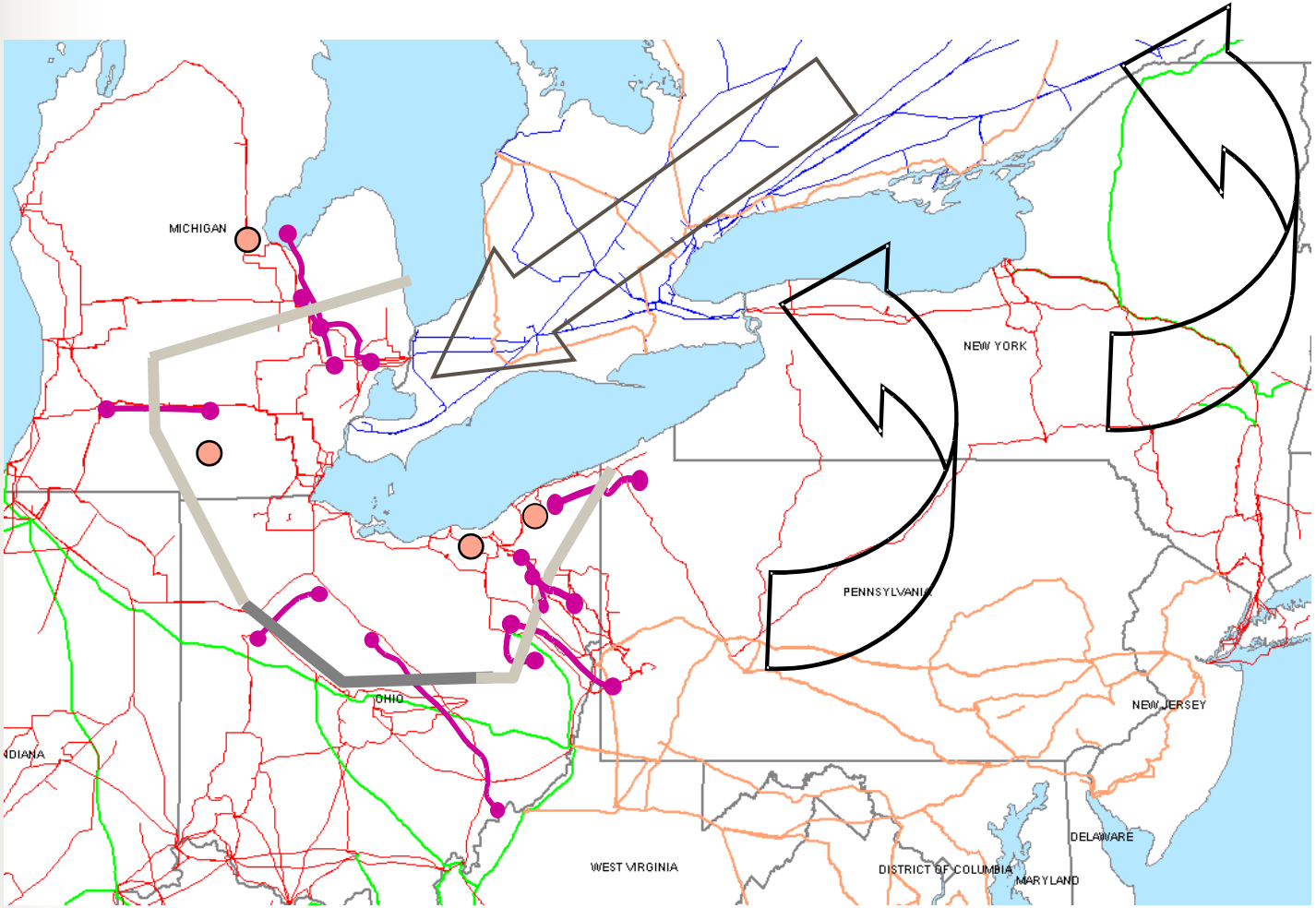
- 765 kV
- 500 kV
- 345 kV
- 230 kV

East Lake 5 Trip: 1:31:34 PM

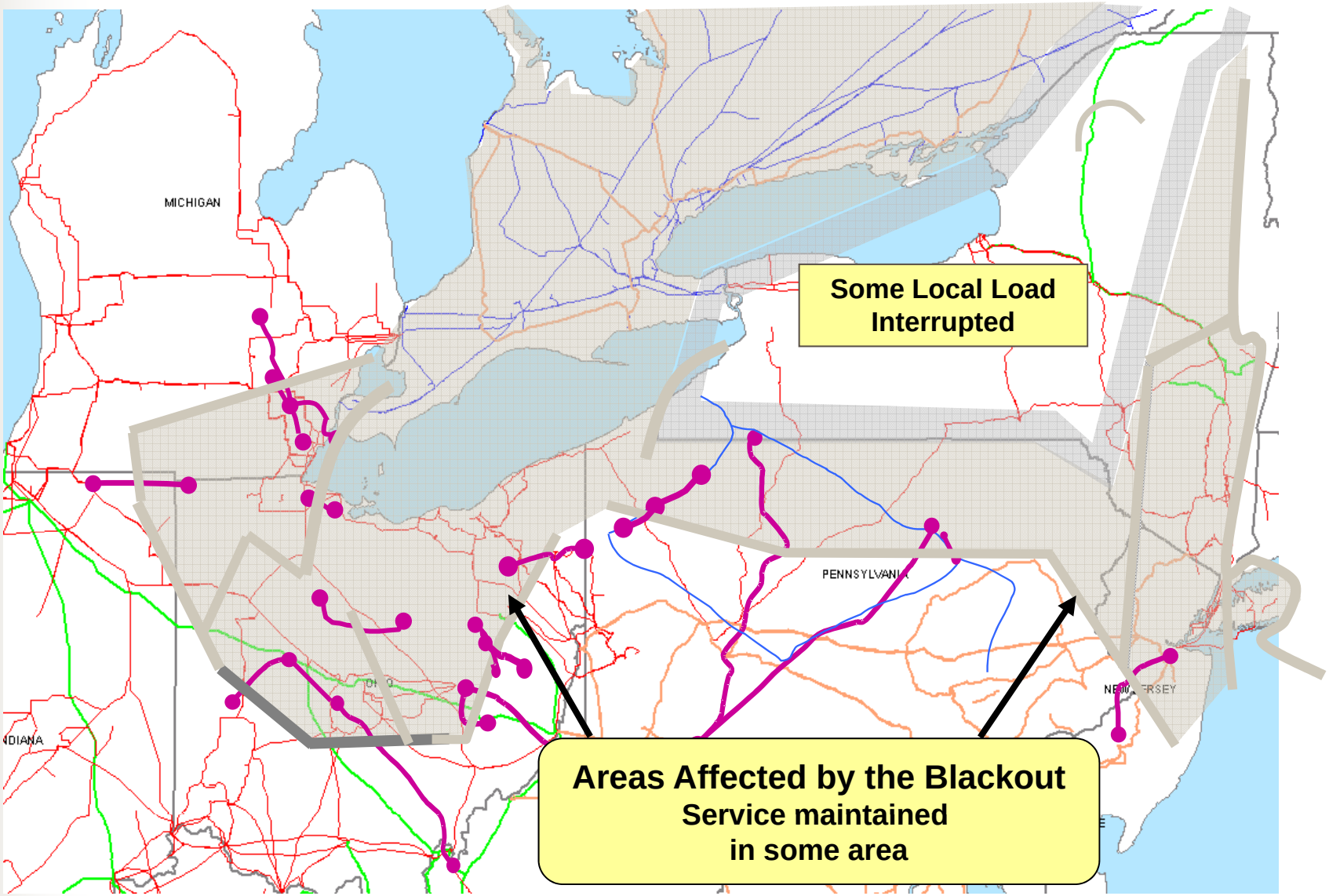



Sammis-Star
(4:05:57.5)
Keith
Kingsville
Fermi
Monroe
Whiting
Bayshore
Davis–Besse
Lakeview
Ottawa
W.Fremont
Fremont
Fremont Ctr.
Tiffin Ctr.
Fostoria
Ctr.
Findlay
Ctr.
Galion
S.Kenton
Marion
Kirby
W.Mt.Vernon
Tangy Orange
Delaware
OHIO
Brookside
Howard
Wellington
Carlisle
Edgewater
W. Lorain
(2001S)
Beaver
Greenfield
(2003S)
Avon
Lake
Lakeshore
Inland
Harding
Cleveland
Fox
Pleasant
Valley
W.Akron
N.Medina
(2005S)
Norton
(2004S)
Energy
Star
Wooster
So.
Canton
Canton
Ctl.
S.
Coshocton
Newcomerstown
Cardinal
Tidd
Sammis
Beaver Valley
Wayne
Mansfield
Perry
Eastlake
Ashtabula
Erie
West
Sanborn
Leroy Center
Chamberlin
Evergreen
Warren
Shalersville
(2007S)
Highland
Hanna
Niles
Mays
Troy
Energy
Brim
End
Lemoyne

