"Energy Systems" A Critical National Infrastructure

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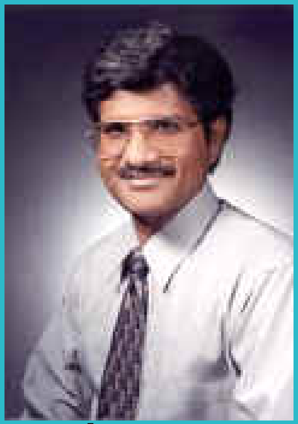
National Academy of Engineering ranks *electrification* as the greatest engineering achievement of the 20th Century

- Evolution of electricity industry
- Integrated electric energy systems
- Power systems: how they work
- Power systems: what can go wrong?
- The 2003 NE Blackout
- The future of energy

ISU Electric Power & Energy Systems Group (EPES)

Chen-Ching Liu

Dionysios Aliprantis



Venkataramana Ajjarapu

Tom Baird

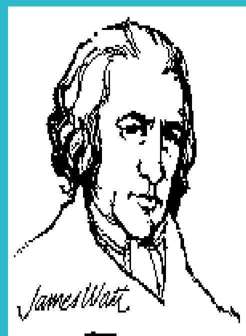
Stephanie Drake

Jim McCalley

Evolution of Electric Industry

1600: William Gilbert invents the compass.

1732: Stephen Gray discovers conduction..



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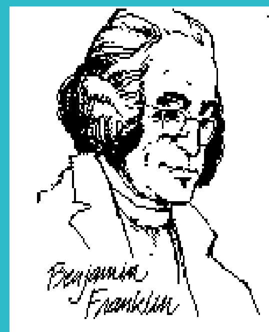

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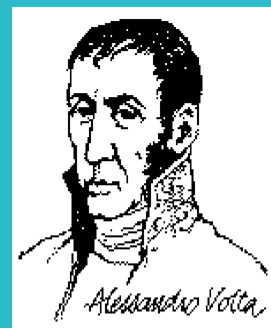

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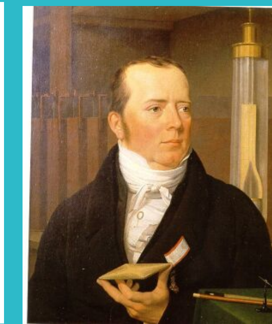
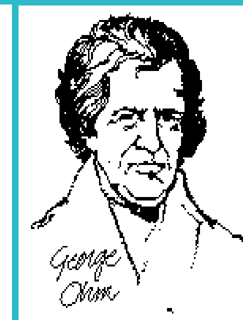


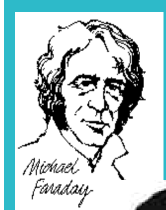
1820: Hans Oerstead discovered magnetic effects of a current on a compass needle.

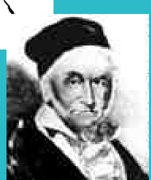
1820:Marie Ampere discovered a coil of wire acts like a magnet when carrying current.



1827: George Ohm discovered the relation between voltage, current, and resistance.

1827: Joseph Henry discovered inductance.





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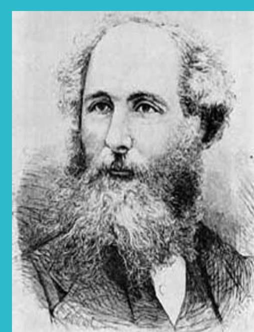
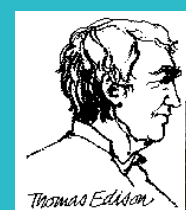
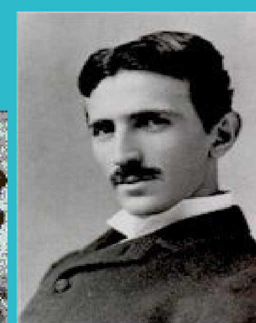


1873: James Maxwell wrote equations describing electro-magnetic fields, and predicted the existence of electromagnetic waves.



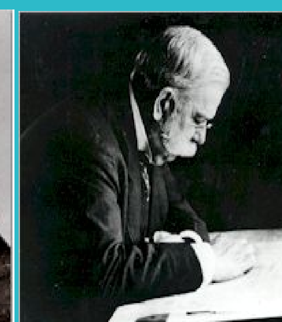
1879: Edison invented the incandescent lamp and in 1882 supplied Pearl St (NY) with light from DC generator.

1886: William Stanley invented the transformer.



1888: Nikolai Tesla patented the AC polyphase motor.

1888: H. Hertz experimentally verified Maxwell's equations



1895: George Westinghouse harnessed Niagara Falls and commercialized AC generation, transformation, and transmission.

Evolution of Electric Industry

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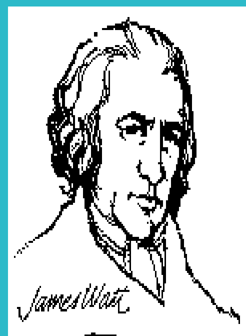

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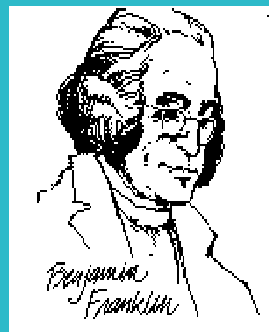

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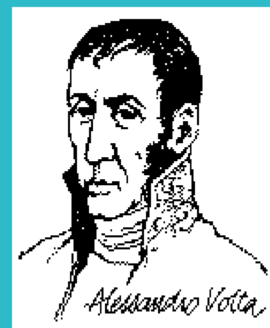

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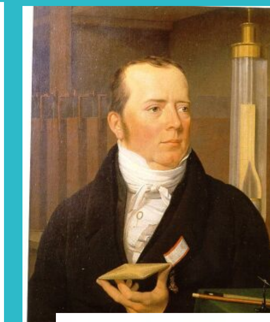

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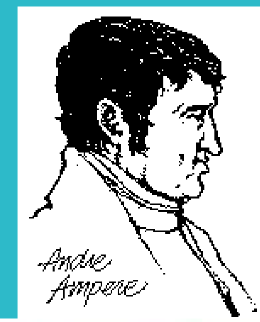

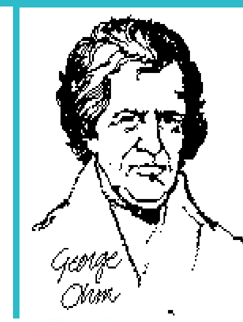

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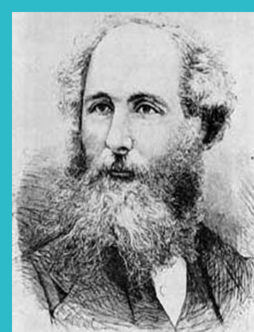

