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EE 521: Analysis of Power Systems

Lecture 1
Introduction

Fall 2009

Mondays & Wednesdays 5:45-7:00

August 24 – December 18

Test 216

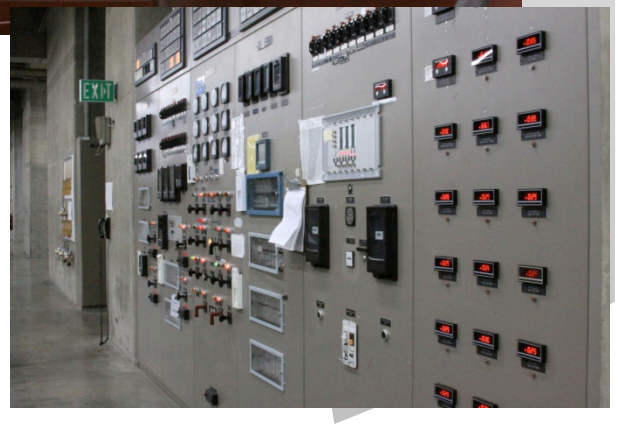
EE 521:Power System Analysis

- Instructor: Zhenyu (Henry) Huang
  - Pacific Northwest National Laboratory
  - (509) 372-6781
  - zhenyu.huang@pnl.gov
- Textbook: Power System Analysis, by Grainger and Stevenson
- Software: MATLAB
- Grading:
  - 20% Homework
  - 15% Midterm 1
  - 15% Midterm 2
  - 25% Project
  - 25% Final
- Acknowledgement: Kevin Schneider

Why do you want to take this course?

Power Plants

Hoover Dam, Nevada



Grand Coulee Hydro Plant, Washington

Wind Turbine

Nine Canyon Wind Farm

Generator Characteristics

- Hydro:
  - Ability to rapidly change output power
  - Further construction of large scale hydro-units in North America is not likely
- Nuclear:
  - Operates as a base load unit
  - Significant negative public perception due to Three Mile Island (Unit 2 March 1979)
- Coal:
  - In general, operates as a base load unit
  - Is a significant source of pollution, but accounts for >50% of installed U.S. capacity
- Combined Cycle:
  - Output can be limited by the use of the secondary steam
  - Higher efficiency and lower emissions than single combustion process
- Gas Turbine:
  - Used primarily as peaking units
  - In general, low capacity factor
- Wind:
  - Near zero emission, significant grid integration issues
  - Approximately 30% capacity factor

Substations

Celilo Substation, Oregon

Power Lines

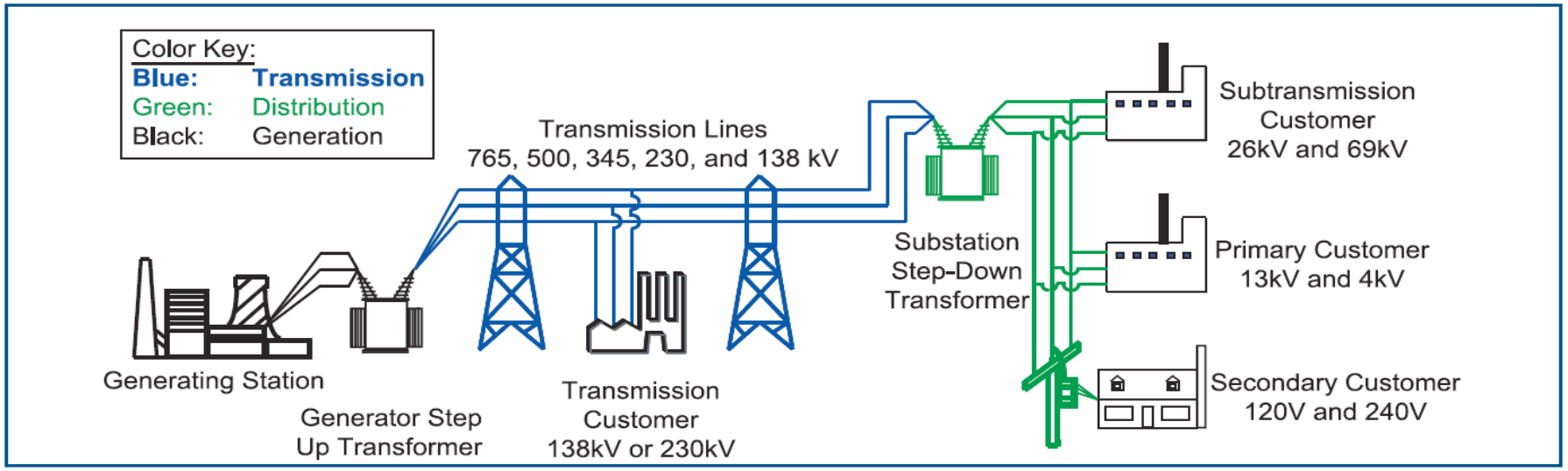
- Predominantly AC
  - 230kV-765kV
- DC has specific applications
  - +/- 500kV
- Extremely expensive to build and maintain
- NIMBY-ism