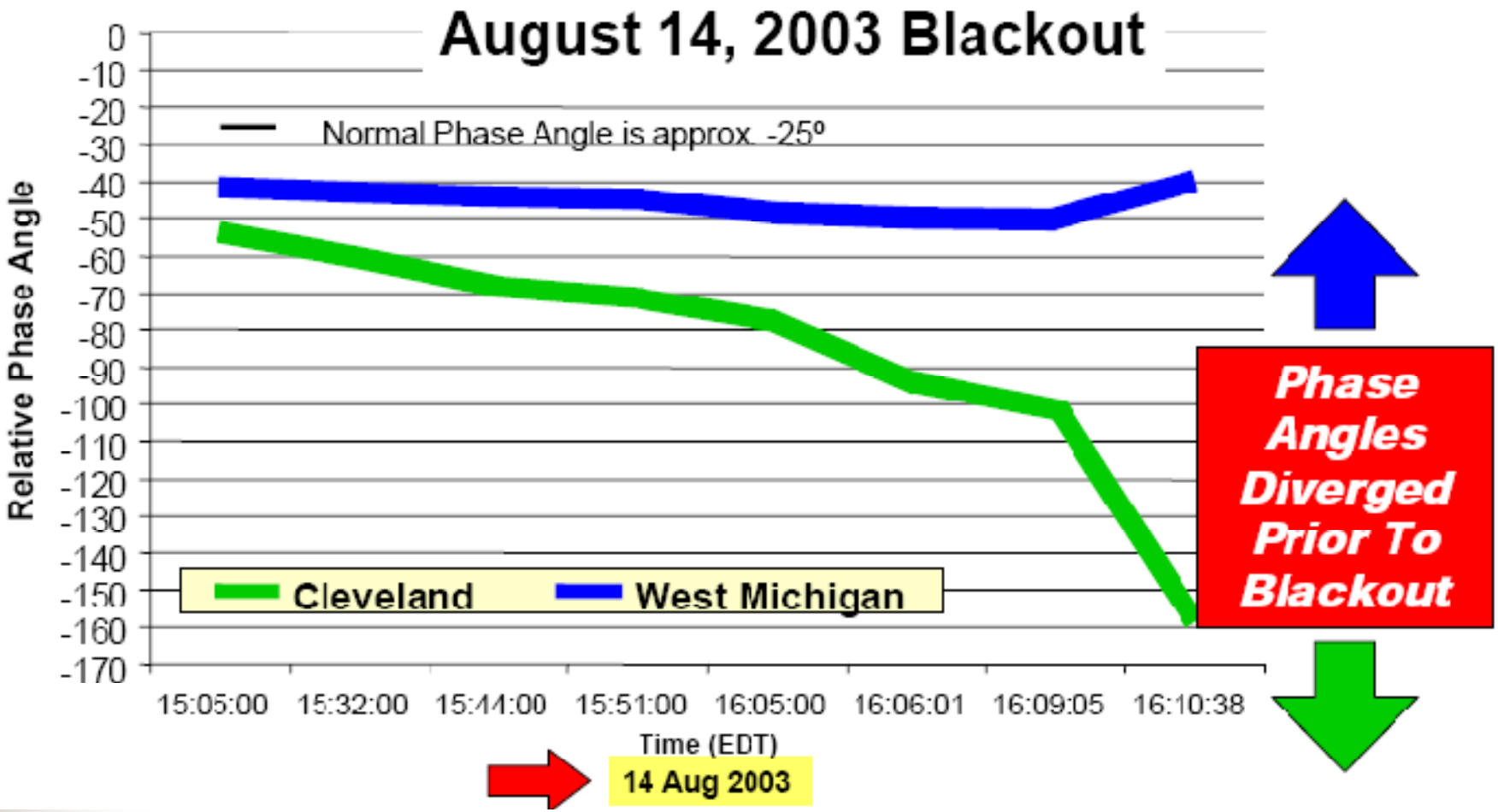
Power Transfers Shift at 4:10:38.6 PM



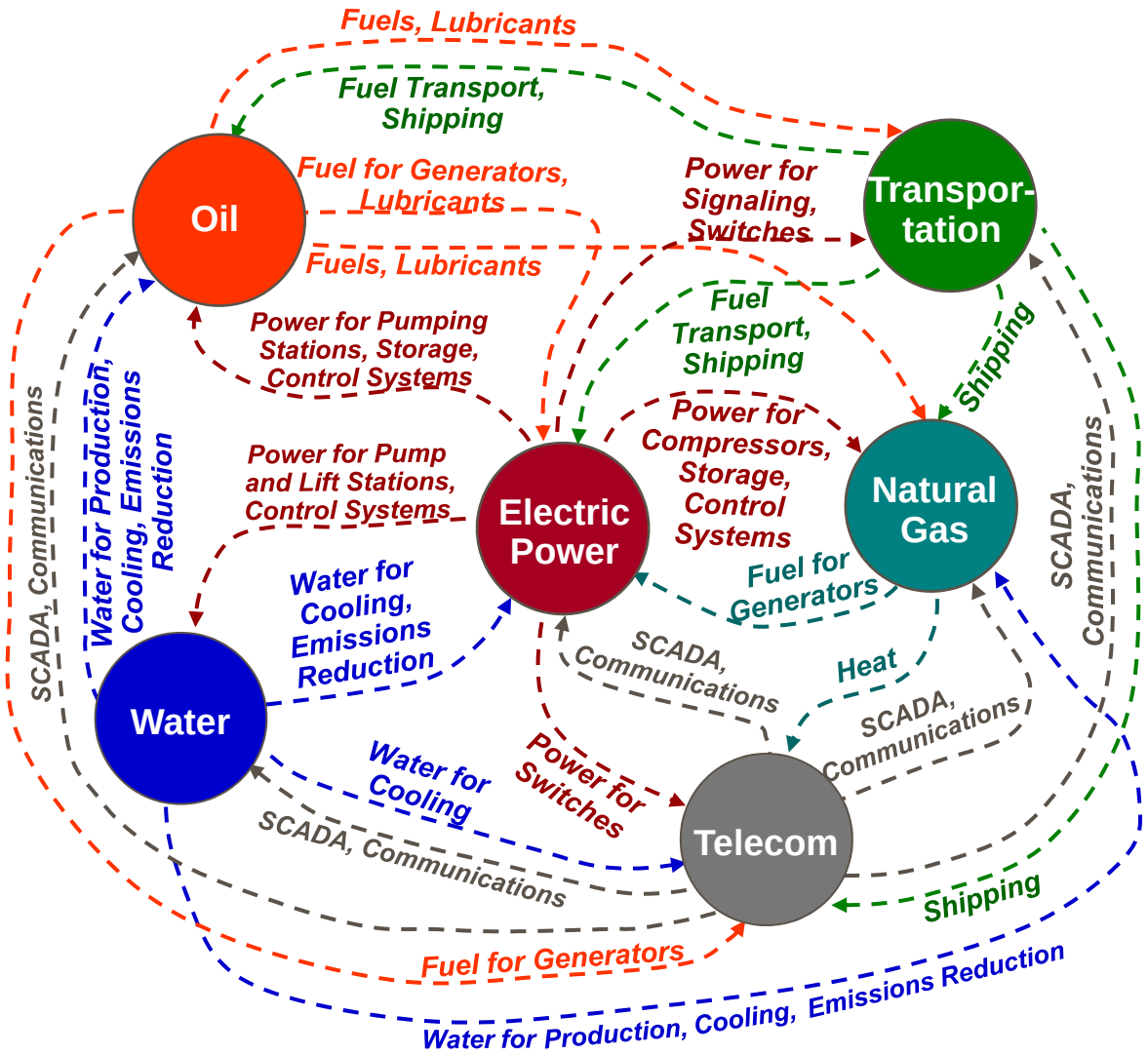
End of the Cascade



Lack of situational awareness led to Blackout



Interdependent Infrastructures



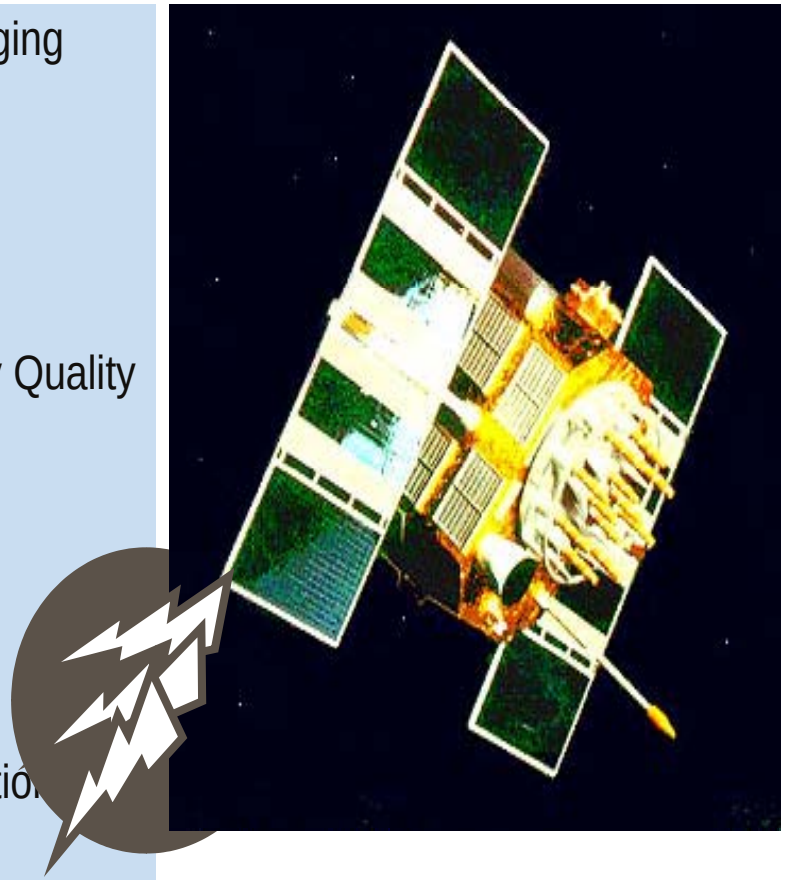
Global Strategic Pathways

By 2030, if governments stick to their current energy policies, the global energy consumption will increase by another 50%

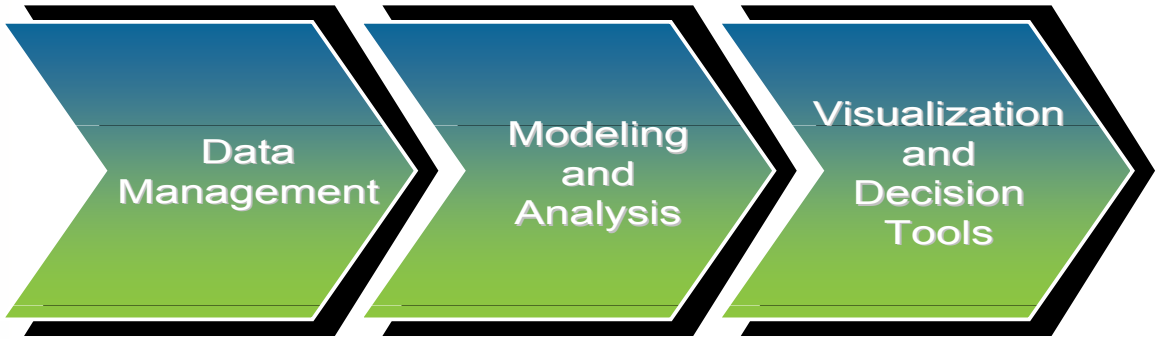
- Adapt the electric grid to a low carbon future (Reduce Emission and Improve Climate Changes)
  - Generation: deploy abundant affordable zero/low carbon domestic resources
  - Transmission: catching up to today's grid needs *and* enabling a low-carbon future
  - Increase the power density of existing corridors
- Develop the Smart Grid (sensor-data collection, monitoring, and automation)
  - Advanced monitoring and analysis (phasor measurement units, RTDS operational modeling, advanced metering, consumer EMS)
  - Enable electrification of human transportation (i.e., plug-in hybrid vehicles)
- Build-in Security (prevent blackouts)
  - Control System Security (vulnerabilities)
  - Diagnostics (intrusion detection, anomalies)
  - Recovery (resiliency) – Survivable Systems

Phasor Measurement Technology – Key for the Future

- Phasor Measurement Units – Mature Hardware, Emerging Networks and Applications
  - Supplements 50-year old SCADA technology
  - GPS time synchronized high resolution data
  - Wide coverage
- Provides MRI of Power System Compared to the X-ray Quality for the Visibility of Traditional SCADA
  - Wide-area situational awareness
  - System dynamics monitoring
  - Improved modeling
- Addresses Current Industry Problems
  - Blackout prevention – early warning - and restoration
  - Visualization – wide area, common data, common displays
  - Reliability standards monitoring
  - Security Assessment – safe operating zones
  - Renewables integration



Computational Issues & Challenges



- Need for Information management and ways to aggregate, organize, and secure data
- Need for advanced models, analysis tools, and visualization for anticipating contingencies and preventing local disturbances from cascading into regional outages.

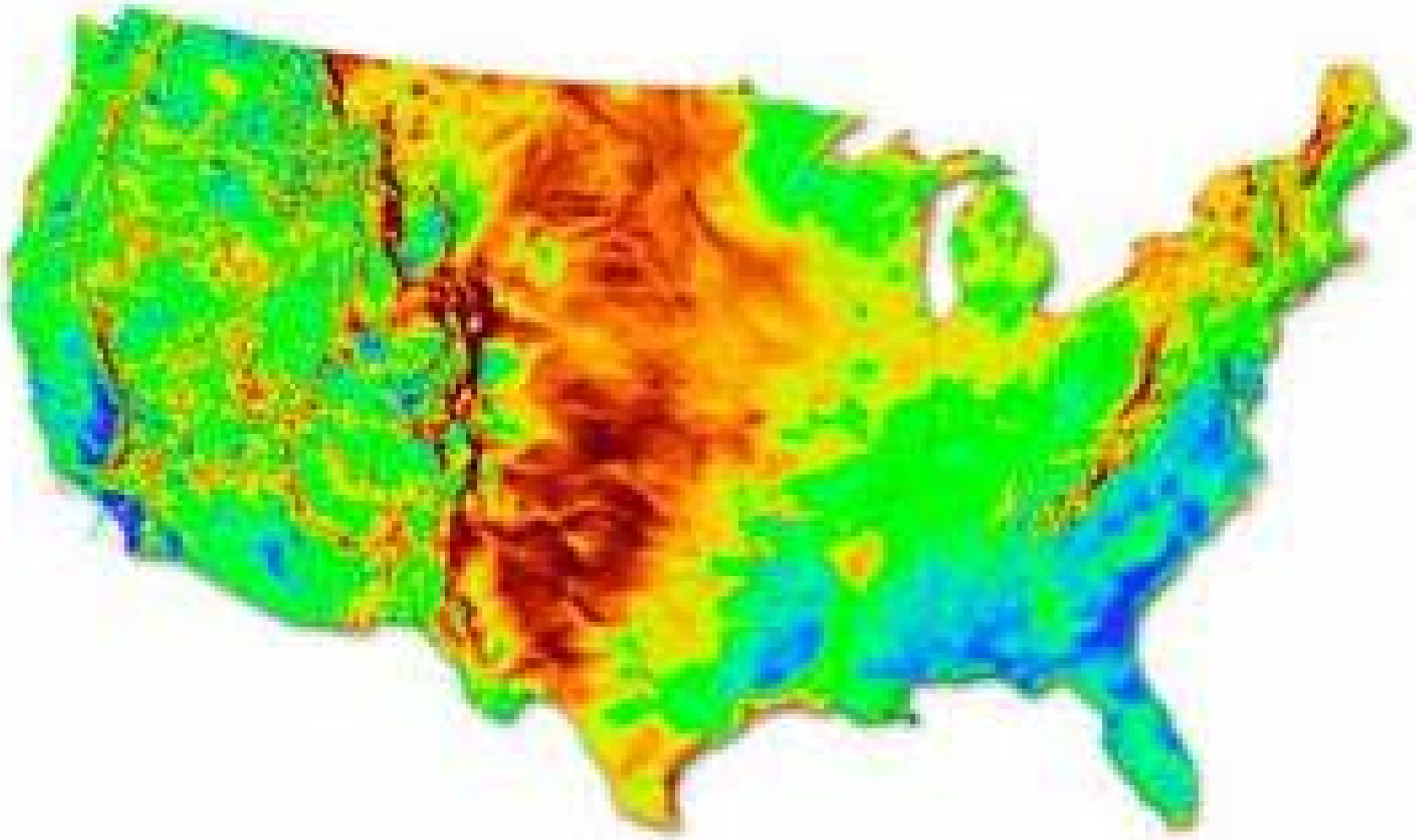
Flexible and Resilient Electric Power Grid