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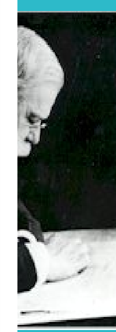
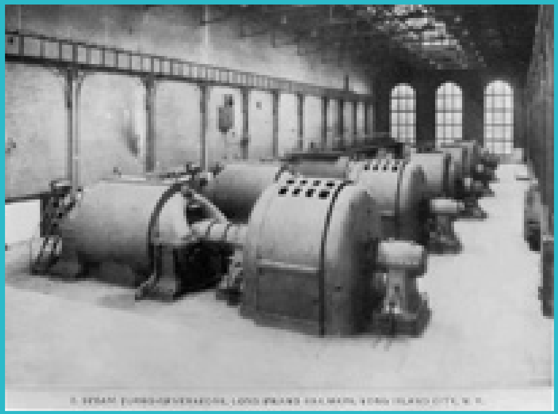


gara Falls
alized AC

transformation, and transmission.

Evolution of Electric Industry

- 1903 Samuel Insull understanding economies of scale (generators when scaled up produce proportionally more power – big is better!) installs 5 MW generator in Chicago and manages load to increase his load factor (avg load/max load) to increase profits
- 1907 Insull realizes that profitability from managing economies of scale and load factor grows with corporate size, and so forms Commonwealth Edison, Chicago, by buying all of his competitors.
- 1907 States begin recognizing electric companies as natural monopolies similar to the railroads, with large economies of scale requiring huge capital investment so that it was not socially efficient to have multiple competitors



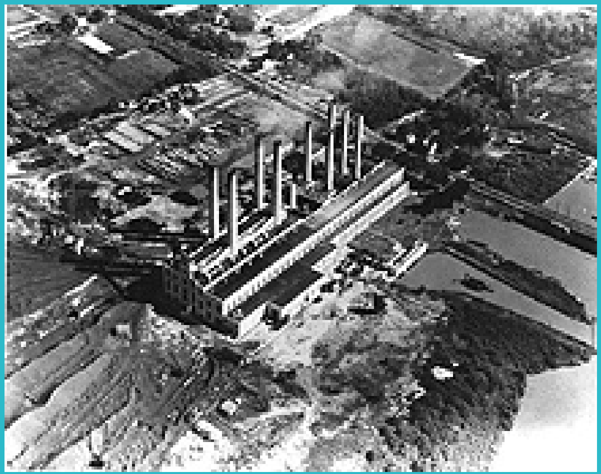
Steam turbo-generators, Long Island railways, c.1907

Fiske Street Station steam turbine Chicago, c.1907

Transmission switches on wooden towers, 1906

Evolution of Electric Industry

- 1914 About 43 states had established government oversight (state regulation) of electric utilities, requiring reliability and the obligation to serve from utilities, and giving right to recover reasonable return from the rate base on their investments, contributing to perspective that utility stocks were good for retirement.
- 1927 In US, 75,400 MWhr sold, from 5700 MWhr in 1907
- Equipment manufacturers (GE) started holding companies that would buy and manage many operating companies, offering them equipment and services that they could not afford themselves, & establishing interconnections between them.



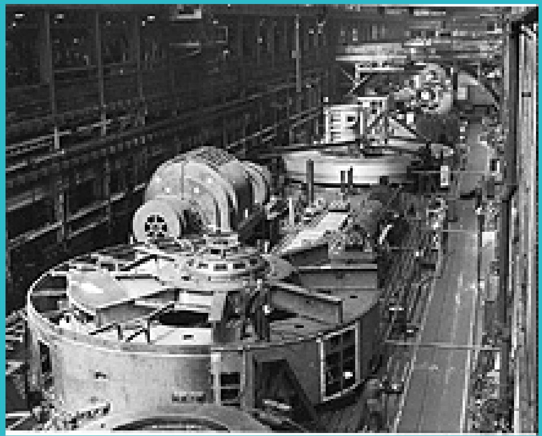
Potomac Electric Power Co.
power station near Washington DC, 1939

Evolution of Electric Industry

- 1927 There were 4400 operating companies, 180 holding companies; top holding companies in pyramids often overcharged subsidiary (operating) companies.
- 1929 Stock market crash caused loss among holding companies; a few survived
- 1932 Only 8 holding companies owned 75% of the operating companies, & they were exempt from state regulation since their business crossed state boundaries.
- 1932 FDR elected on promise to reform the industry of "the Ishmaels and the Insulls, whose hand is against everyman's."
- 1935 Investor-owned utilities (IOUs) resisted supplying rural areas on grounds it would not be profitable. So US Rural Electrification Administration created to facilitate creation of municipals and co-operatives in rural areas.
- 1935 Public Utility Holdings Company Act (PUCHA)
  - Broke up layered interstate holding companies; allowed 1 level above operating company; required them to divest holdings that were not within a single circumscribed geographical area; reduced existing monopoly power.
  - Required companies to engage only in business essential for the operation of a single integrated utility, and eliminated non-utility generators (NUGs-didn't want companies moving into other areas); reduced future monopoly power.
  - Required companies to register with Security & exchange commission (SEC)

Evolution of Electric Industry

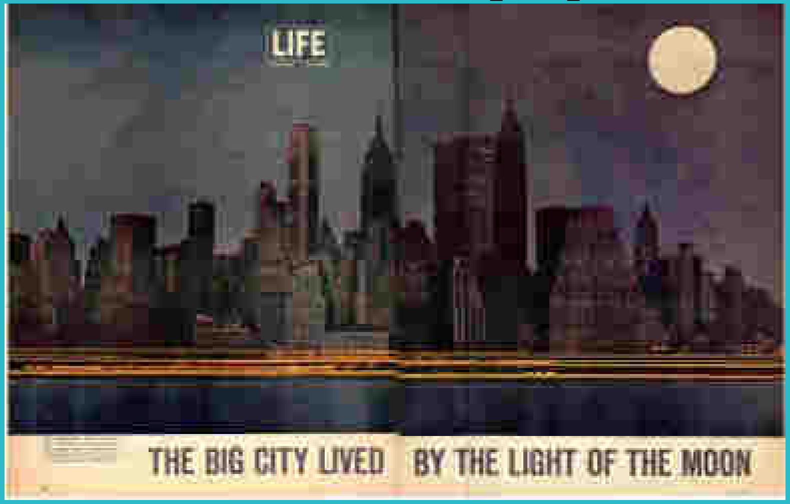
- 1938-1964: Golden years!
  - Holding companies declined from 216 to 18.
  - Generator max plant efficiencies increased from ~20% to ~40%.
  - Generation max size increased from ~110 MW to ~1000 MW.
  - Transmission typical voltage increased from mostly 60 kV to 230, 345, and 500 kV.
  - Load grew at ~8%/year, doubling every 10 years.
  - Price declined at 50 cents/kWhr to 10 cents/kWhr.
  - Grow and build!
- 1964 About 77% electric energy from IOUs and 23% from municipals, co-ops, and government (e.g., WAPA, BPA, TVA).