Source: http://www.tonyboon.co.uk/imgs/pages/powerlines.htm

Control Center

Electricity Infrastructure Operations Center (EIOC), PNNL

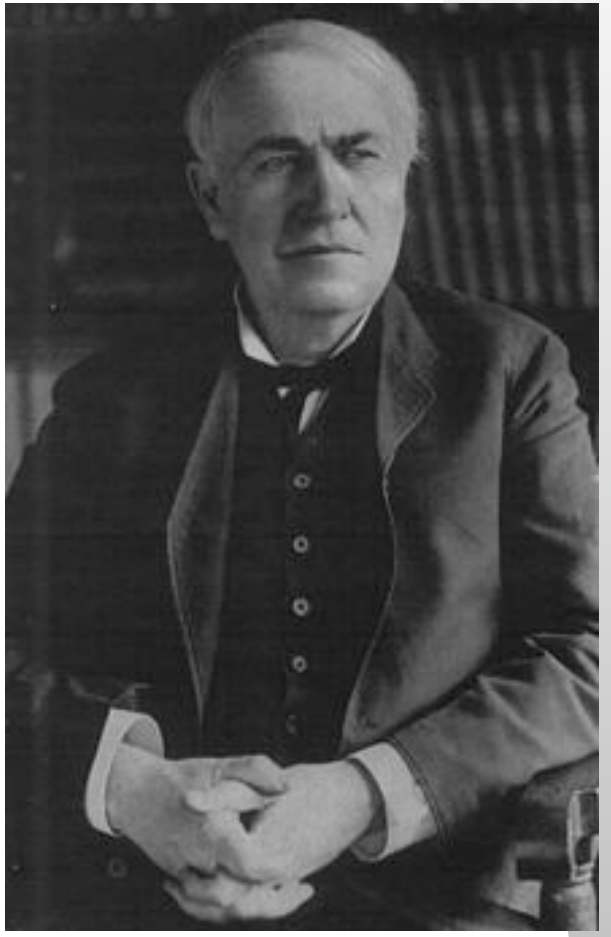
Typical Power System



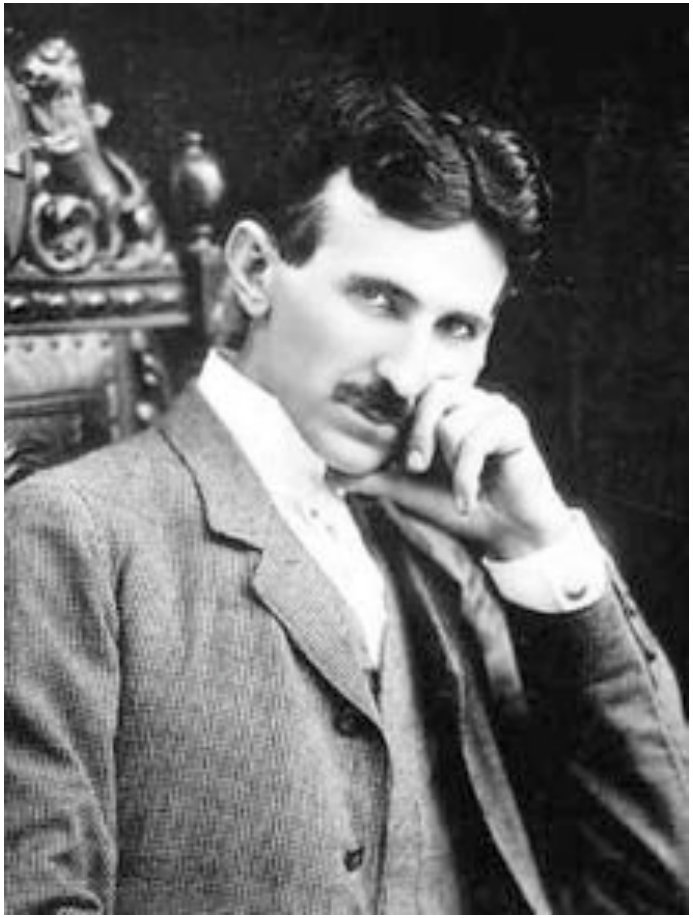
- Generation: 10-33kV
- Transmission: 138-765kV
- Sub-Transmission: 66-230kV
- Distribution: 8-26kV

Thomas Edison

- 1847-1931
- DC-General Electric
- First industrial laboratory "Menlo Park"
- Pearl Street Station
  - Sept. 4th 1882
  - 1 DC generator
  - <100 customers

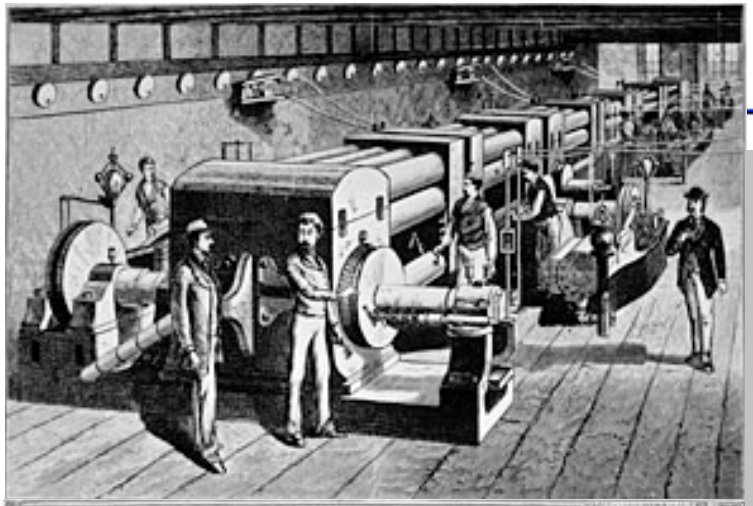


Nikola Tesla

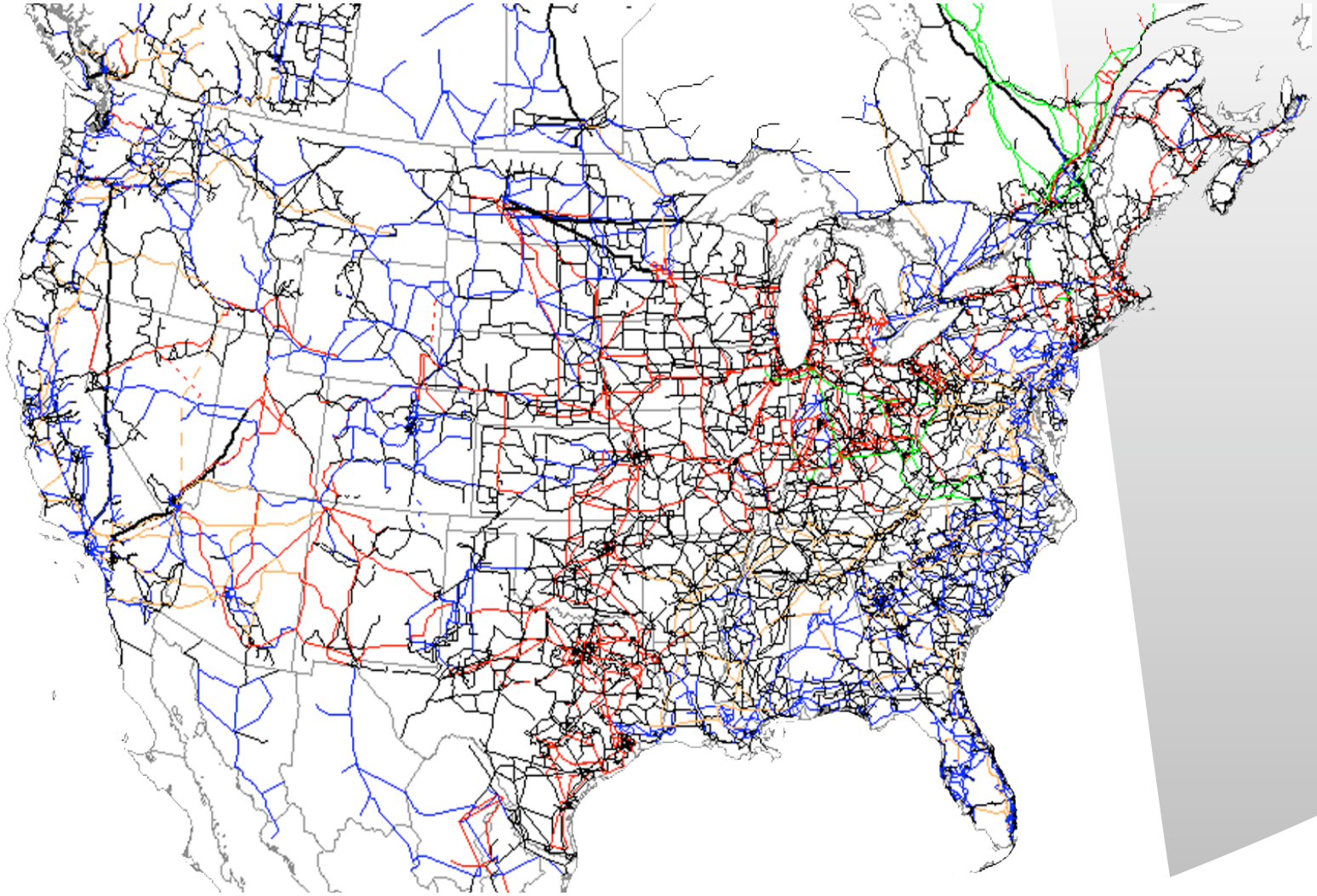


- 1856-1943
- AC-Westinghouse
- Patents
  - Polyphase distribution system
  - AC electric motor
- Envisioned the modern electricity infrastructure