Reliability Areas	System Needs	Science & Technologies: Near Term	Science & Technologies: Long Term
Transmission Congestion	Control power flow & grid stability	• Power/flow control • FACTs devices ($$) • HVDC ($$)	• Power electronic devices • Solid state switch
	Increase power flow within existing corridors	• Advanced conductors • Next-gen transformers	• HT Superconducting cable • Energy Storage
Major Disruptions	Real-time control and responsive loads	• Advanced components • Distributed resources • Ancillary services • Real-time controls	• Advanced control concepts
	Wide area monitoring & visualization	• Phasor Measurement Units • Real time visualization	• State Estimation & Extreme Contingency
Power Quality & Momentary Outages	Power conditioning	•FACTs devices ($$) • HVDC ($$) •SuperVar • Energy storage ($$)	• Low cost storage •High-power electronics
	Rapid fault response	•Sensing & Detection •Real-time controls	• Fault current limiters • Real-time prediction tools
Security	Monitoring & visualization	• Remote wireless monitoring devices • Wide area visualization tools • Embedded sensors	
	Secure real-time controls & DG	• MicroGrid concepts •Advanced ICT & cyber security	• Survivable systems

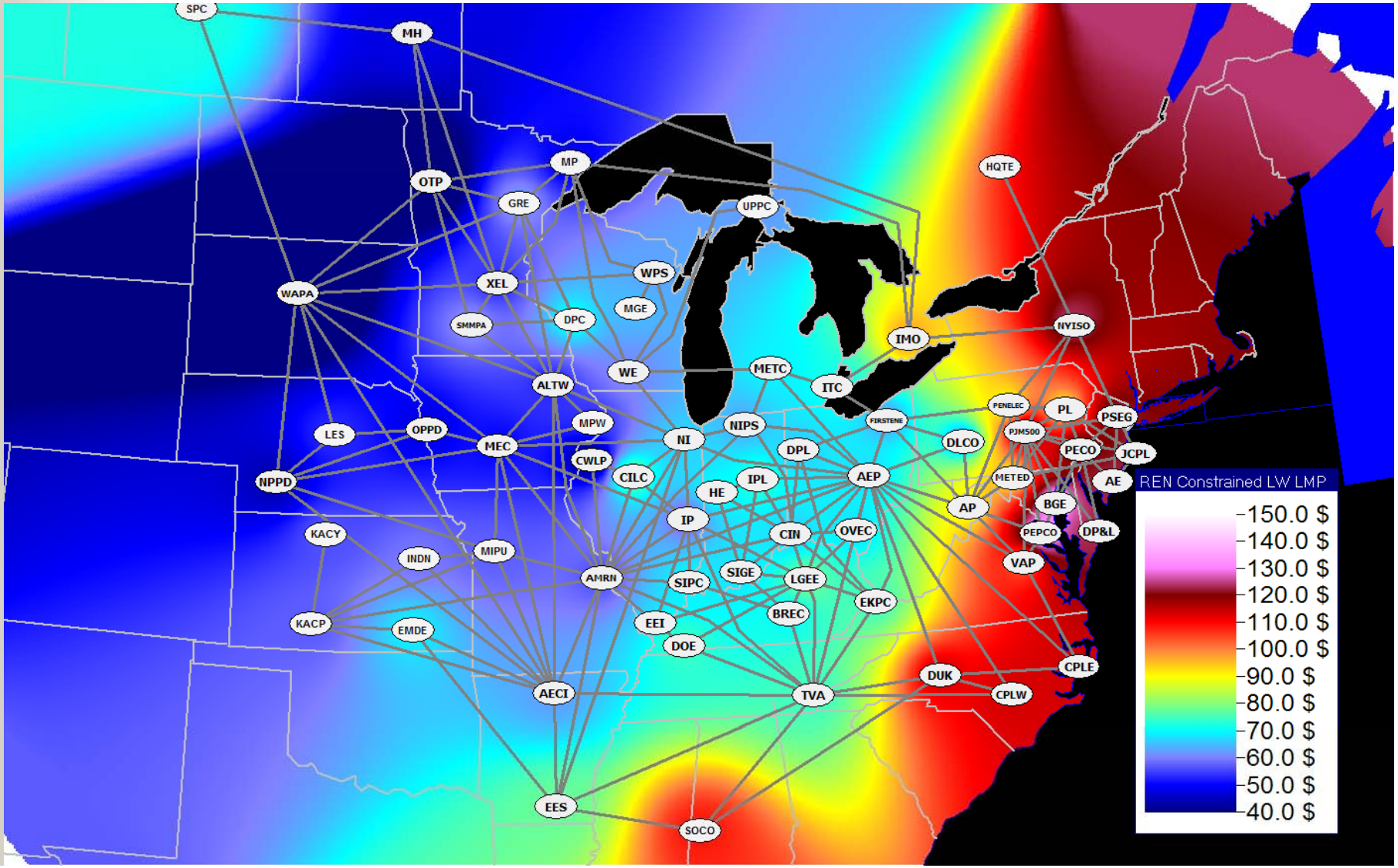
Attributes of Distributed Generation

- Clean energy source with a long life
- Fixed cost of electricity (cents per kWh)
- Pollution free and very quiet
- Reliable with minimal maintenance
- Competitive in price with other energy sources
- Modular and expandable with no T&D costs
- Energy independent (requires no fuel) with no contribution to green house gases