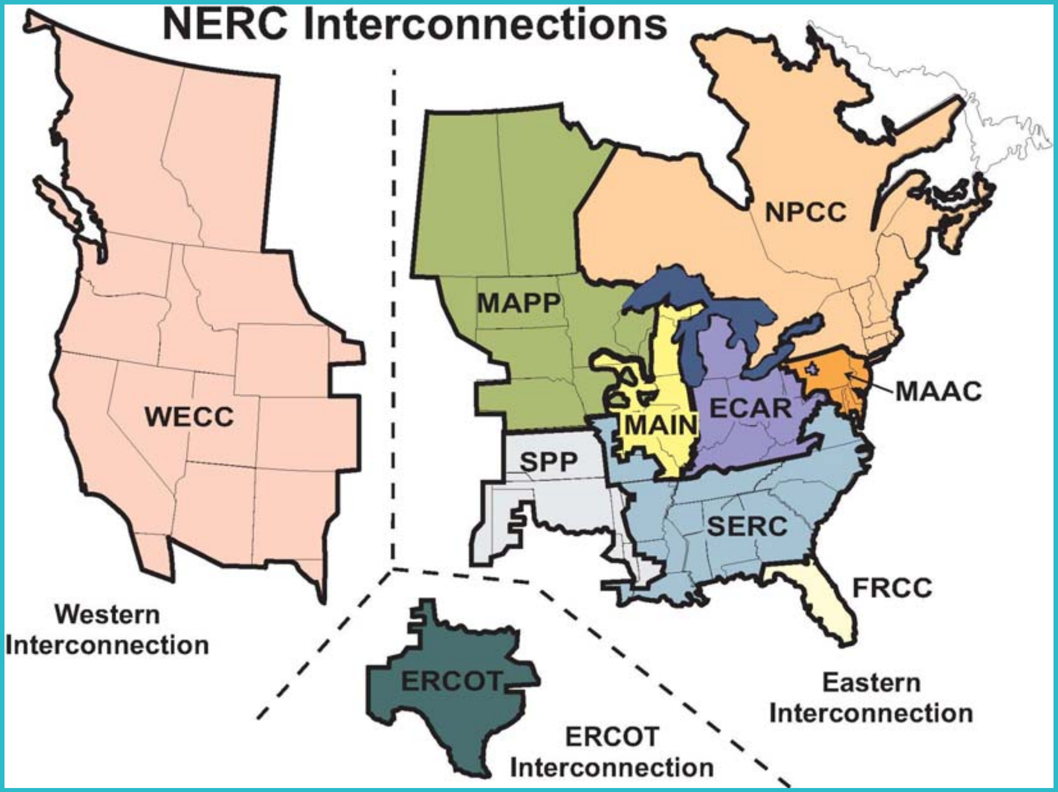
45,000 Kilovolt-ampere waterwheel for Tennessee Valley Authority (foreground), c.1938

Evolution of Electric Industry

- 1965, 5:27 pm, Nov 9: Northeast Blackout, 20000 MW lost, 80,000 people interrupted in northeast US, including NYC.

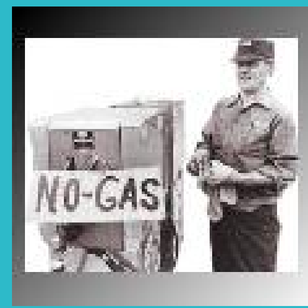


- 1968 North American Electric Reliability Council (NERC) created.



Evolution of Electric Industry

- 1970 Technical limits to economies of scale and to plant efficiencies, aversion to coal due to cheap petroleum and nuclear, & OPEC.
- 1973 Energy Crisis
- 1977 Department of Energy (DOE) created.



- 1978-1980 Airline, telecom industries deregulated.

"the moral equivalent of war."

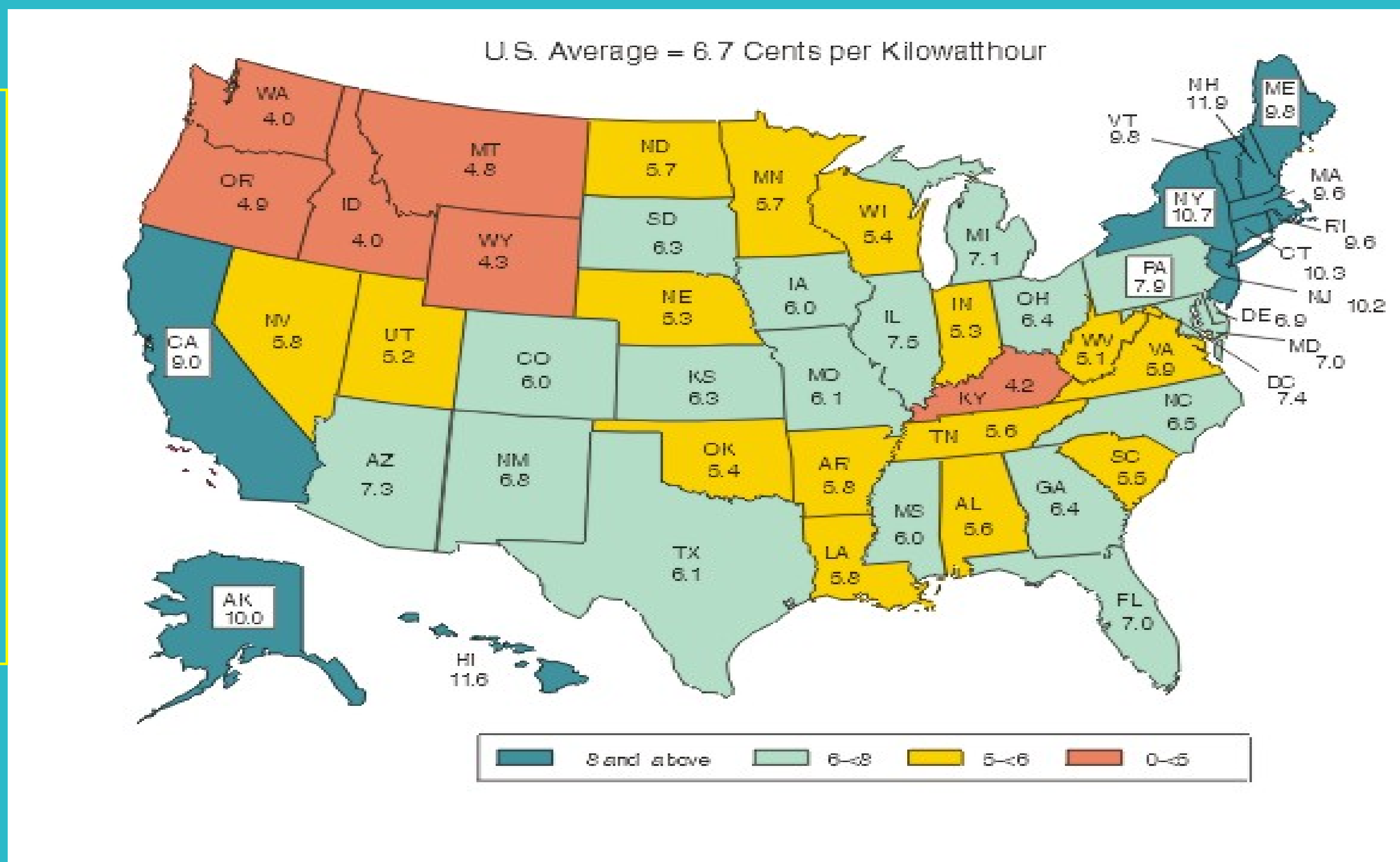
- 1978 Public Utility Regulatory Policies Act (PURPA): utilities had to interconnect, buy, at avoided cost from qualifying facilities (small power producers using 75% renewables or cogeneration).
- 1978: Fred Schweppe at MIT proposed "spot pricing" of electricity
- 1979 Three-mile island accident.
- 1987 Non-utility generation exceeds 5% ➔