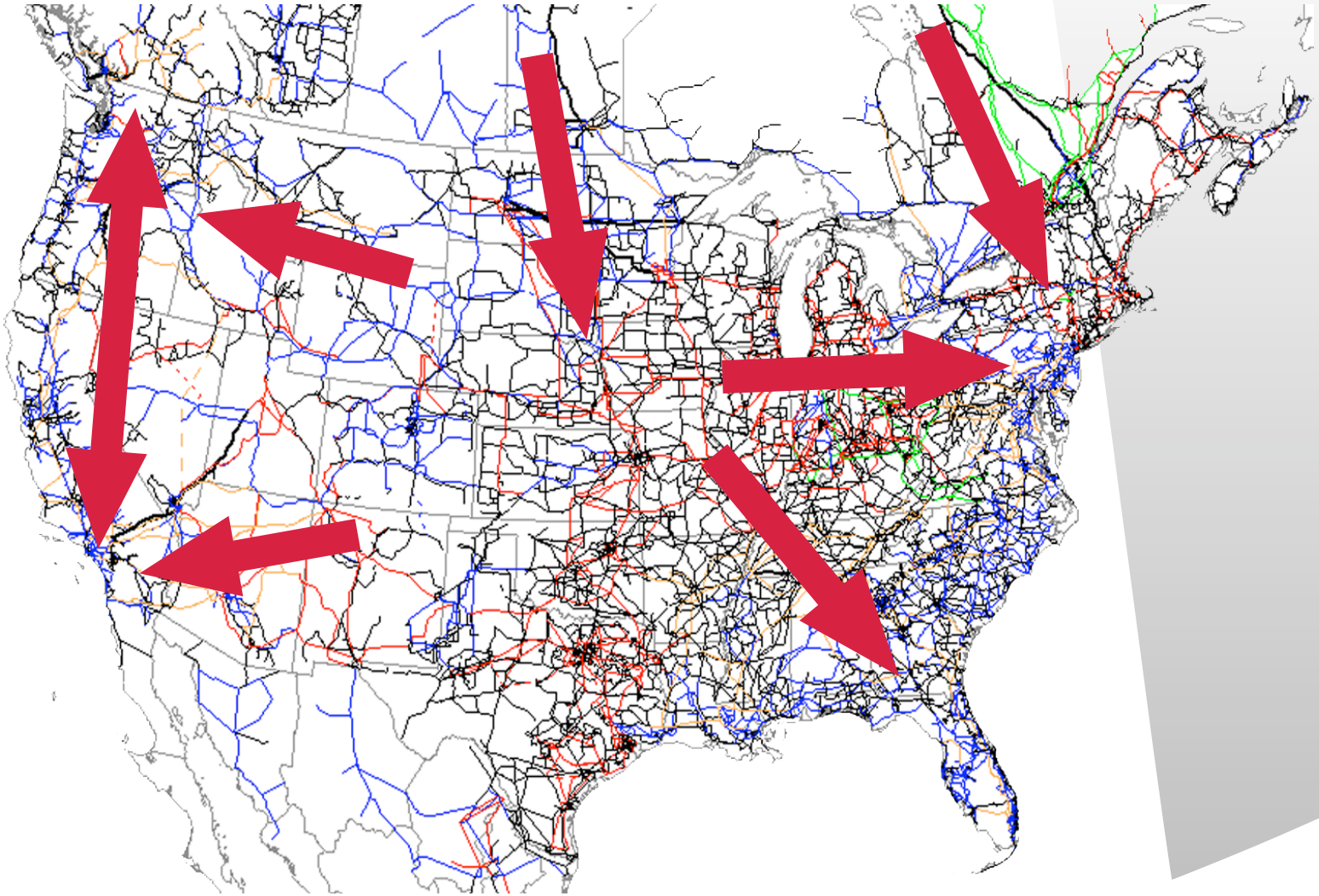
Point of Departure: Edison's Pearl St. Station and the Neighborhood Grid



A Little Over a Century Later …
"the Most Complex Machine in the World"