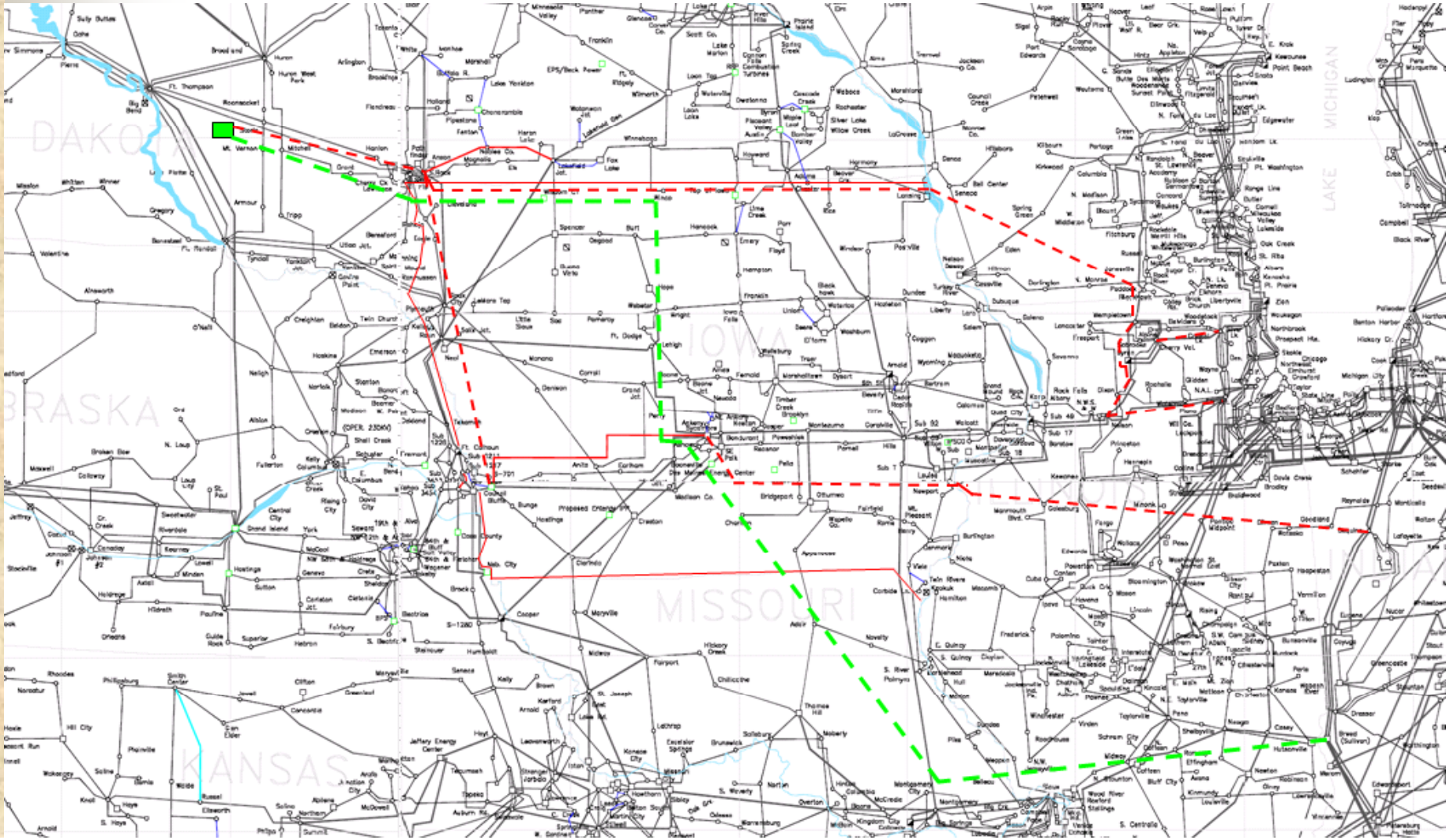
Transmission Expansion for Wind Power



Enhancing Wind Power Opportunities

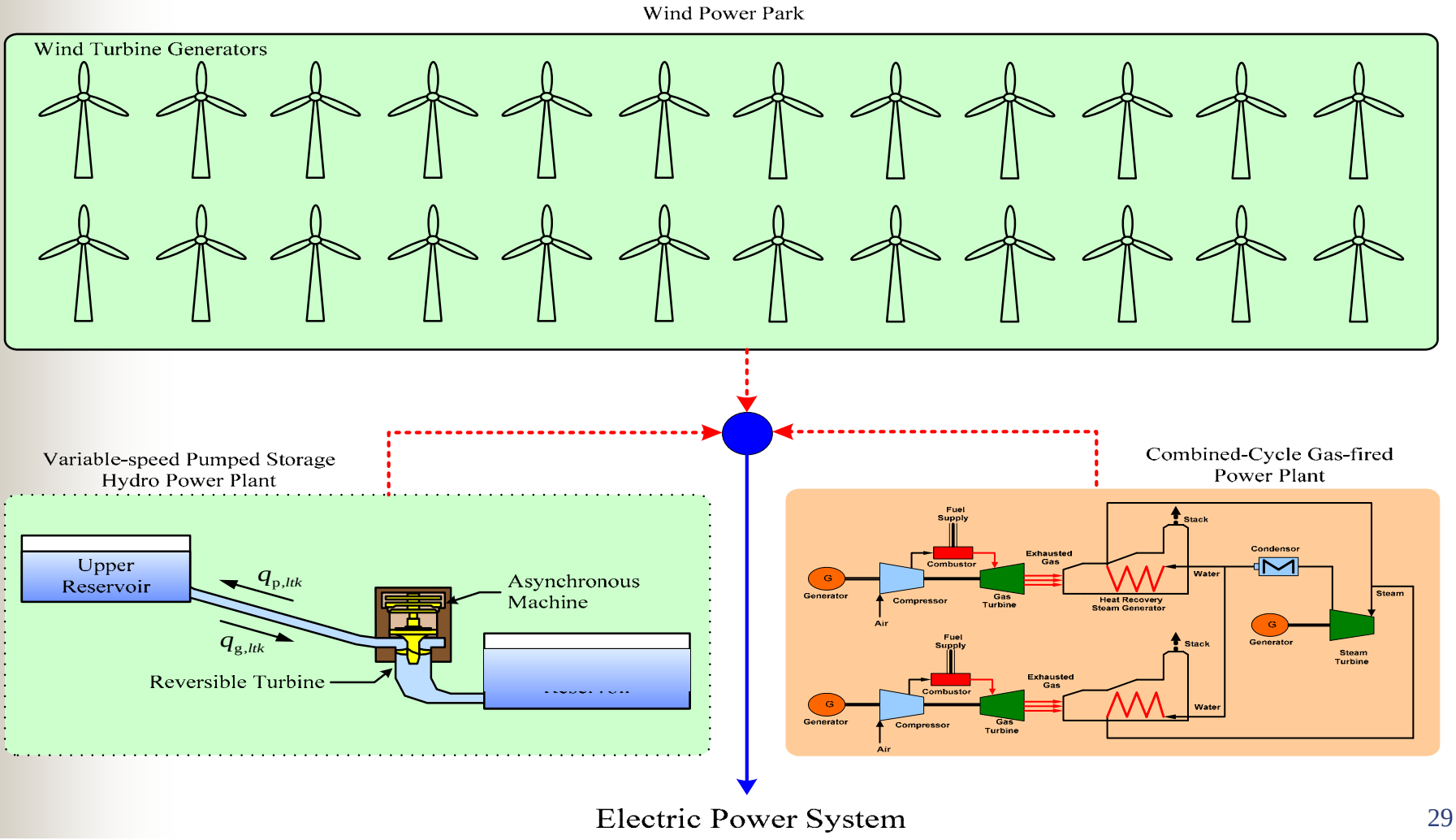


Wind Power Transmission



Renewable Supply Coordination

Coordinated Wind, Hydro, and Gas (WGH) Generating Resources



Major Rivers and Waterbodies in United States

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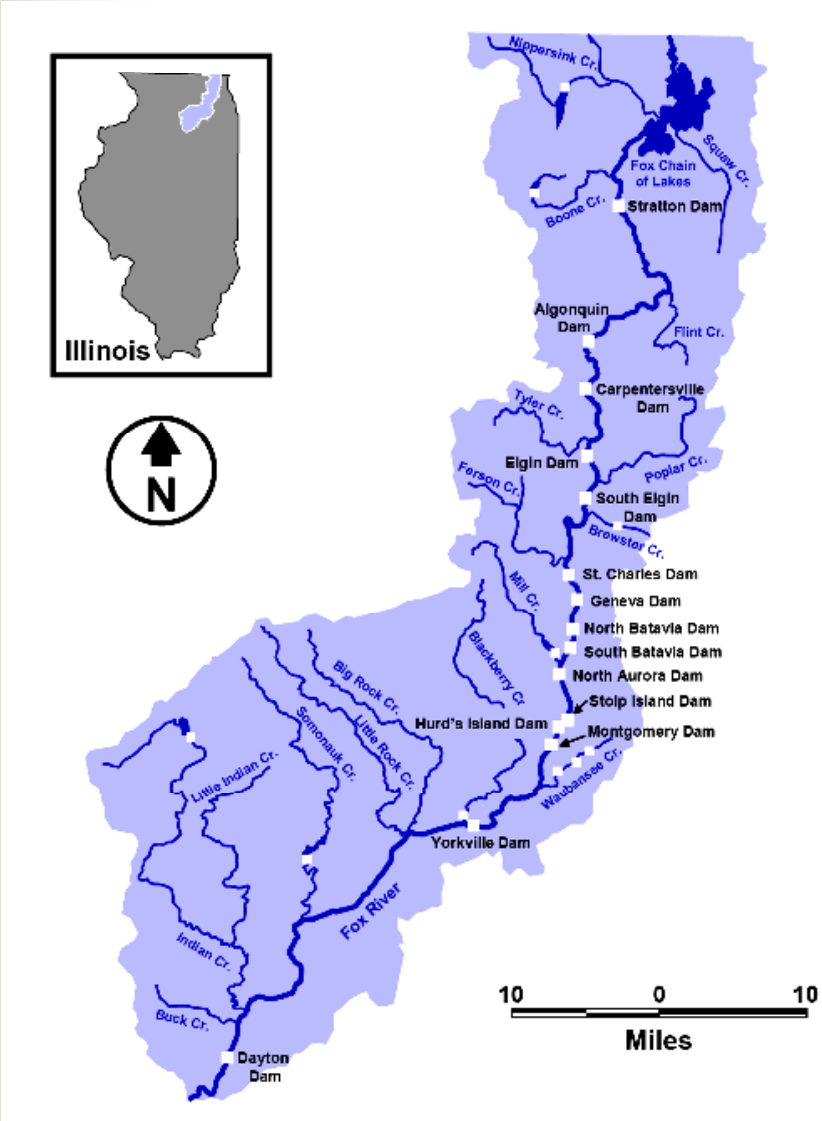
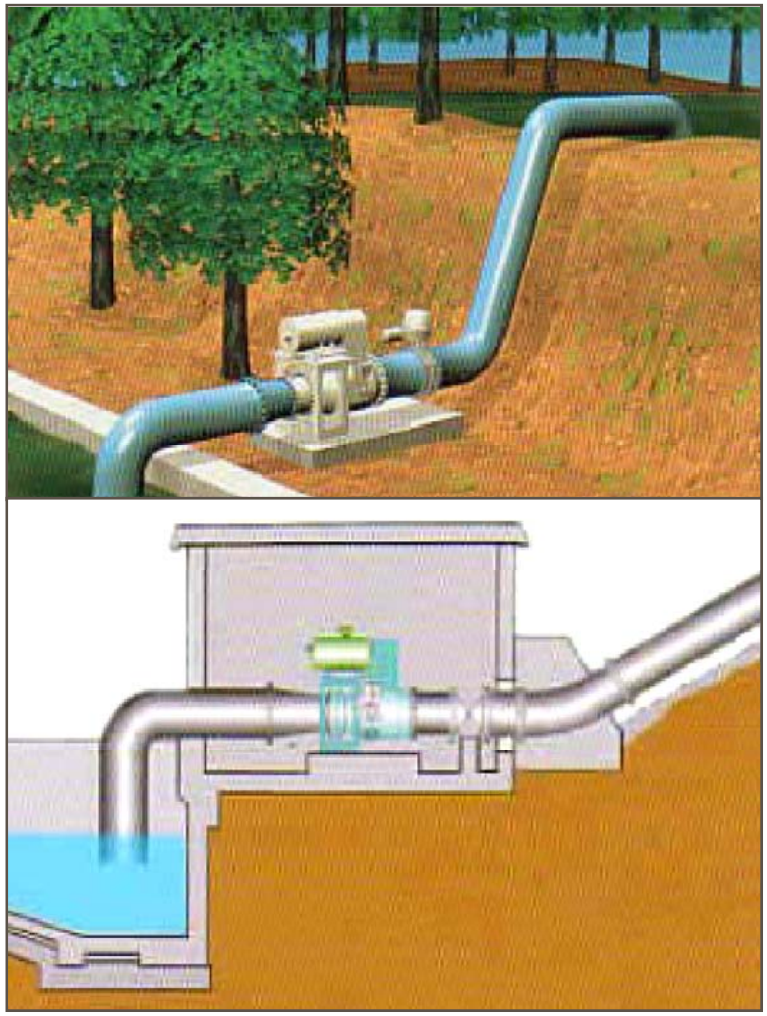
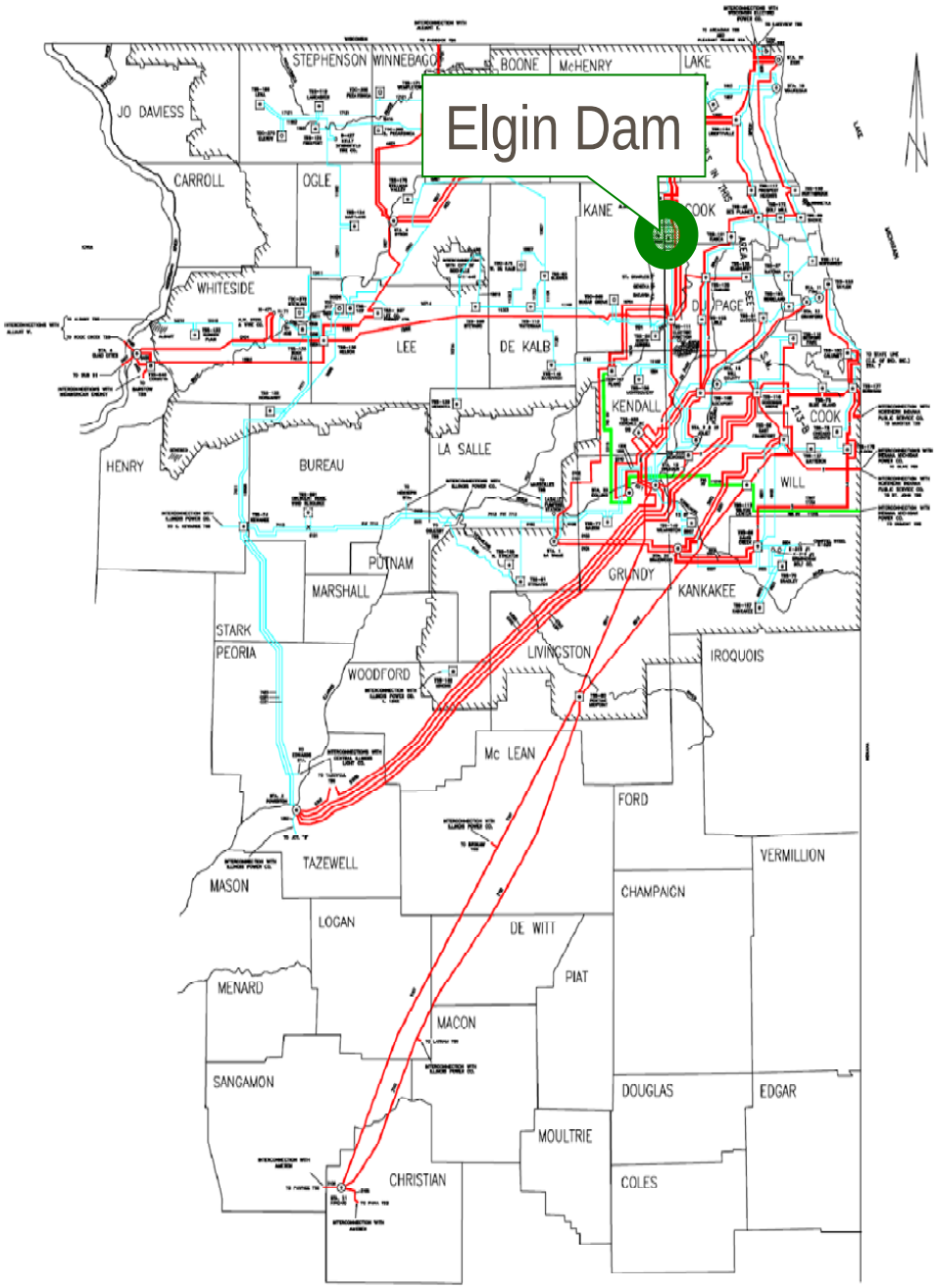