MAJOR QUESTION: Are electric utilities natural monopolies?

Evolution of Electric Industry

- 1992 Electric Policy Act
  - Exempt Wholesale Generators: class of unregulated generators of any technology, utilities did not have to buy their energy.
  - But utilities did have to provide transportation (wheeling) for wholesale transactions; no rules were specified regarding transmission service price.

The 1992 EPA motivated by price disparity throughout the US. Large industrials were hungry for lower prices.



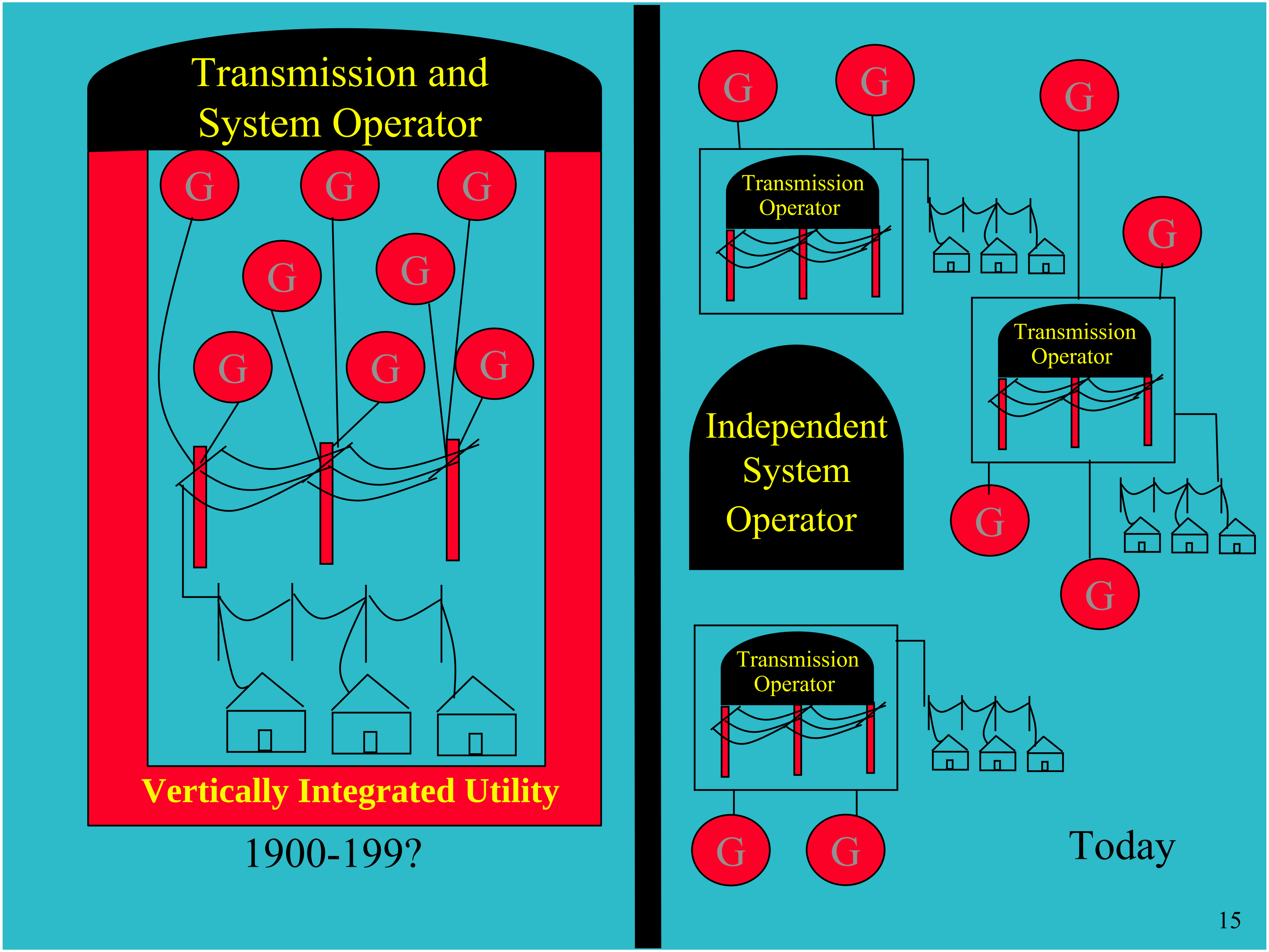
Evolution of Electric Industry

- 1996 FERC Orders 888, 889, required IOUs to
  - file nondiscriminatory transmission tariffs
  - pay tariffs for transmission service for their own wholesale transactions
  - maintain an information system that gives equal access to transmission information (OASIS)
  - functionally unbundle their generation from "wires"
  - FERC order did not specify how; can be done via divestiture or "in-house"
- Major outages: WSCC ('96,'97), Bay area ('98), NY ('99), Chicago ('00)
- 1997: Startup of 21 OASIS nodes across US
- 1998 (April) California legislation gave consumers right to choose supplier
  - 1999 (June) 1% residential, 3% small commercial, 6% commercial, 21% large industrial, 3% agricultural have switched providers in California
  - 2000 (Jan) 13.8% of total load switched in Cal