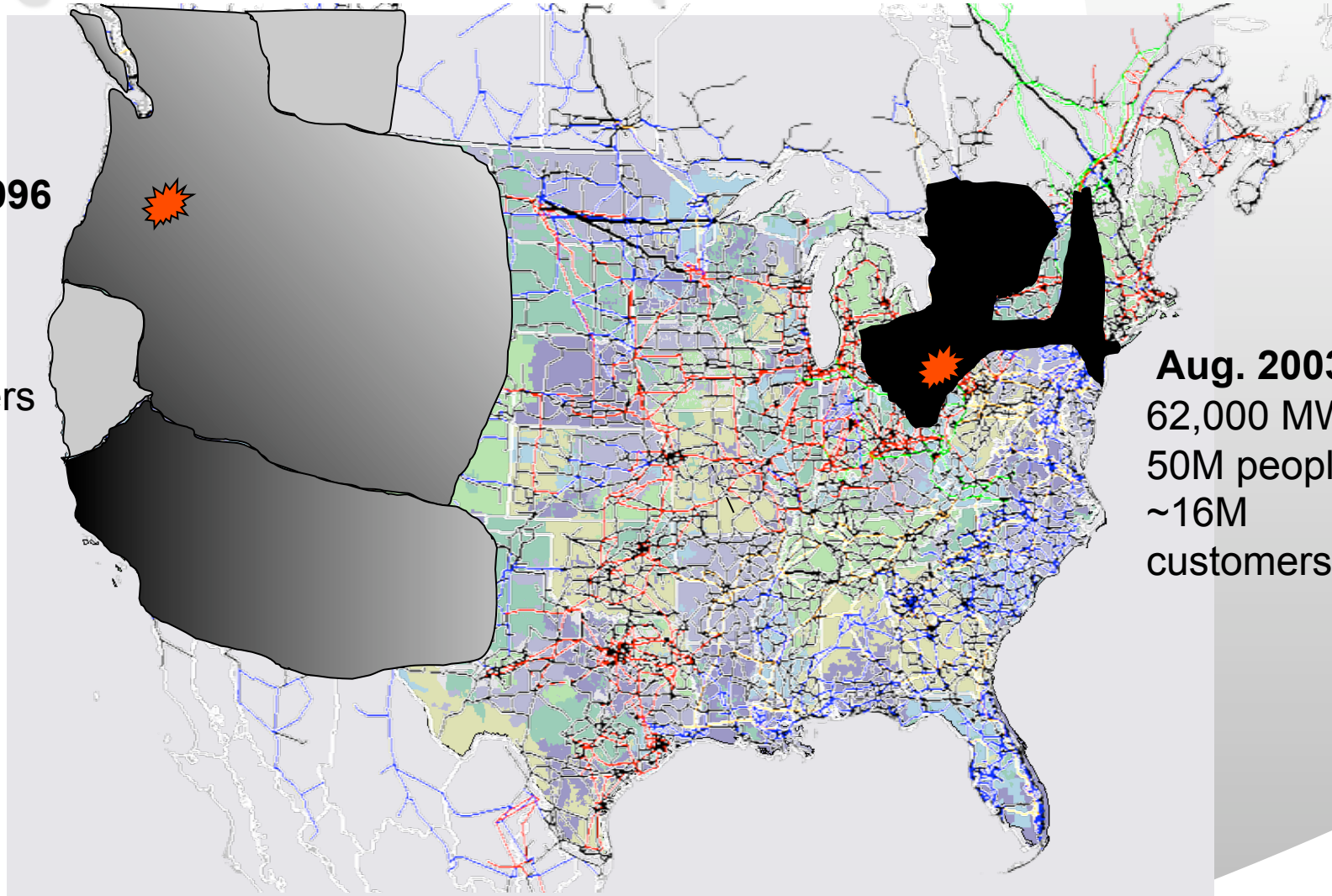


But It Wasn't Conceived to Support Today's Long Distance Power Exchanges



Tough Lessons Learned 1996 & 2003: Large-Scale Blackouts Span Awareness Horizon

Aug. 1996
30,000 MW
8M customers
~24M people

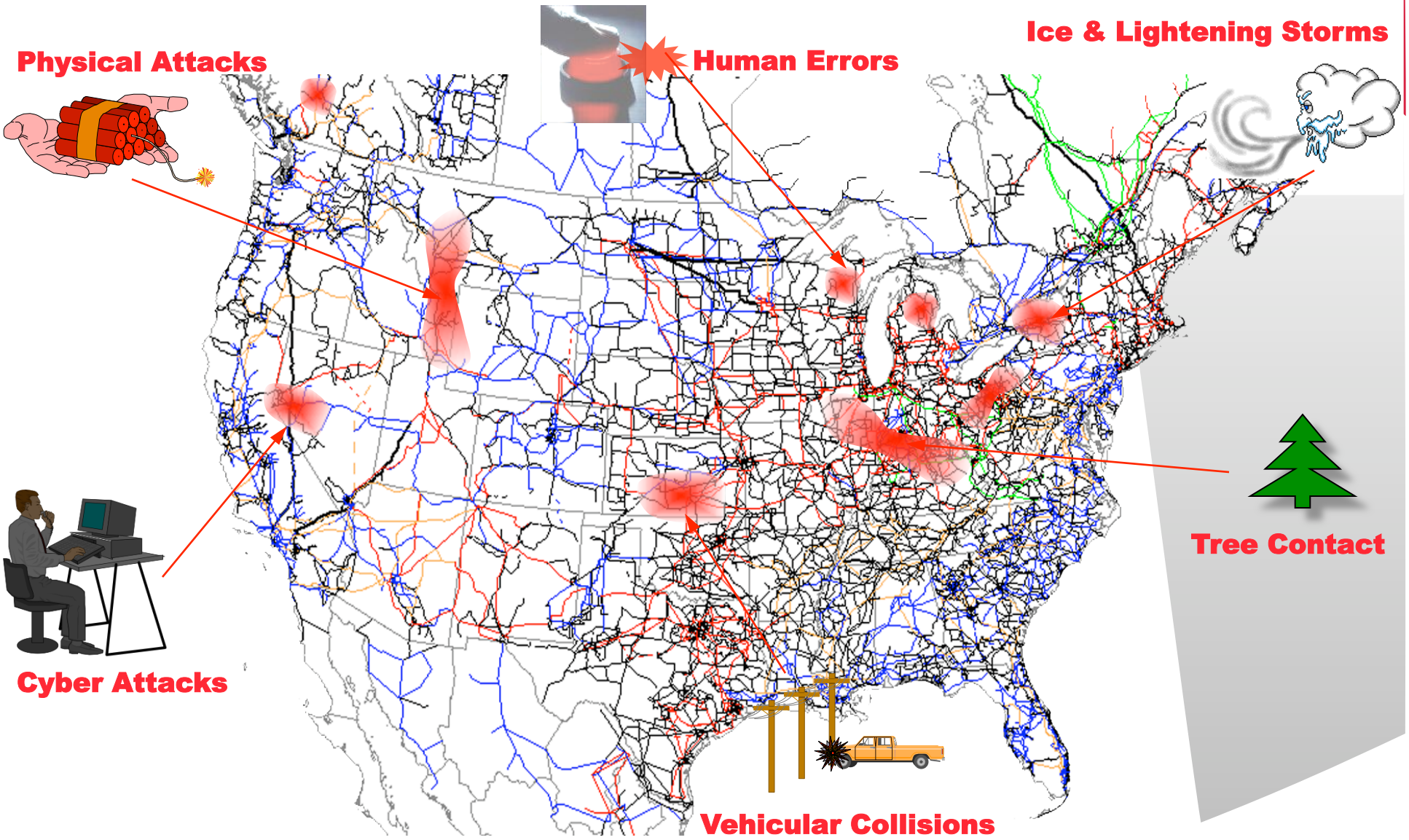


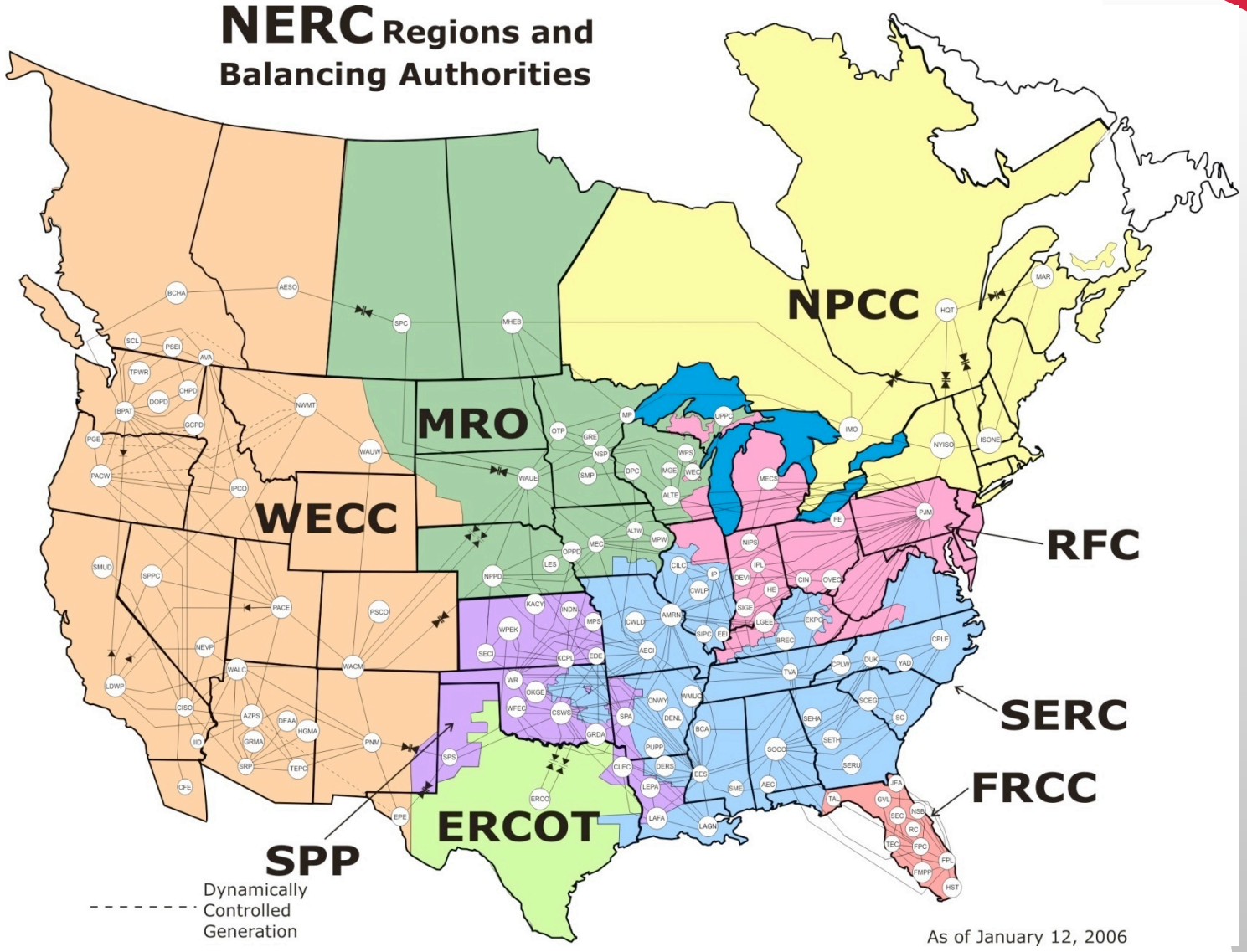
Aug. 2003
62,000 MW
50M people
~16M customers

Significant North American Blackouts

Date	Location	Load Interrupted
November 9, 1965	Northeast	20,000 MW
July 13, 1977	New York	6,000 MW
December 22, 1982	West Coast	12,350 MW
January 17, 1994	California	7,500 MW
December 14, 1994	Wyoming, Idaho	9,336 MW
July 2, 1996	Wyoming, Idaho, other	11,743 MW
August 10, 1996	Western Interconnection	30,489 MW
June 25, 1998	Midwest	950 MW
August 14, 2003	Northeast	61,800 MW