Illinois
N
Nippersink Cr.
Fox Chain of Lakes
Squaw Cr.
Boone Cr.
Stratton Dam
Algonquin Dam
Flint Cr.
Carpentersville Dam
Tyler Cr.
Elgin Dam
Poplar Cr.
Ferson Cr.
South Elgin Dam
Browster Cr.
St. Charles Dam
Mill Cr.
Geneva Dam
North Batavia Dam
South Batavia Dam
Blackberry Cr.
North Aurora Dam
Stolp Island Dam
Big Rock Cr.
Hurd's Island Dam
Montgomery Dam
Somonauk Cr.
Little Rock Cr.
Little Indian Cr.
Waubansee Cr.
Yorkville Dam
Fox River
Indian Cr.
Buck Cr.
Dayton Dam
10
0
10
Miles





ComEd Power System

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North Elgin Dam

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North Elgin Dam

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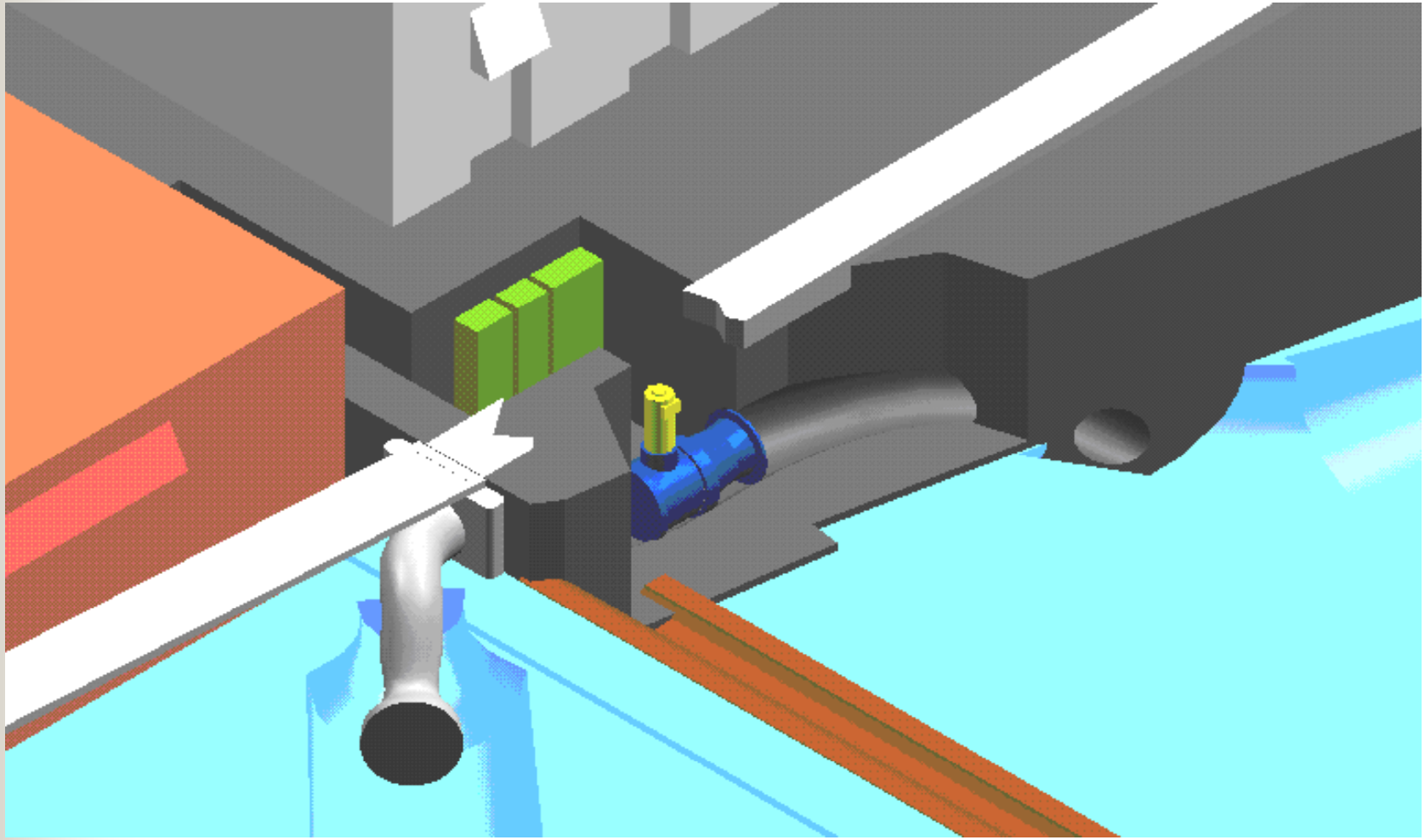
Small Hydro Project



Stolp Island Dam, Illinois

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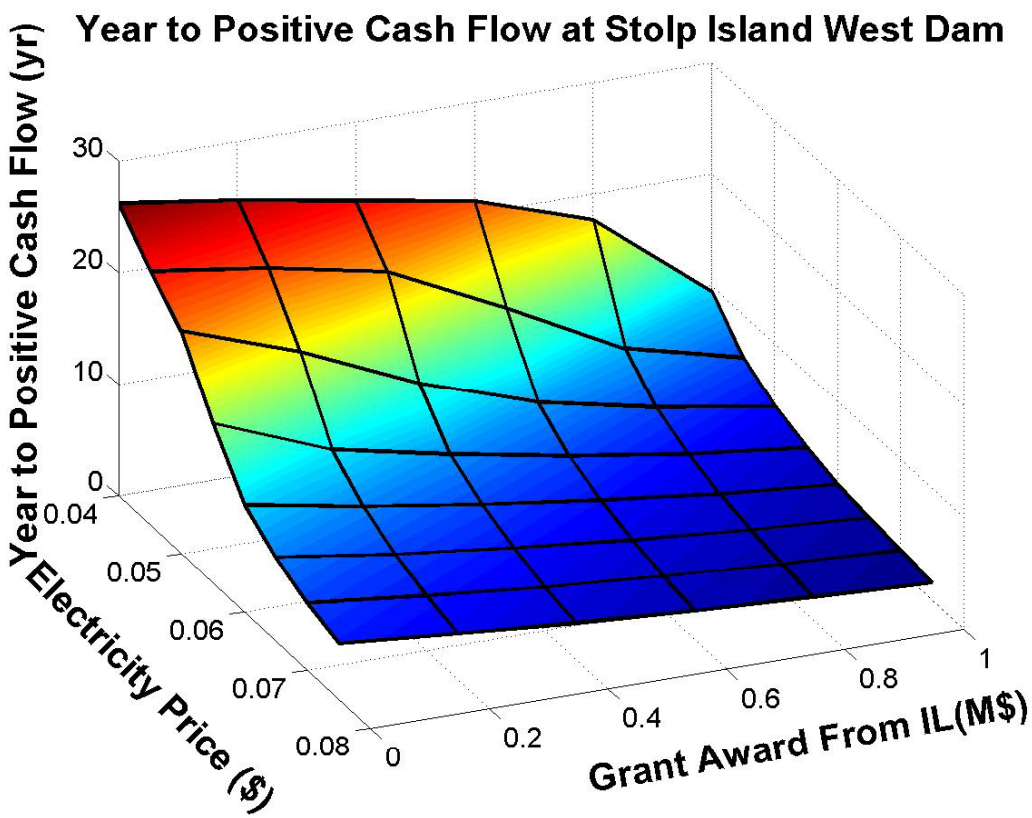
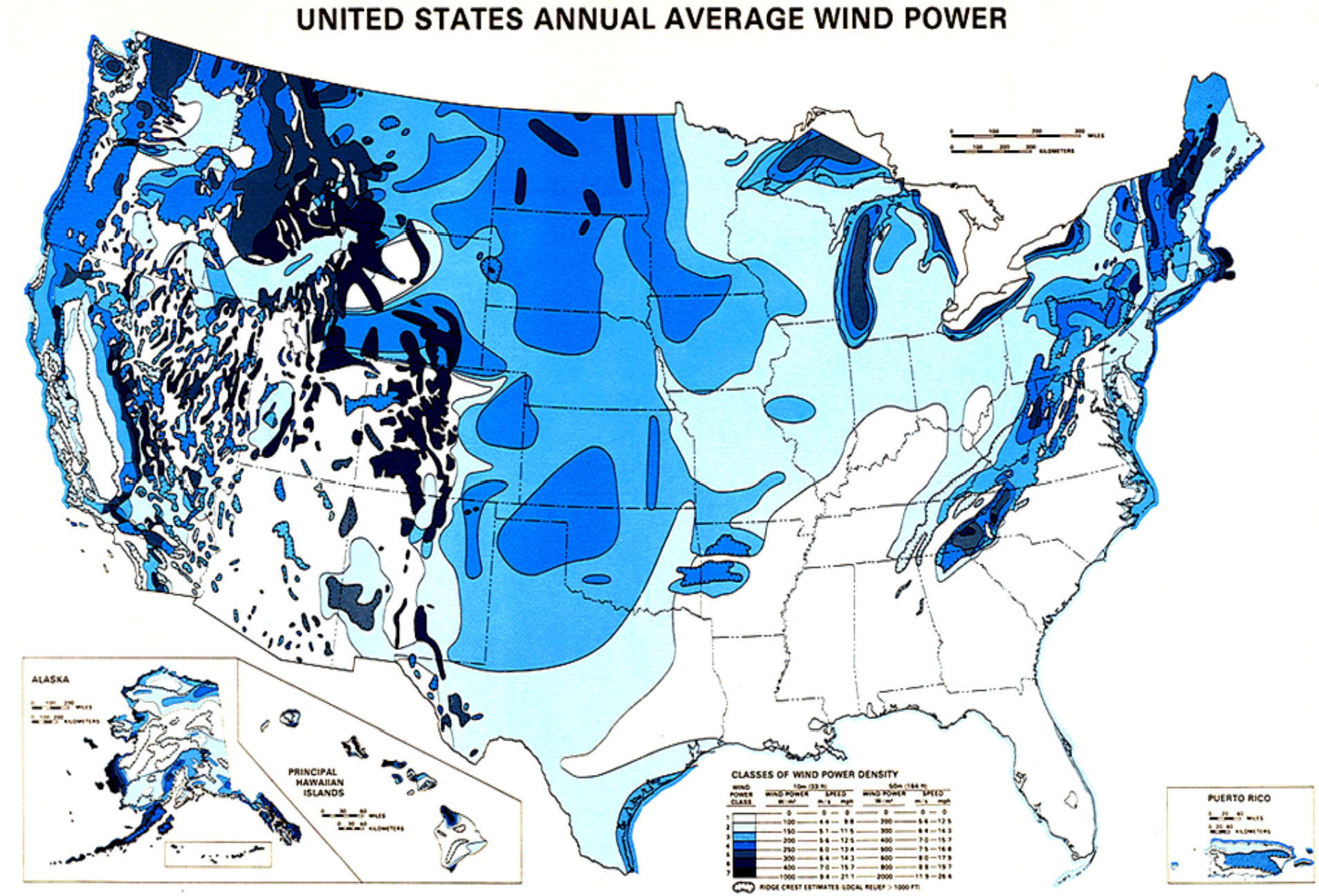
Year-to-Positive Cash Flow
Stolp Island West Dam

- **Dam Height:**15ft
- **Gross Head:**10 ft
- **Discount Rate:**10%
- **Efficiency:**81%