Evolution of Electric Industry

- 2000 FERC Order 2000 requires utilities to form regional transmission organizations (RTOs) to operate, control, possibly own transmission
- 2000-2001 California energy crisis
  - Drought, hot weather, outaged generation, natural gas shortage, transmission bottlenecks, flawed market design allowing price manipulation by some companies, problematic political forces
- 2001, April PG&E went bankrupt

- 2001, November Enron collapse
- 2002 FERC standard market design issued.
- 2003 Major blackout in the northeast US.
- 2004 Things going well in Texas, Northeast, Midwest, getting better in the west.
- 2005, The National Energy Policy Act: Quotas on ethanol, $$ for clean coal R&D, large incentives to build nukes, repeals PUCHA (SEC authority to FERC).
- 2006,
- 2007, DOE Greenhouse Gas Emission Report
- 2008


Transmission and
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Vertically Integrated Utility
1900-199?
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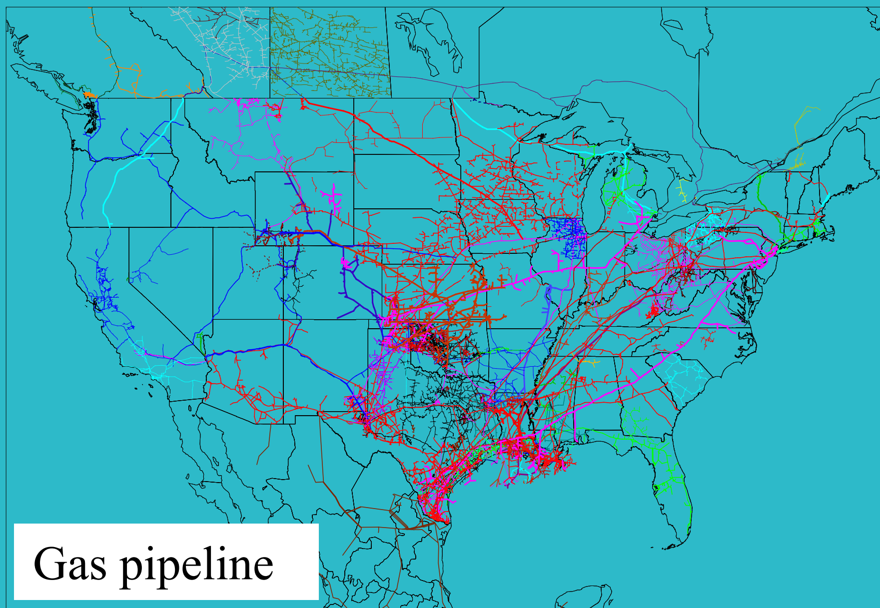
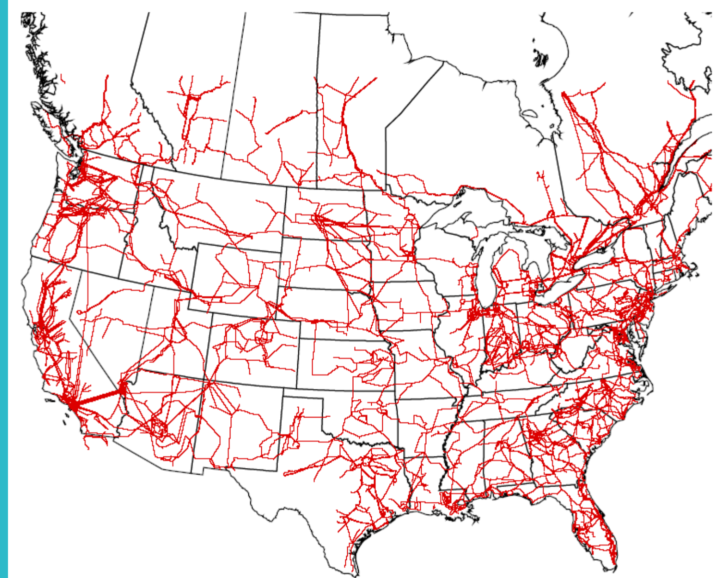
Today