Electricity Infrastructure Vulnerabilities

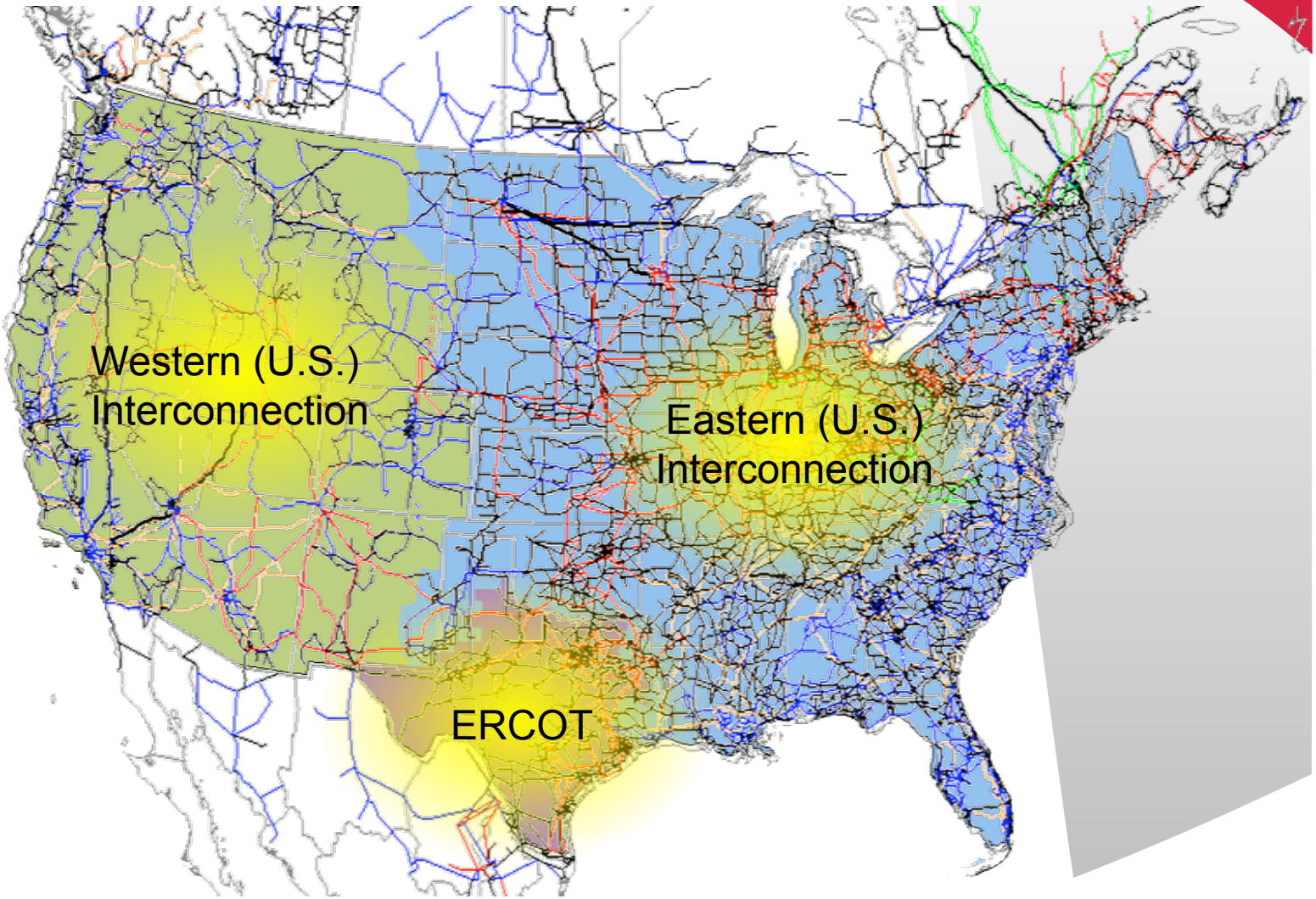



NERC Regions and
Balancing Authorities
NPCC
MRO
WECC
RFC
SERC
FRCC
ERCOT
SPP
Dynamically
Controlled
Generation
As of January 12, 2006

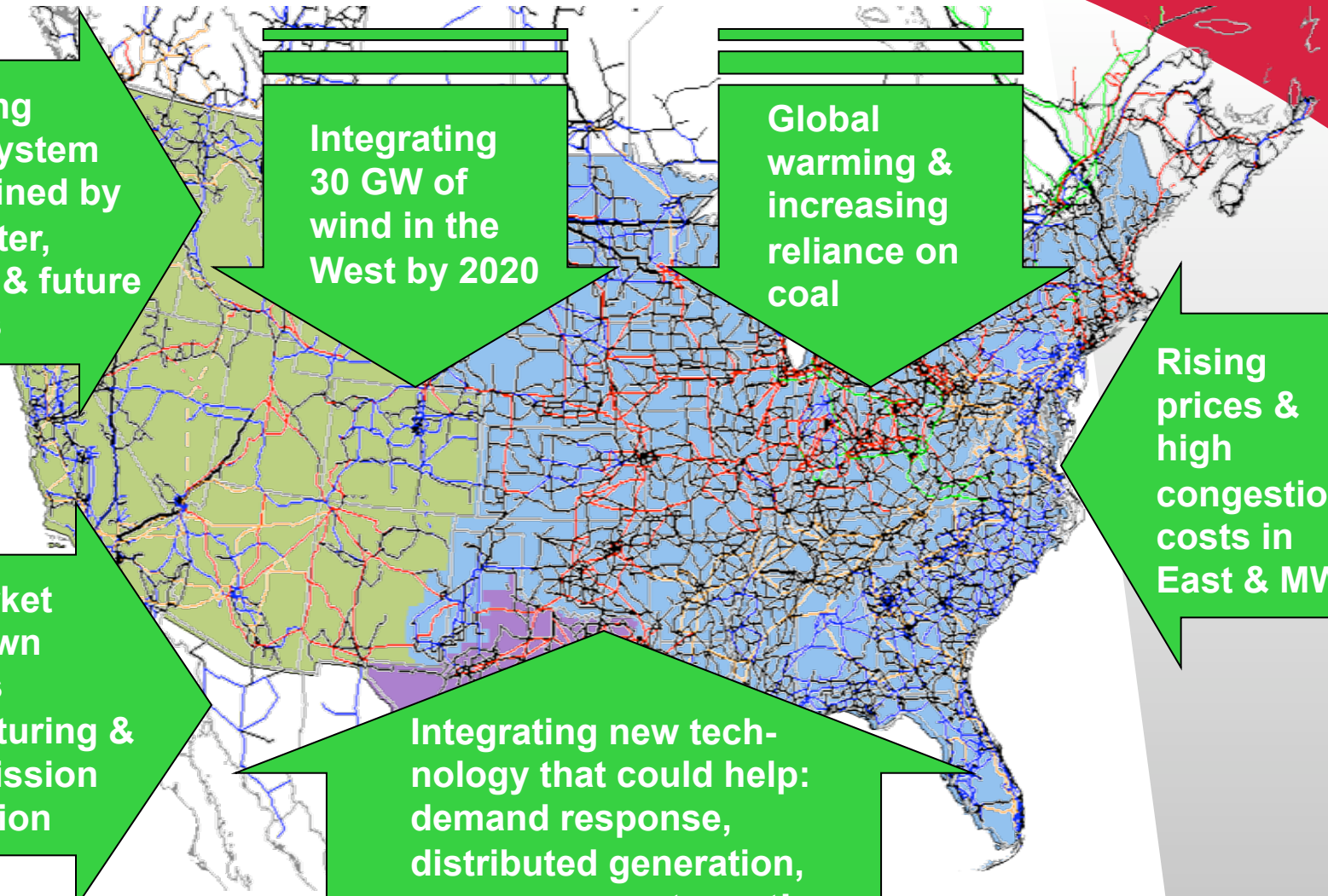
Reliable Grid Management and Situational Awareness are Interconnection-Scale Issues

WECC

- >14,000 buses
- 1000s generators
- 1000s miles of transmission lines
- Long distance transmission lines, mixed AC and DC
- Significant inter-area power transfers