Wind Resource in the United States

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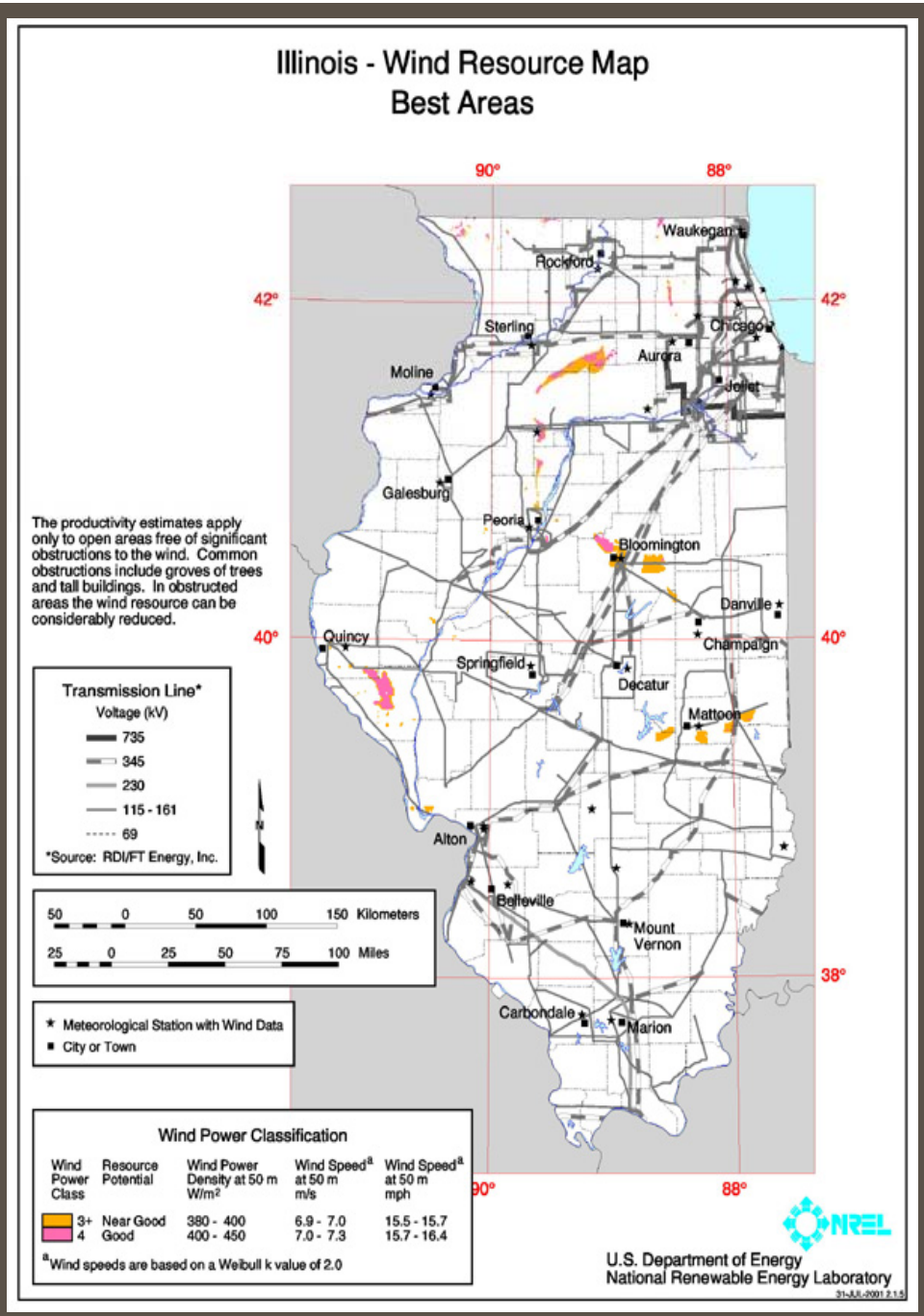

Wind Resource Map

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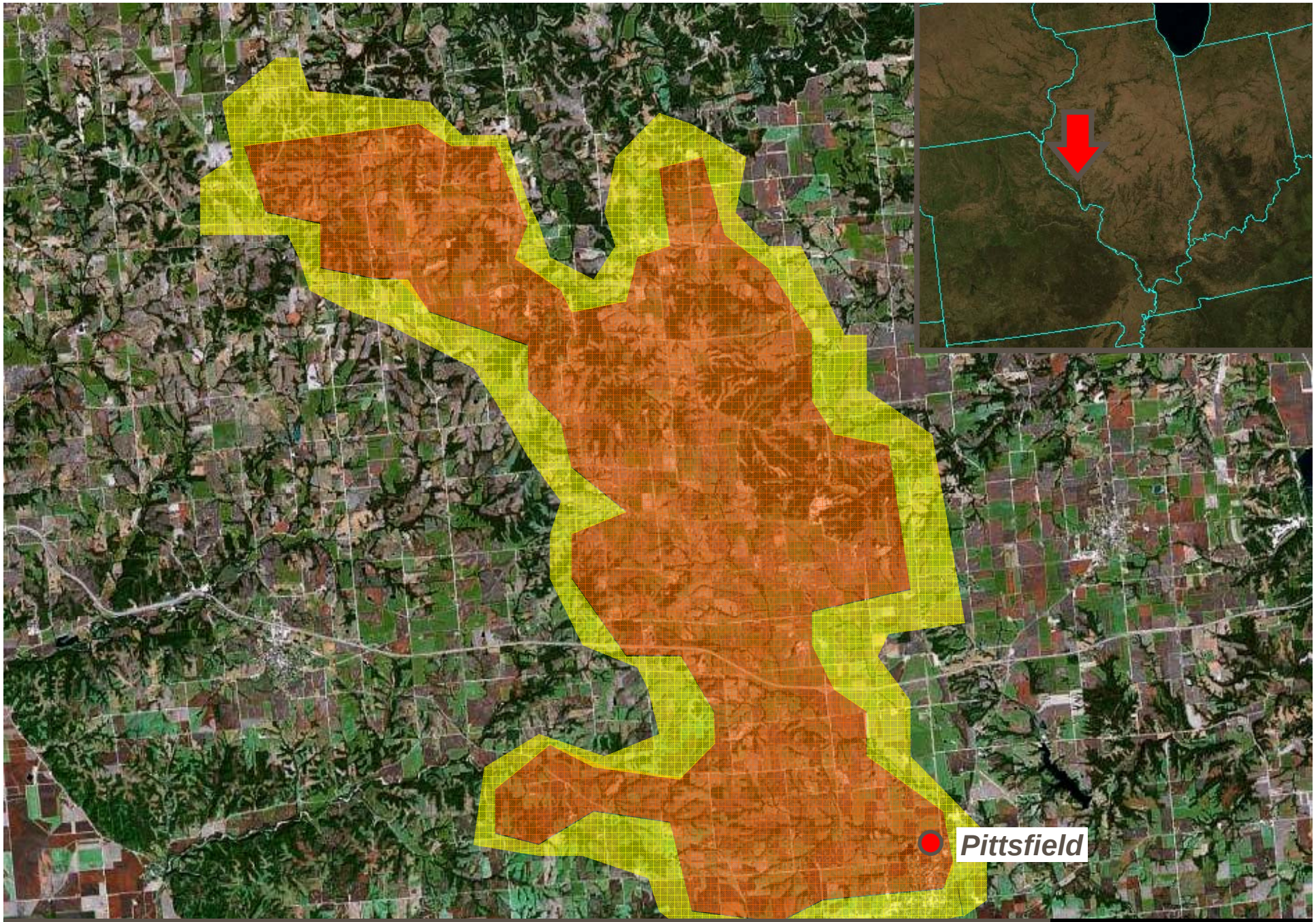

Pittsfield, IL

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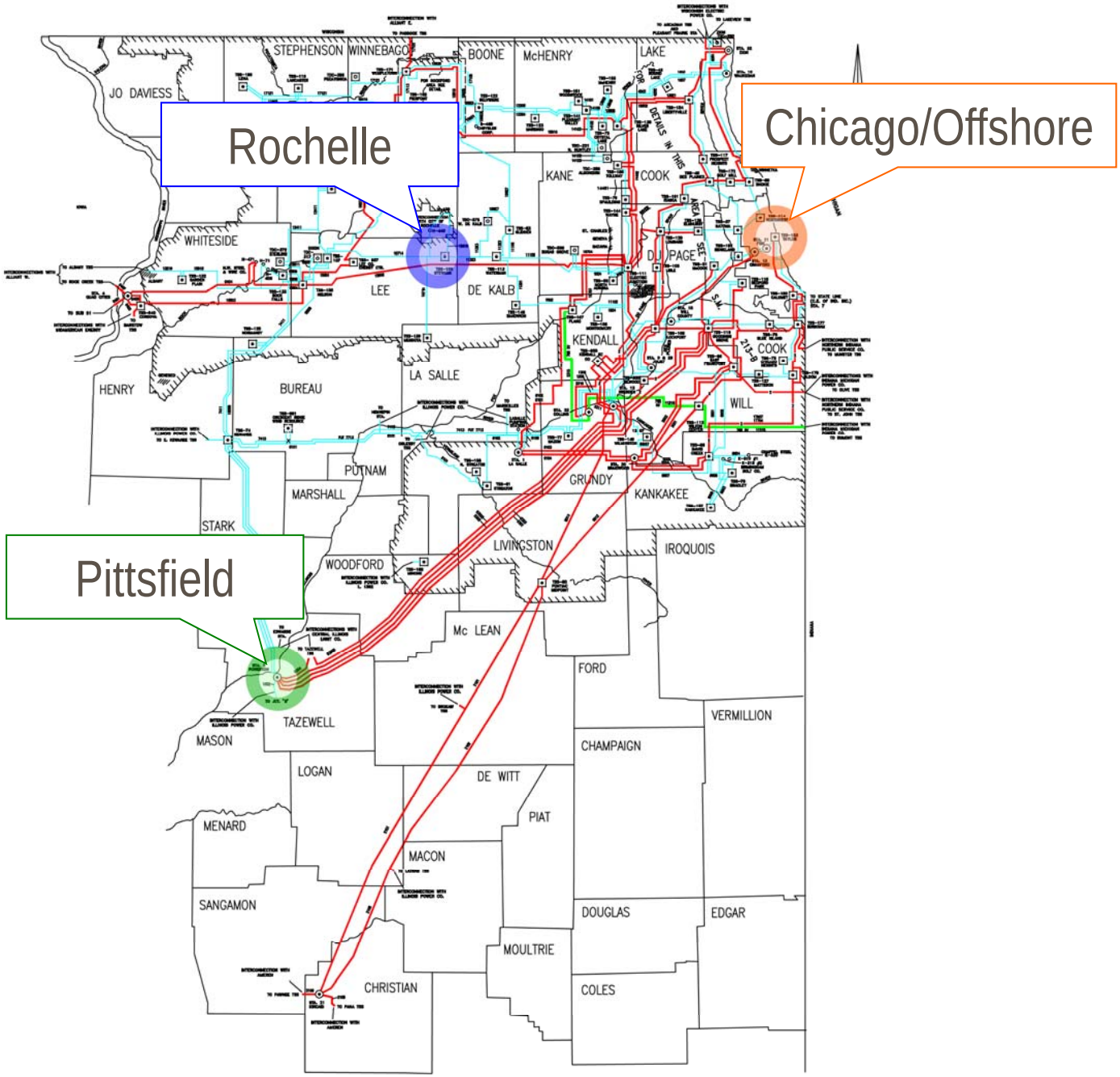