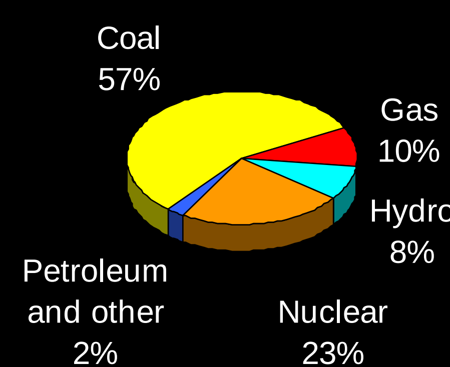
Integrated Electric Energy Systems



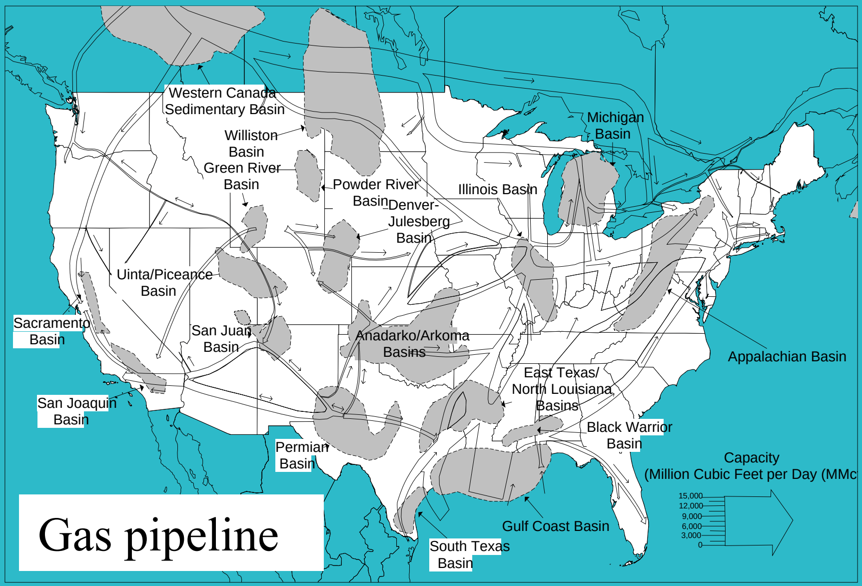
Electric transmission

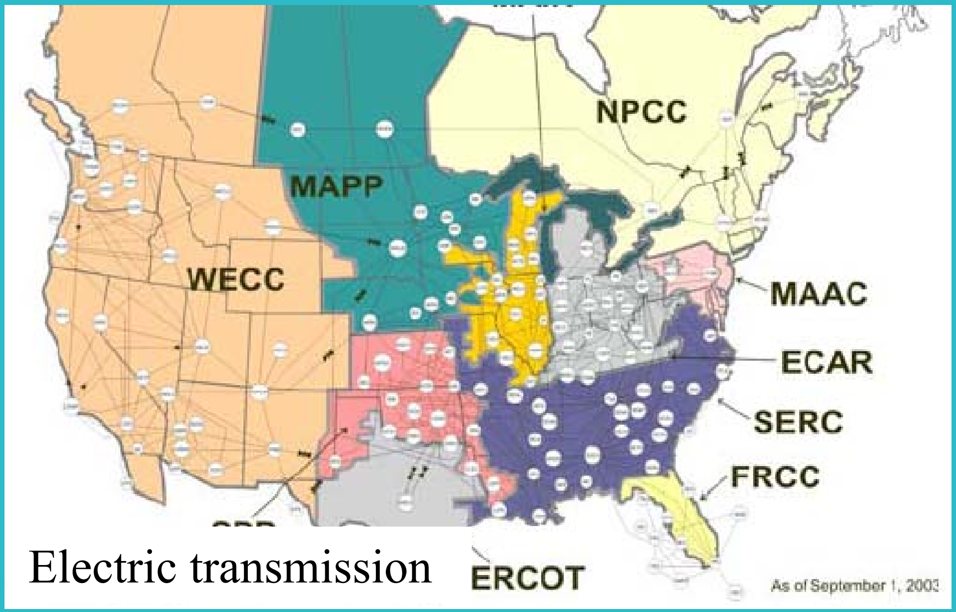


Shares of electric generation, by energy source, 2000

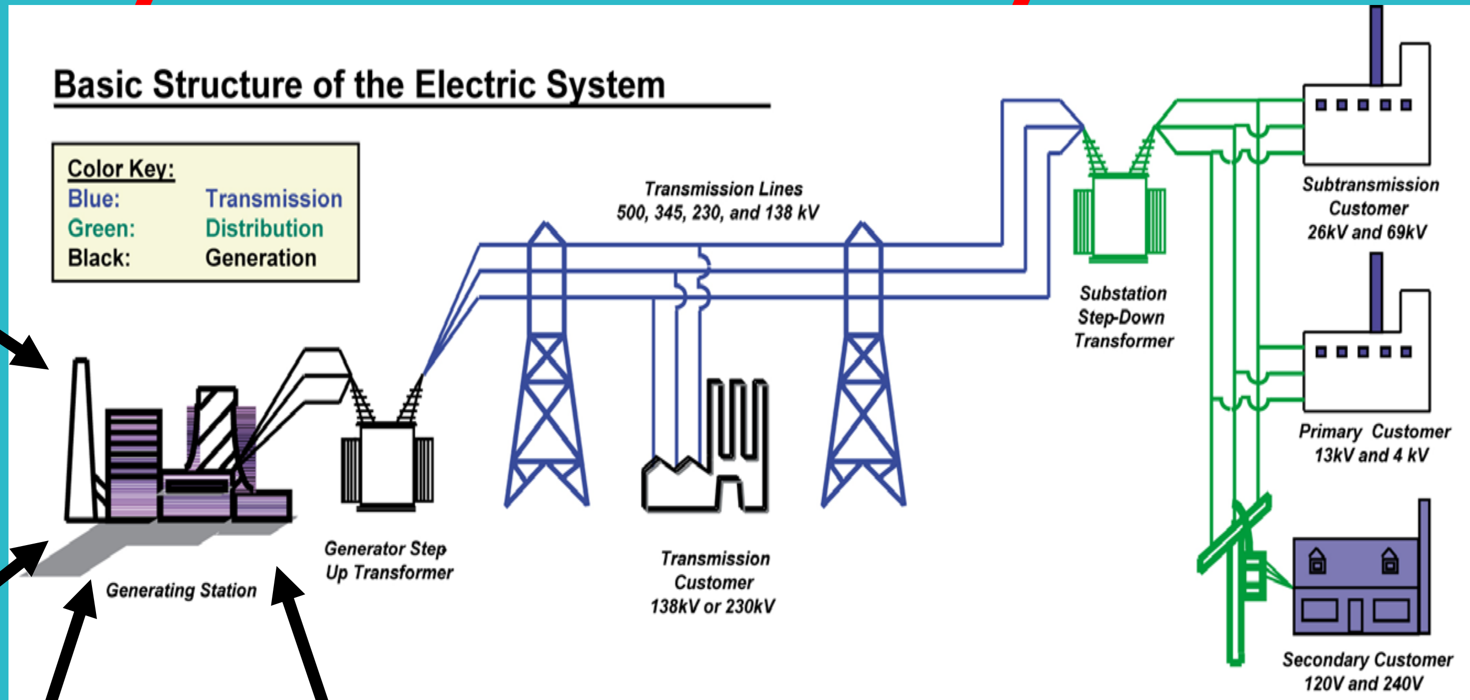


Higher-Level View of Gas & Electric



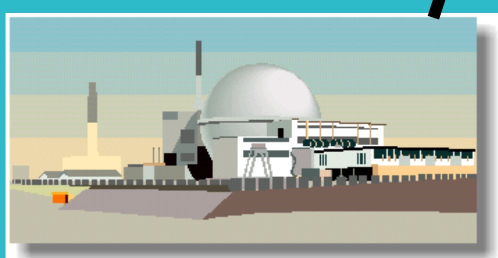


Power systems: How they work



Hydro

Gas or CC



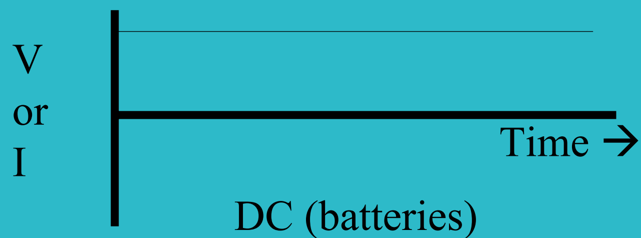
Nuclear

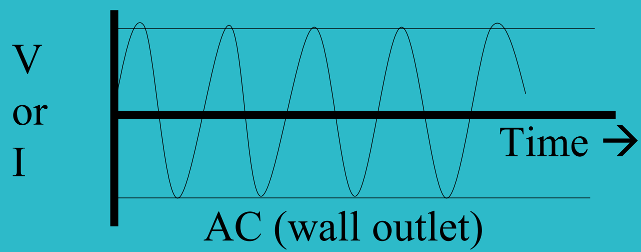
Coal

- Basics
- Generation & transmission
- Substations & transformers
- Control centers