Current Issues Make the Problem Harder



Managing hydro system constrained by fish, water, treaties & future markets

Integrating 30 GW of wind in the West by 2020

Global warming & increasing reliance on coal

Rising prices & high congestion costs in East & MW

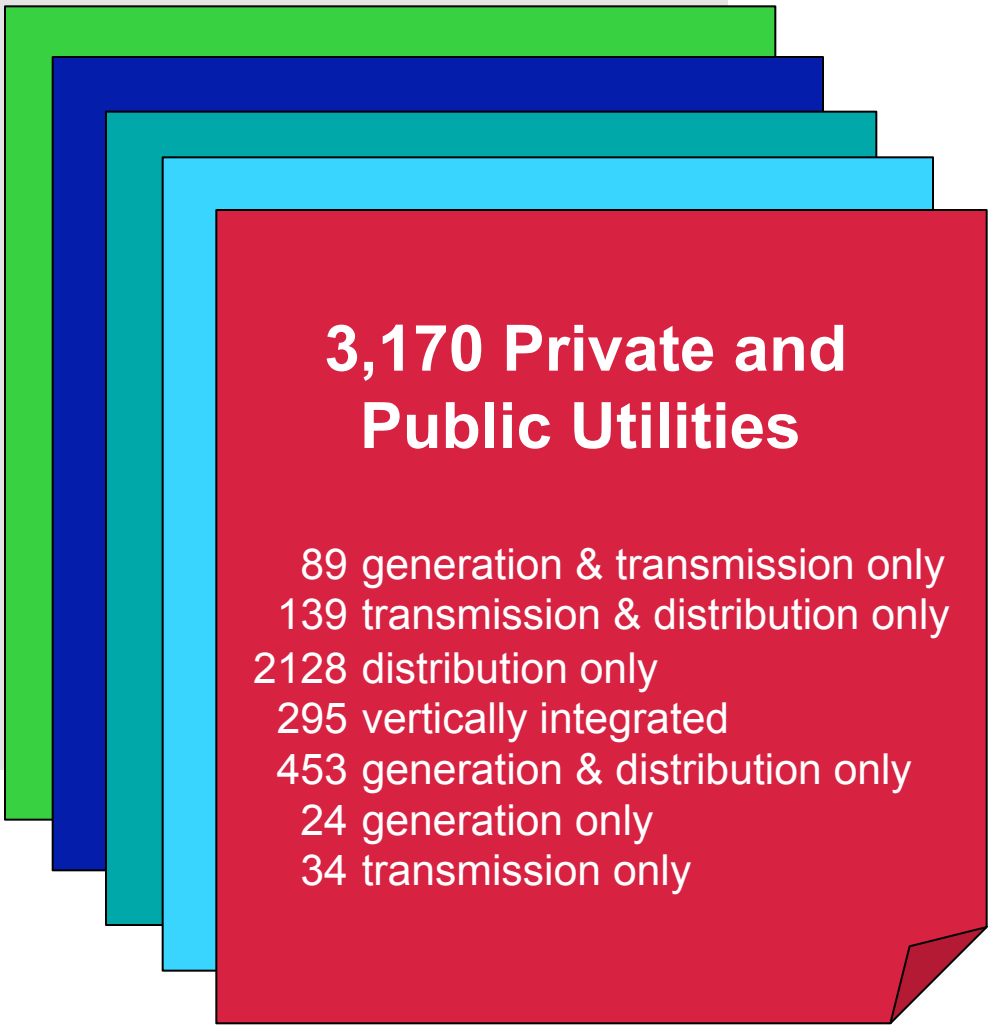
CA market meltdown strands restructuring & transmission expansion

Integrating new tech-nology that could help: demand response, distributed generation, distribution automation, AMR & phasor data …

Why do you want to take this course?

- Reason 1: it is a very exciting field.

Grid Operations and Planning Governed by Multiple Balance Sheets



3,170 traditional utilities …
- 239 investor owned
- 2009 publicly owned
- 912 rural electric associations
- 10 Federal

… operating
- 351,000 miles of transmission
- 21,688 substations

4,769 generating plants
- 861 utility owned
- 1930 non-utility
- 400 power marketers

130 control areas

More than 125 million end users
- 110 million residential
- 15 million commercial
- 610,000 industrial

EIA, "The Changing Structure of the Electric Power Industry 2000: An Update"

Big Balance Sheets with Big Dollars!

Generation **Transmission** **Distribution** **End Use**






~$940 B **~$120 B** **~$140 B**

(replacement costs)

$97 B residential

$94 B commercial

$78 B industrial

Total annual electric sales: $270 B

Congestion costs:
In NY ISO, 23% of wholesale price is congestion—which is passed along to consumers.

Why do you want to take this course?

- Reason 1: it is a very exciting field.
- Reason 2: there are lots of potential employers.

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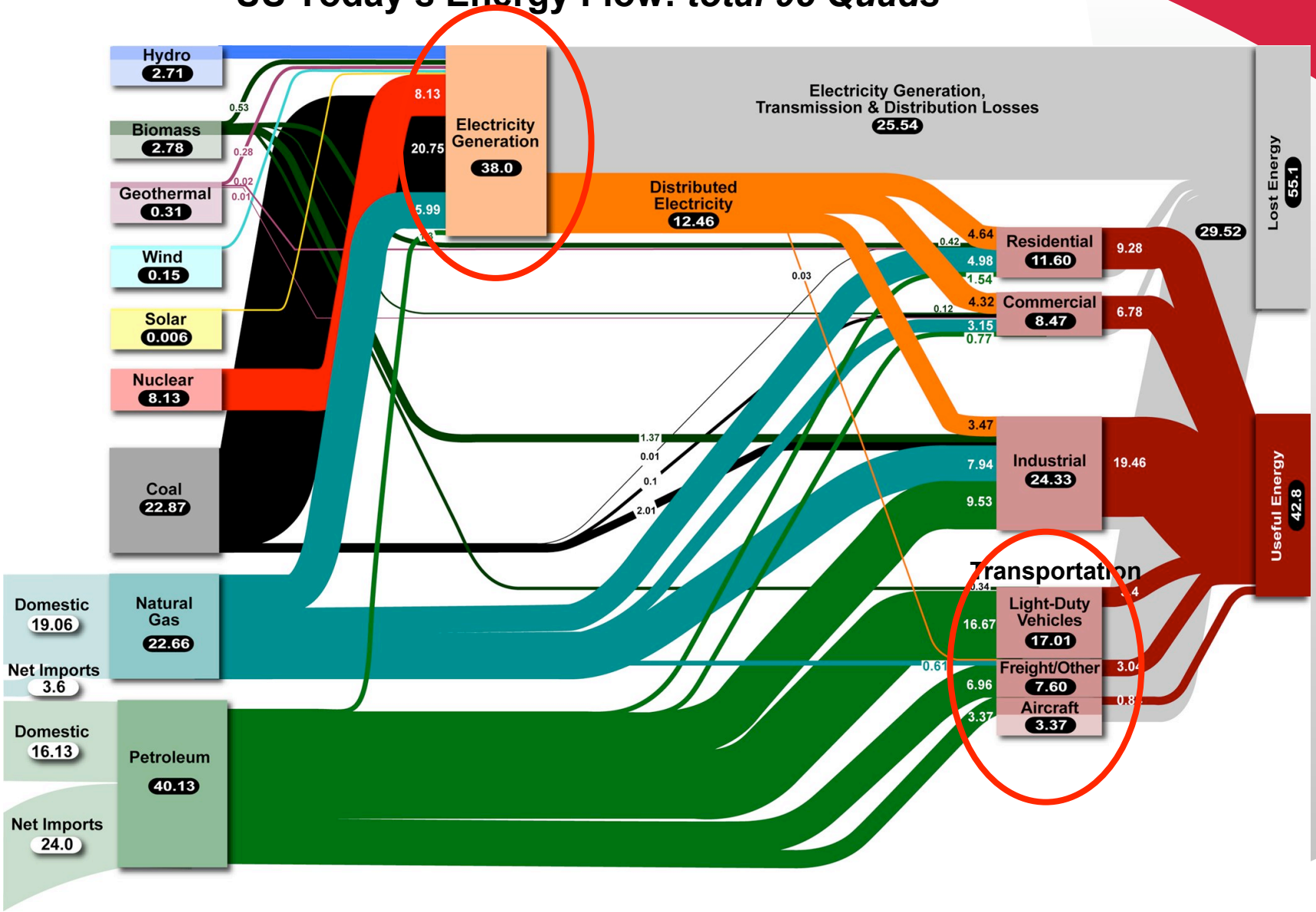
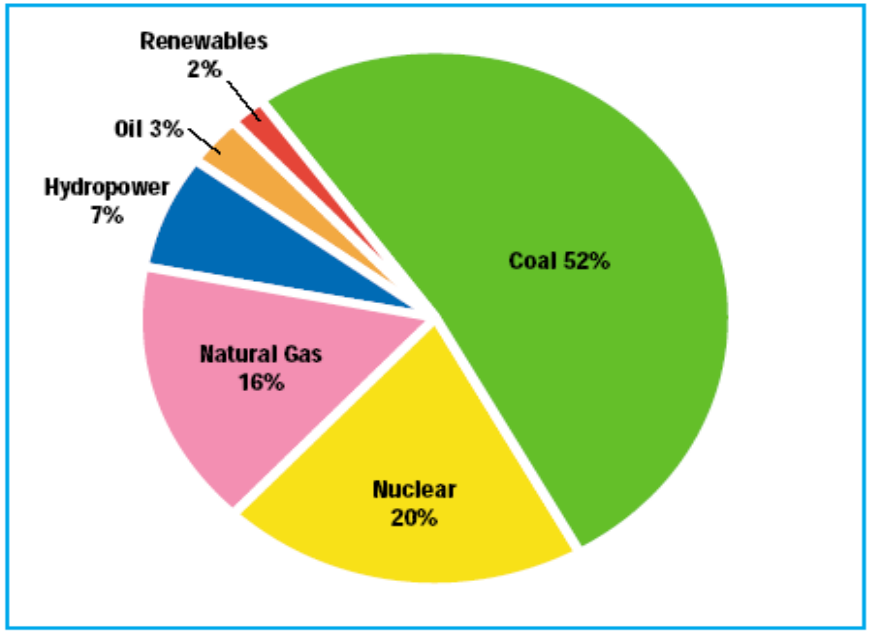
The "Energy Challenge"