ComEd Power System

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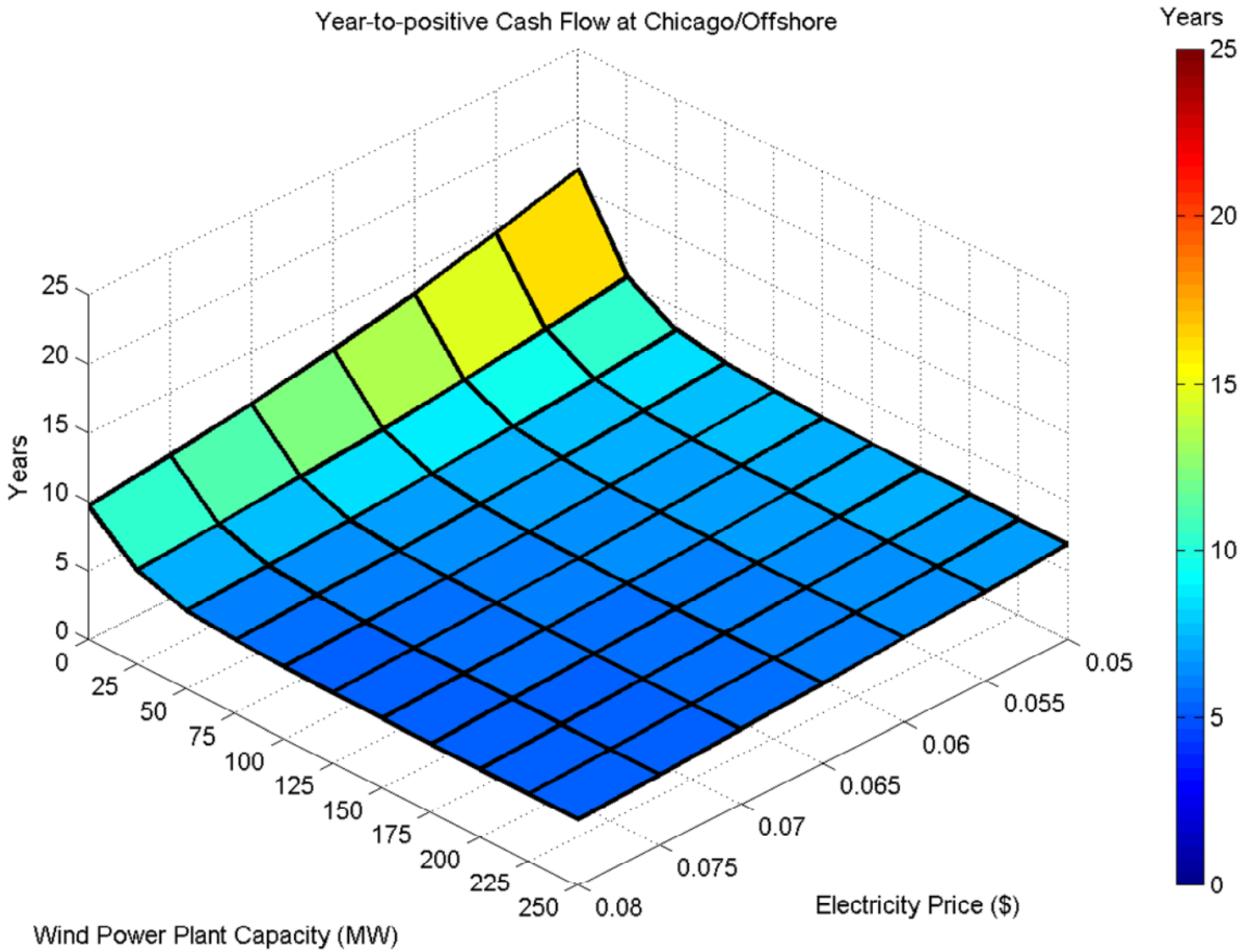
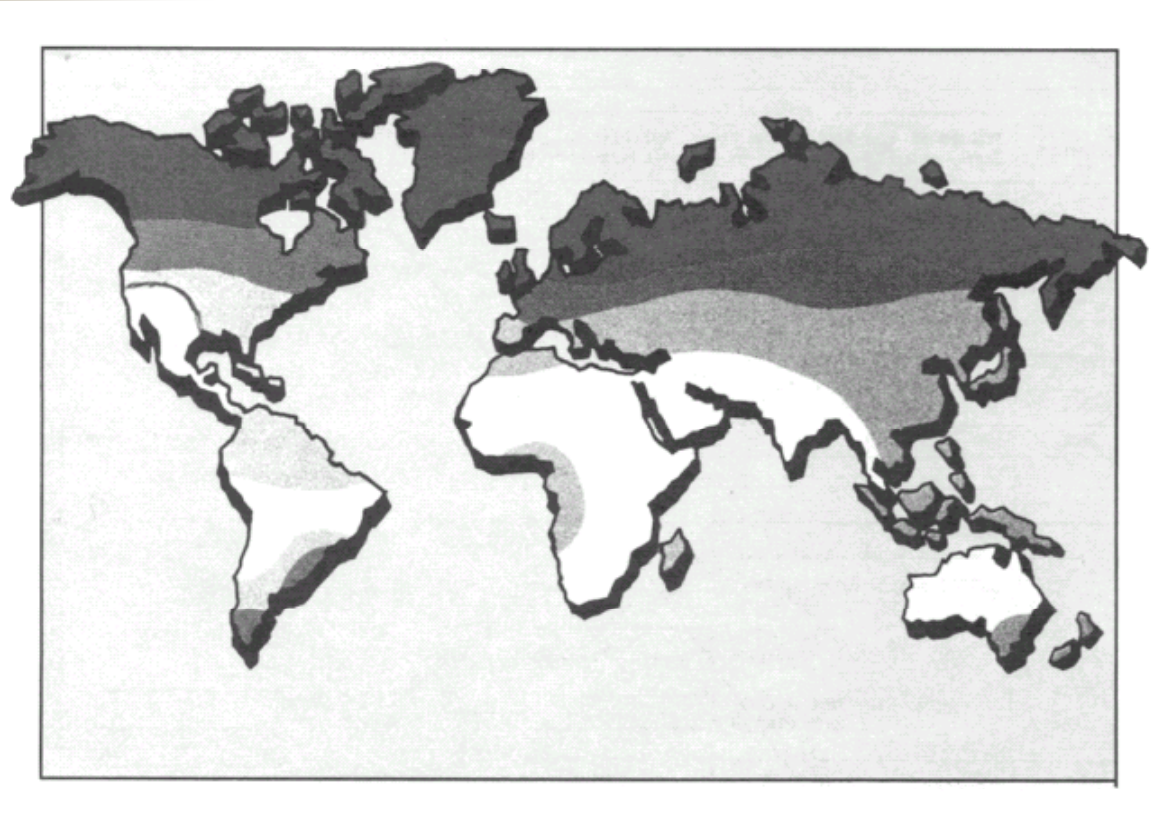
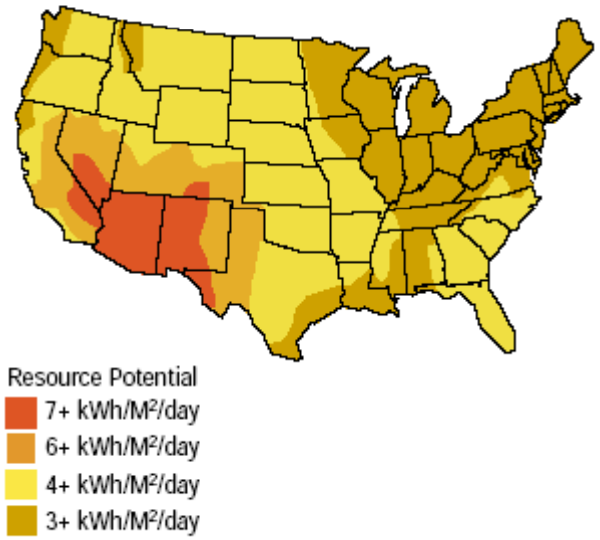


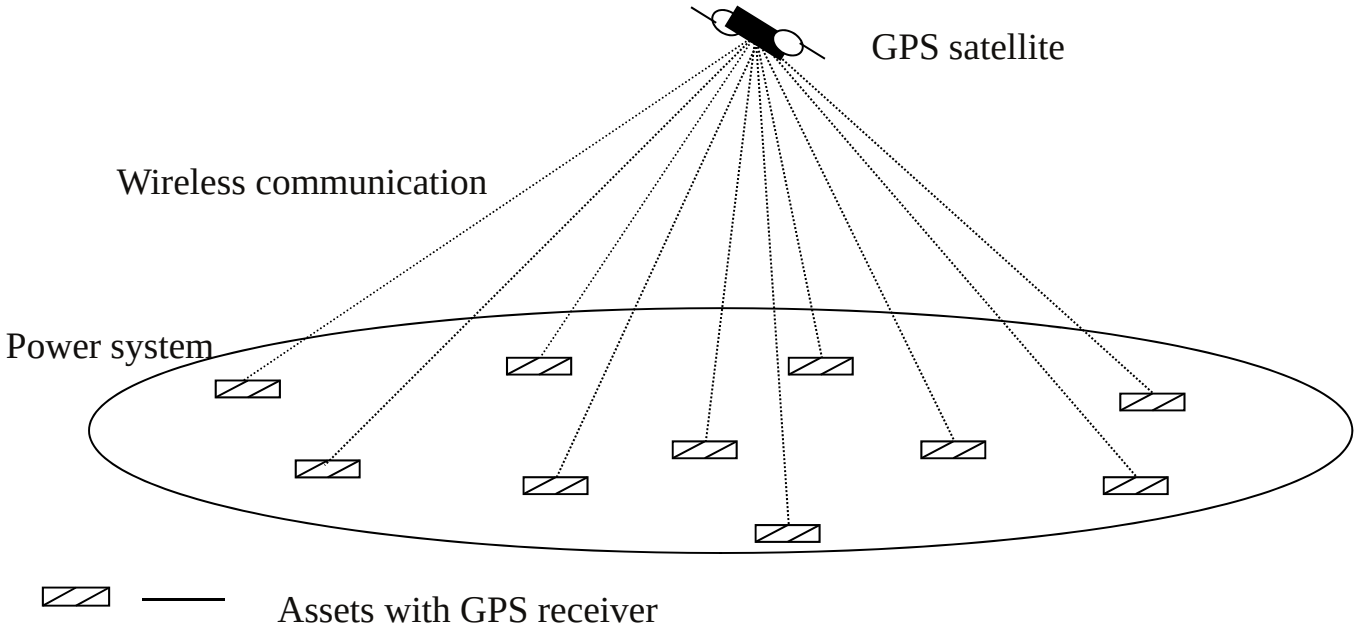
Chicago/Offshore




Resource Potential
7+ kWh/M²/day
6+ kWh/M²/day
4+ kWh/M²/day
3+ kWh/M²/day

Control and Monitoring of Power Systems

- Utility communications architecture (UCA)
  - Web-based diagnostic monitoring in real-time.
- Wide area measurement system (WAMS) for monitoring the grid as an integrated system.



Benefits of Energy Efficiency/ Smart Grid

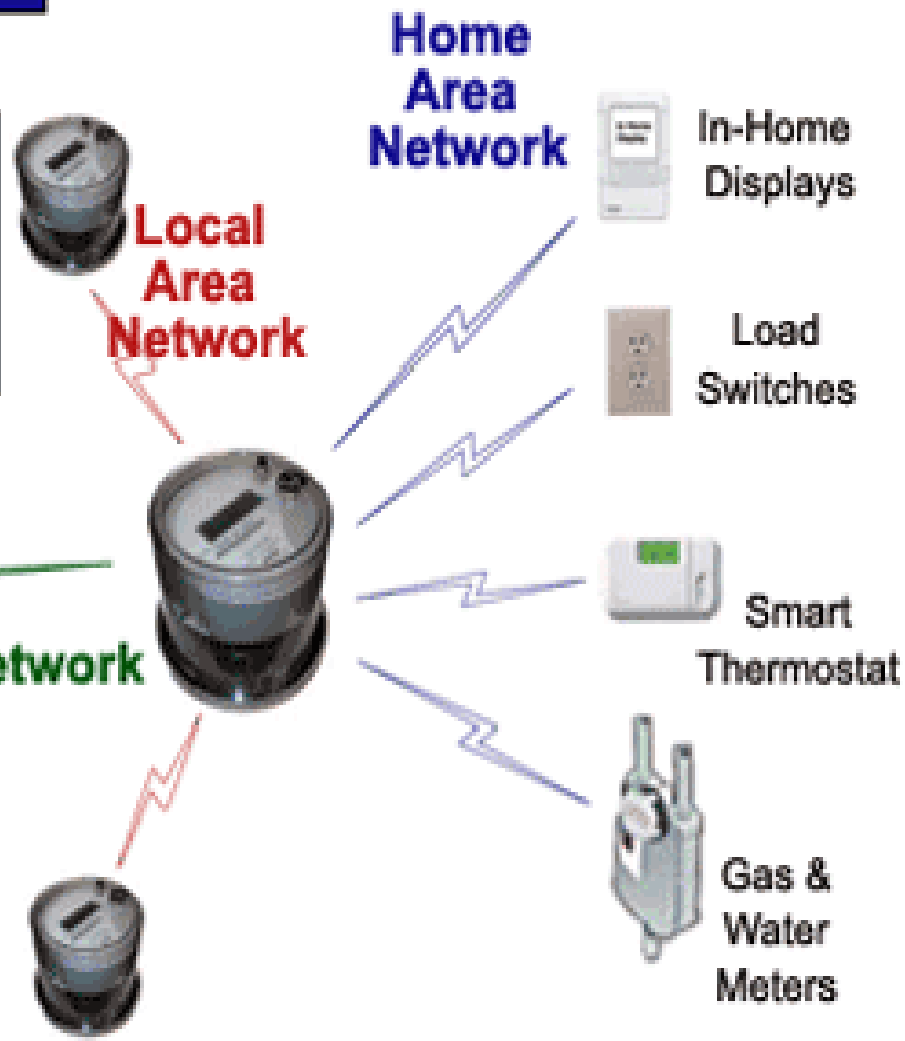
- Fewer blackouts and greatly reduced local interruptions
- Options for consumers to manage their electricity use
- Improved resilience to natural disasters and operator errors
- Savings from reduced interruptions, reduced congestion and reduced need to build expensive plants and lines
- **Avoided cost savings are substantial.** Smart grid upgrades will ease congestion sending 50 to 300 percent more electricity through existing corridors.