Power System Basics

- Current (amperes), is like water flow
- Voltage (volts), is like water pressure
- Resistance (ohms), is like 1/pipe diameter: $I=V/R$
- Electricity is either DC or AC





- Real power (watts), is ability to do work, light a bulb

$$P=3VI\cos\theta$$

- Reactive power (vars), does no work, but anything with a winding (motor) must have them. $Q=3VI\sin\theta$

Power System Basics

- AC voltages can be easily changed from one level to another using power transformers

- Power generation occurs at low voltages (less than 25,000 volts) because of insulation requirements

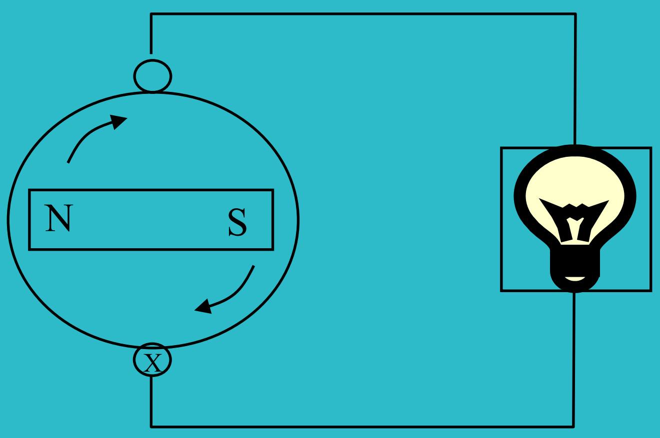
- Power transmission occurs at high voltages (69,000 to 765,000 volts) to minimize current for given power transfer capability and thus minimize losses in wires

- Power distribution occurs at low voltages below 34,500 volts) for safety reasons

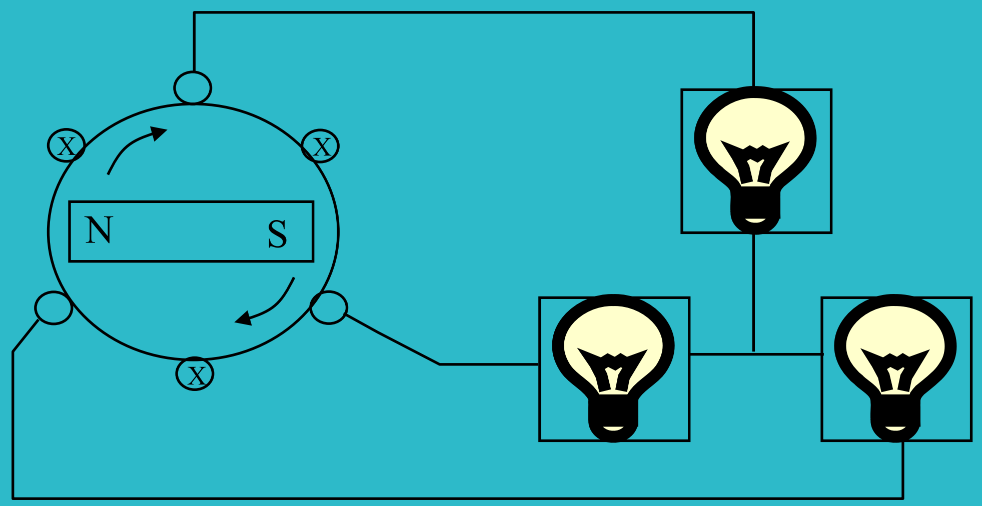
- So power systems are mainly AC because of ability to easily transform AC voltages from low levels in the generators to high levels for transmission and back to low levels for distribution and usage.

Power System Generation & Transmission

- Power circuits can be single-phase or 3-phase



Single phase

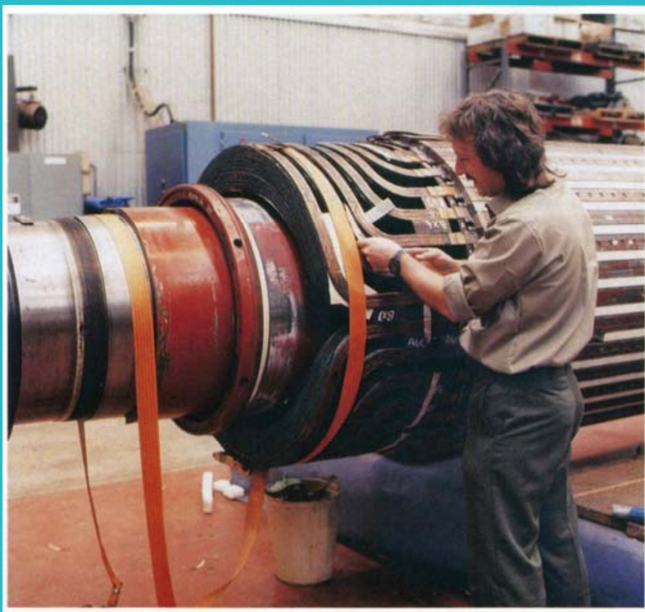


3-phase

- Generation & transmission is always 3-phase because
  - Requires 3 wires (if balanced) instead of 6
  - Power is constant and large motors run smoother