US Today's Energy Flow: *total 98 Quads*



Electricity Fuels for North America

Fuel Sources for Electricity Generation in 2000

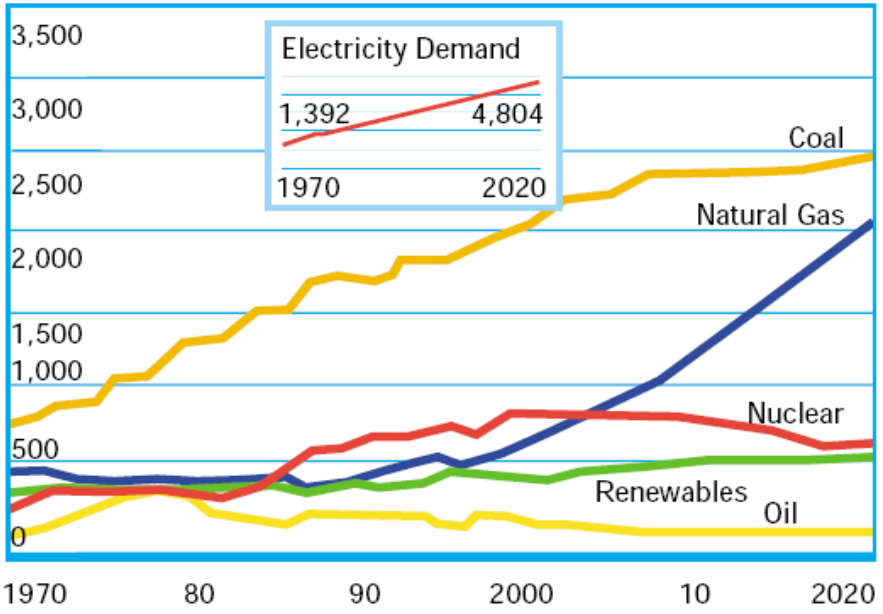


Electricity is a secondary source of energy, generated through the consumption of primary sources. Coal and nuclear energy account for nearly 75 percent of U.S. electricity generation.

Source: U.S. Department of Energy, Energy Information Administration

Electricity Generation by Fuel: Current Trends

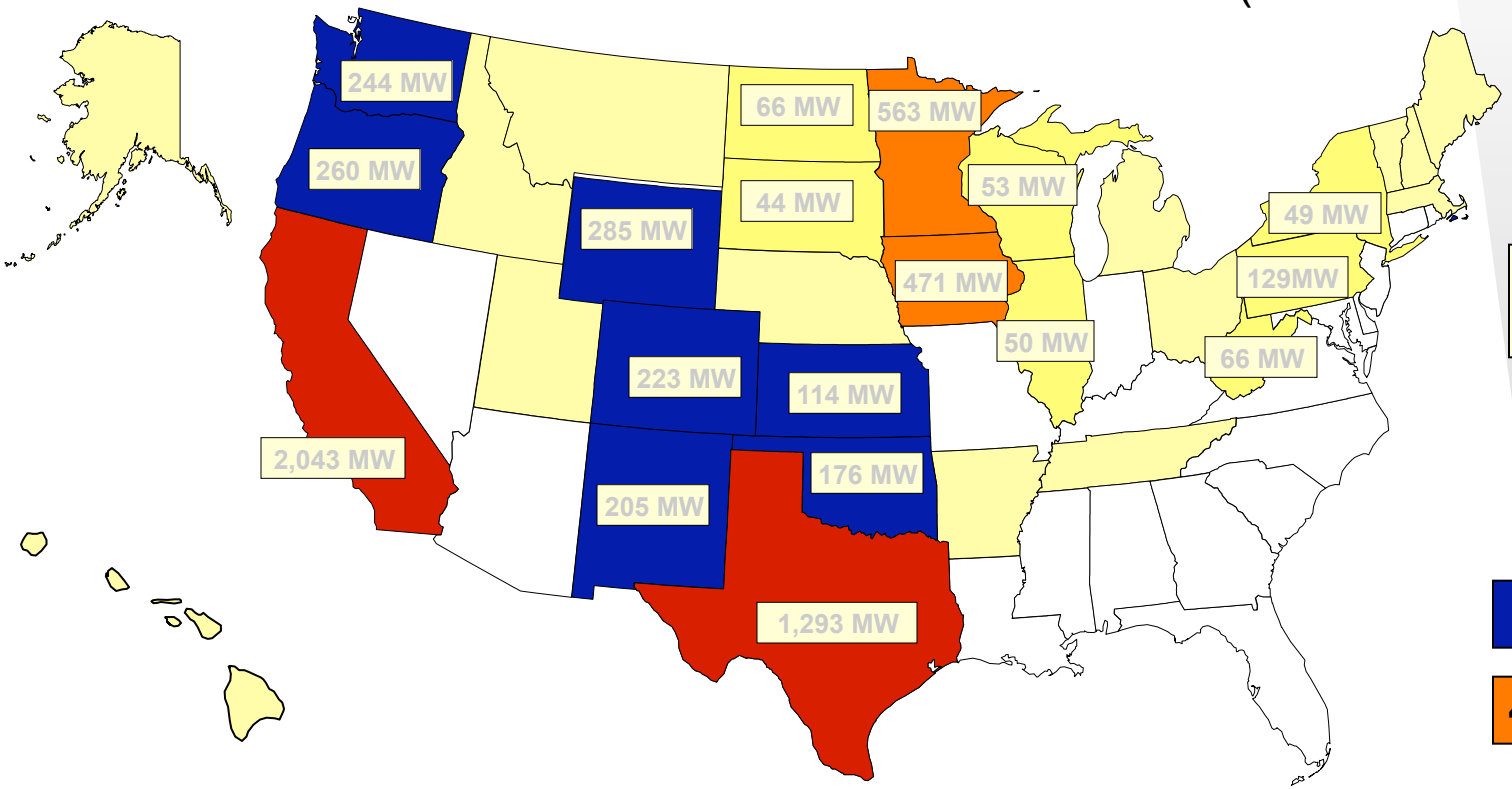
(Billions of Kilowatt-Hours)



Source: U.S. Department of Energy, Energy Information Administration

Wind Energy Development in U.S.