Advanced Metering Infrastructure

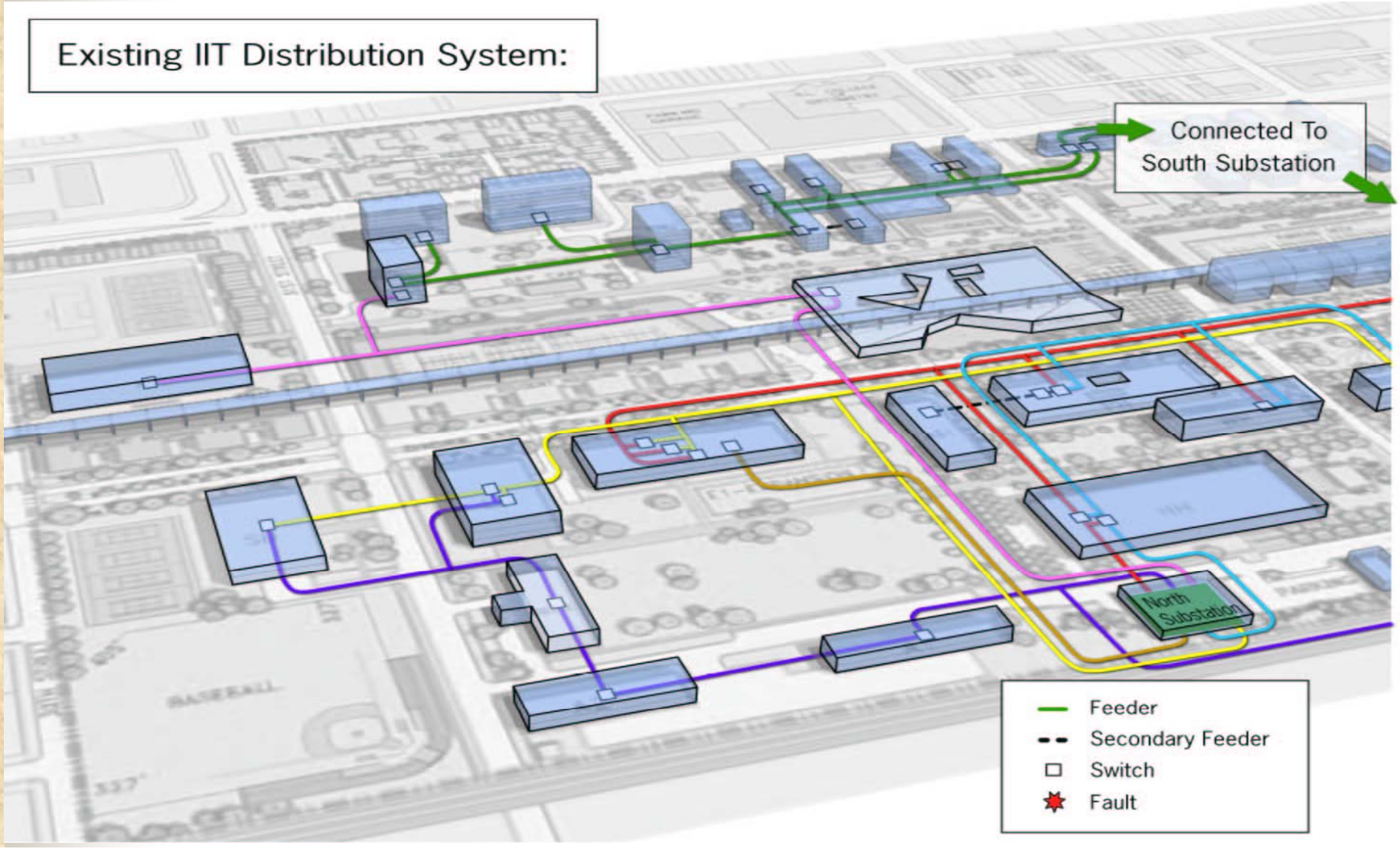
Home Area Network (HAN) links Utility & Meter to Customer through 2-way open standards based wireless communications (ZigBee)

Local Area Network (LAN) links meters together in a 2-way wireless mesh network for reliability through an aggregator (one meter may act as the aggregator)

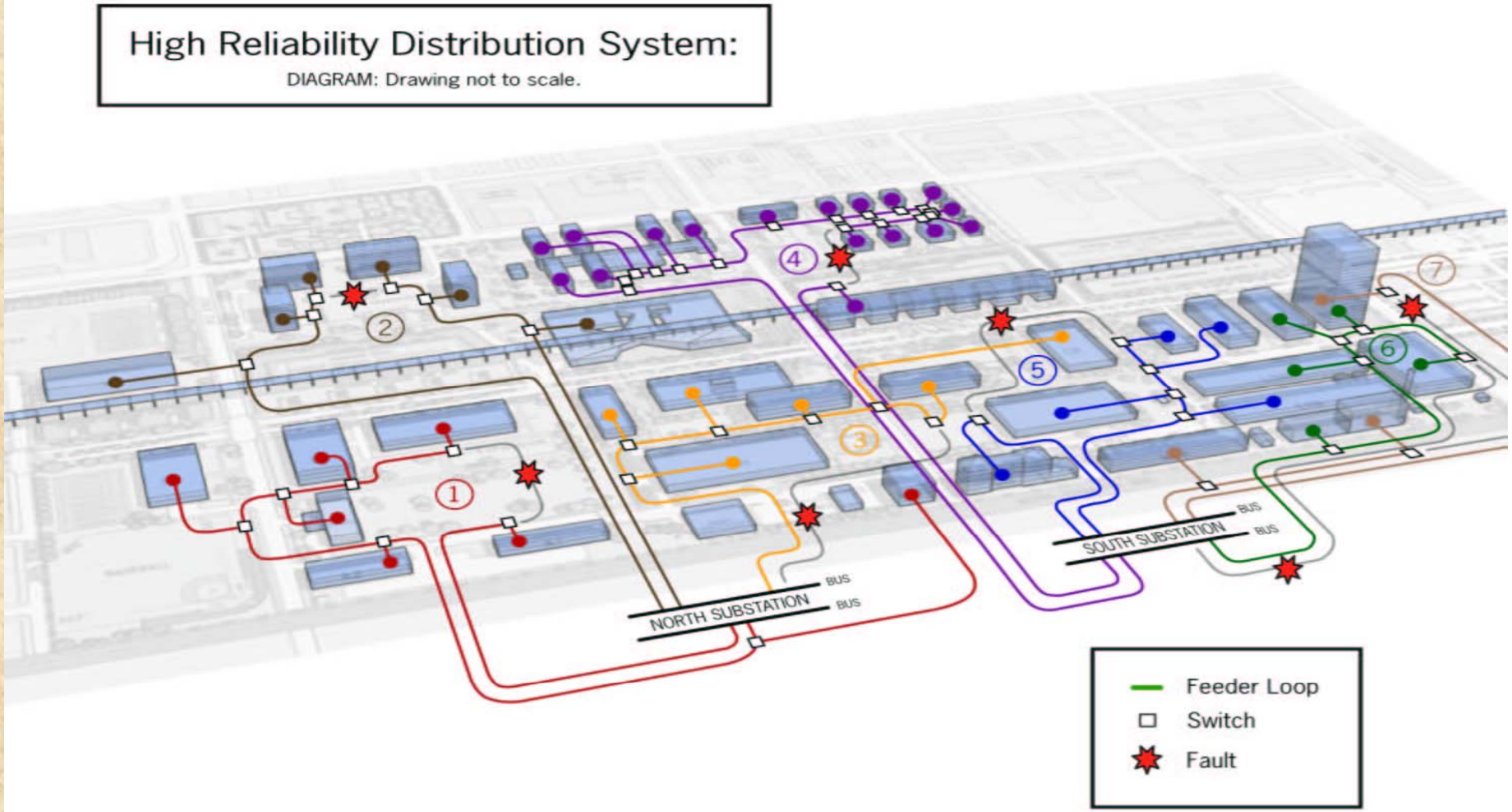
Wide Area Network (WAN) links utility backoffice systems through 2-way public or private network to the meter aggregators in the field



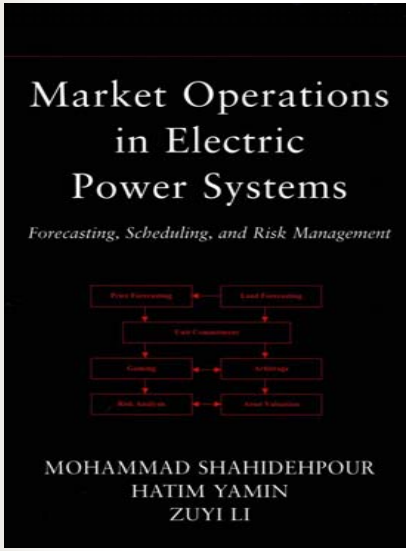
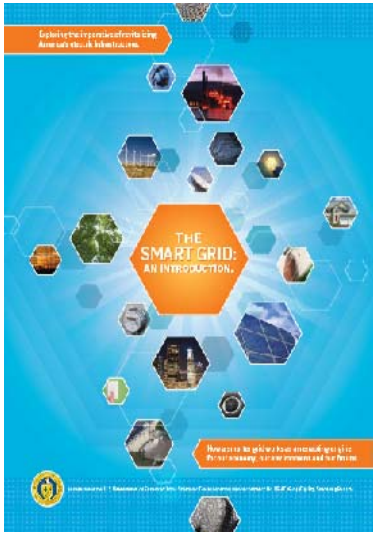
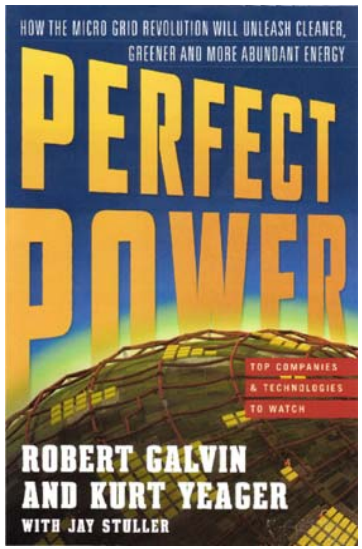
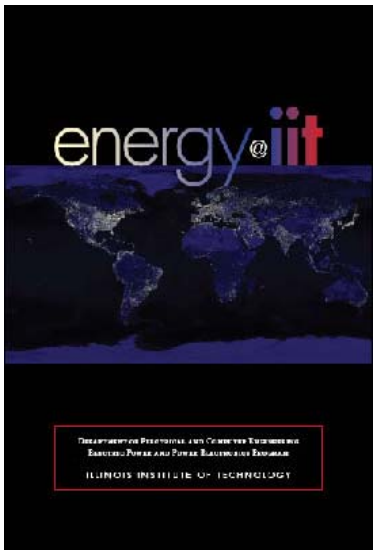
Current Distribution Grid at IIT



Smart Grid at IIT



Electricity Infrastructure of the Future

- Establish a comprehensive and competitive electric market structure
- Deploy new technologies to transform the static grid to a smart and automatically switched network
- Encourage customer participation in efficiency, demand side management, and market price signal utilization
- Integrate distributed technologies for generation and storage to support customer micro-grids
- Establish an all-inclusive generation and transmission planning criterion to assert reliability needs of power grid and its interdependence with other infrastructure
- Deploy new devices such as FACTS and superconductors for mitigating power flow congestions in stressed power systems

Coverage of Perfect Power Project