(as of end 2003)



Installed MW by state

- 0.1-20 MW
- 20-100 MW
- 100-400 MW
- 400-1,000 MW
- >1,000 MW

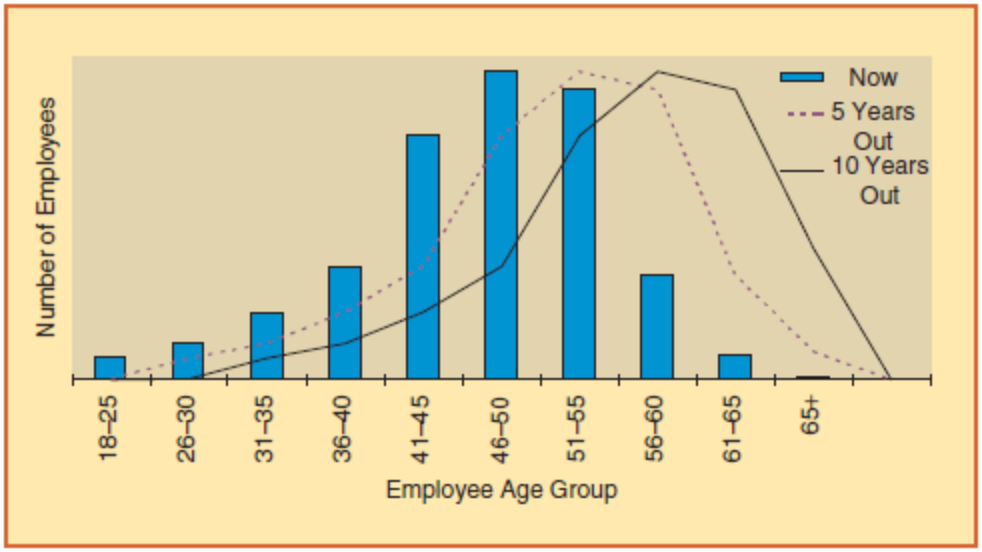
U.S. Total: 6,374 MW at the end of 2003

Why do you want to take this course?

- Reason 1: it is a very exciting field.
- Reason 2: there are lots of potential employers.
- Reason 3: I can make the future grid better… and want to be part of the solution.

Aging Workforce

- 50% of the technical workforce will reach retirement in 5-10 years (2003 poll by EPRI)
- Average age: ~50
- Power engineering students: ~2000/1980s → 500/2006 (IEEE)

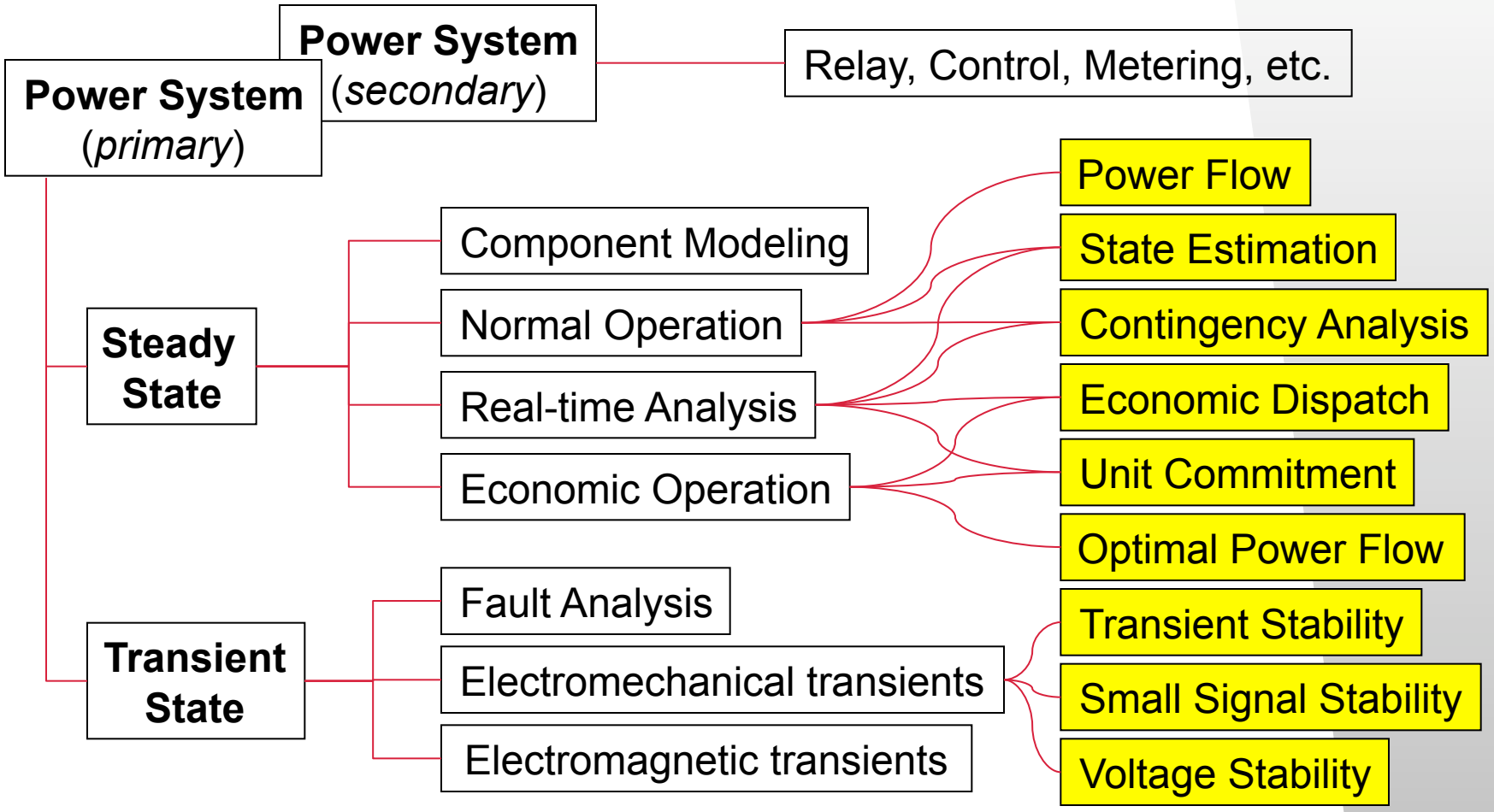


Source: Reder, W.K., "The technical talent challenge", Power and Energy, Vol 4, No 1, Jan/Feb 2006.

Why do you want to take this course?

- Reason 1: it is a very exciting field.
- Reason 2: there are lots of potential employers.
- Reason 3: I can make the future grid better… and want to be part of the solution.
- Reason 4: job opportunities … as well as responsibilities.

What will you learn…



Course Goals

- Understanding of quasi-steady state analysis, as applied to large systems
- Understanding of economic considerations in power system operations
- Understanding of dynamic issues
- Ability to use numeric simulation to solve complex problems (design project)

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What do engineers do?

Engineers make modern civilization possible!

What do *power* engineers do?

Power engineers make modern engineering possible!

– Dr. John Hauer, PNNL Lab Fellow (Retired), IEEE Fellow

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Questions?