Steam Generator

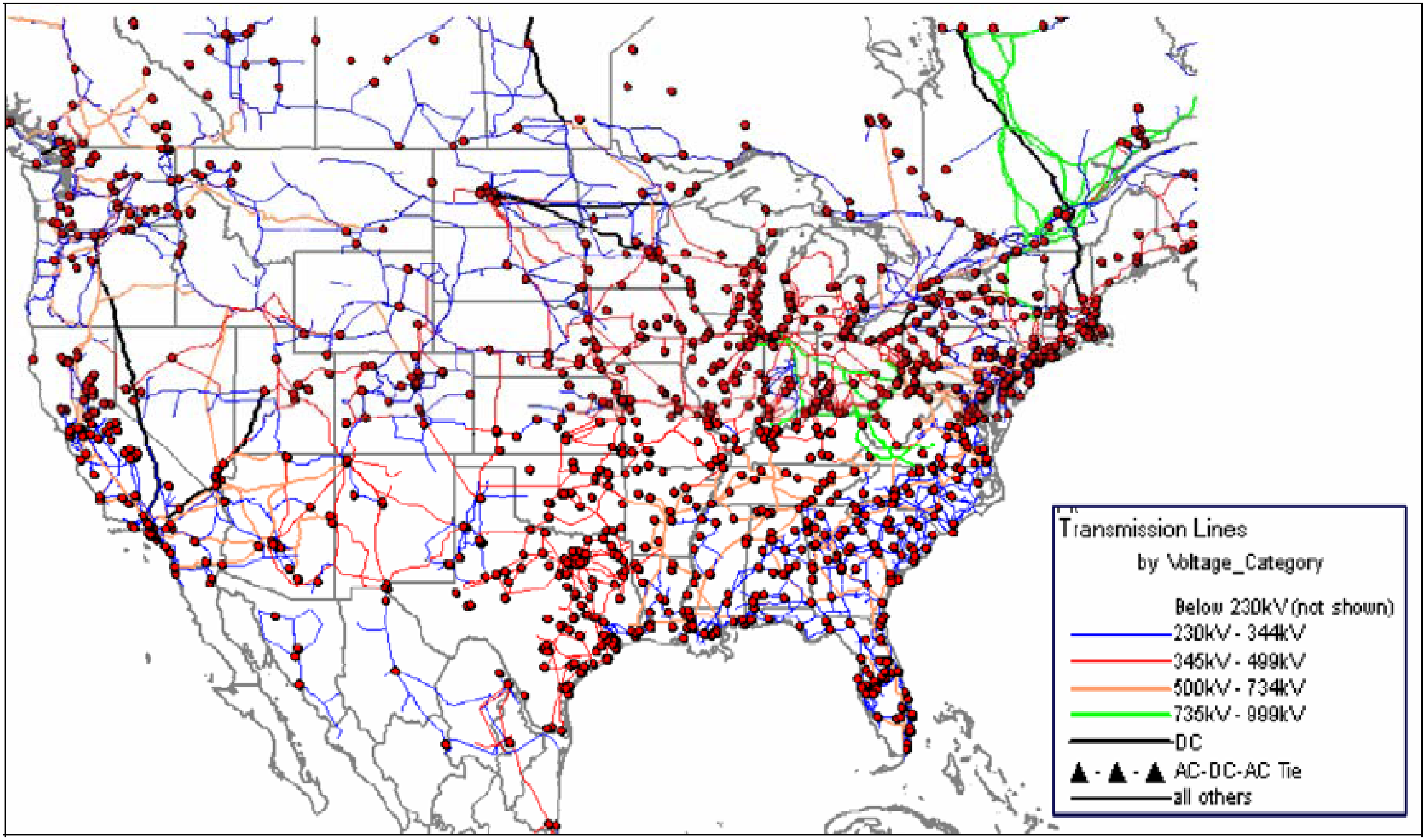
Hydro Generator



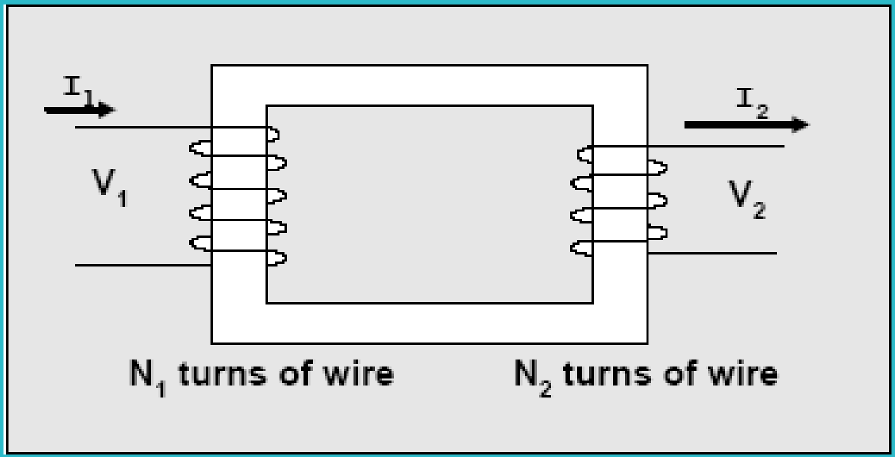
Repairs to the overhand insulation of this 200MW generator rotor were carried out by experienced tradesmen working on shift to ensure the earliest possible return to service.

Transmission consists of multiples of 3 wires.

US Electric Transmission System



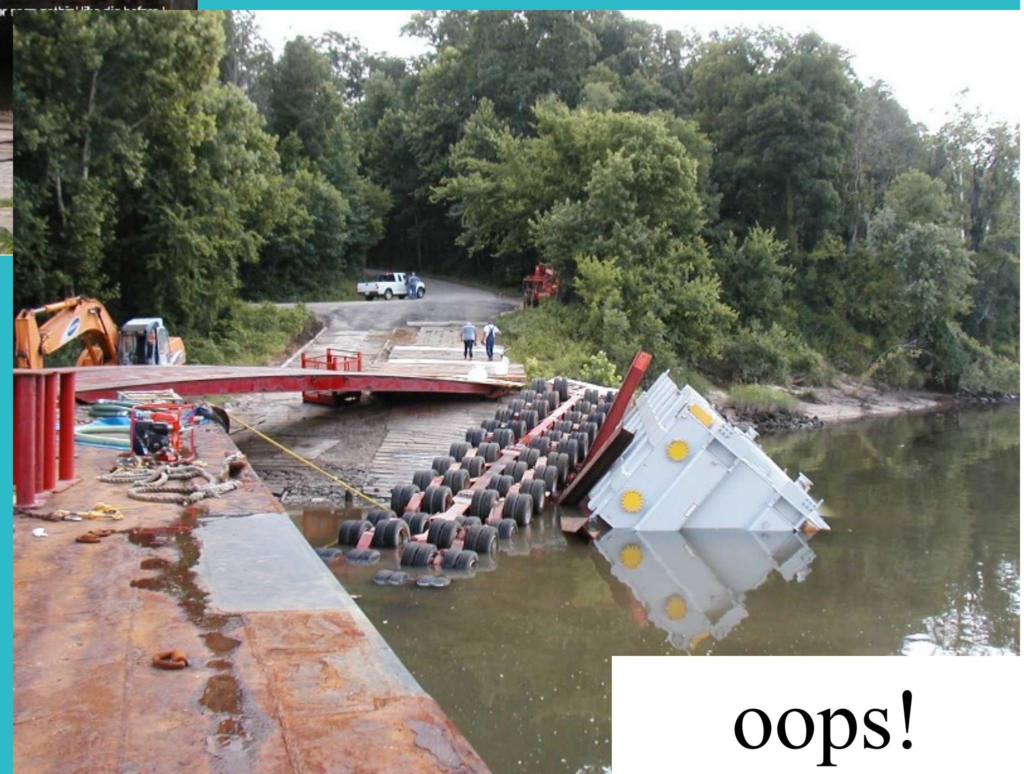
Transformers; how they work



$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

- Only works with AC!
- V_2 can be larger or smaller than V_1

loading a transformer on a barge

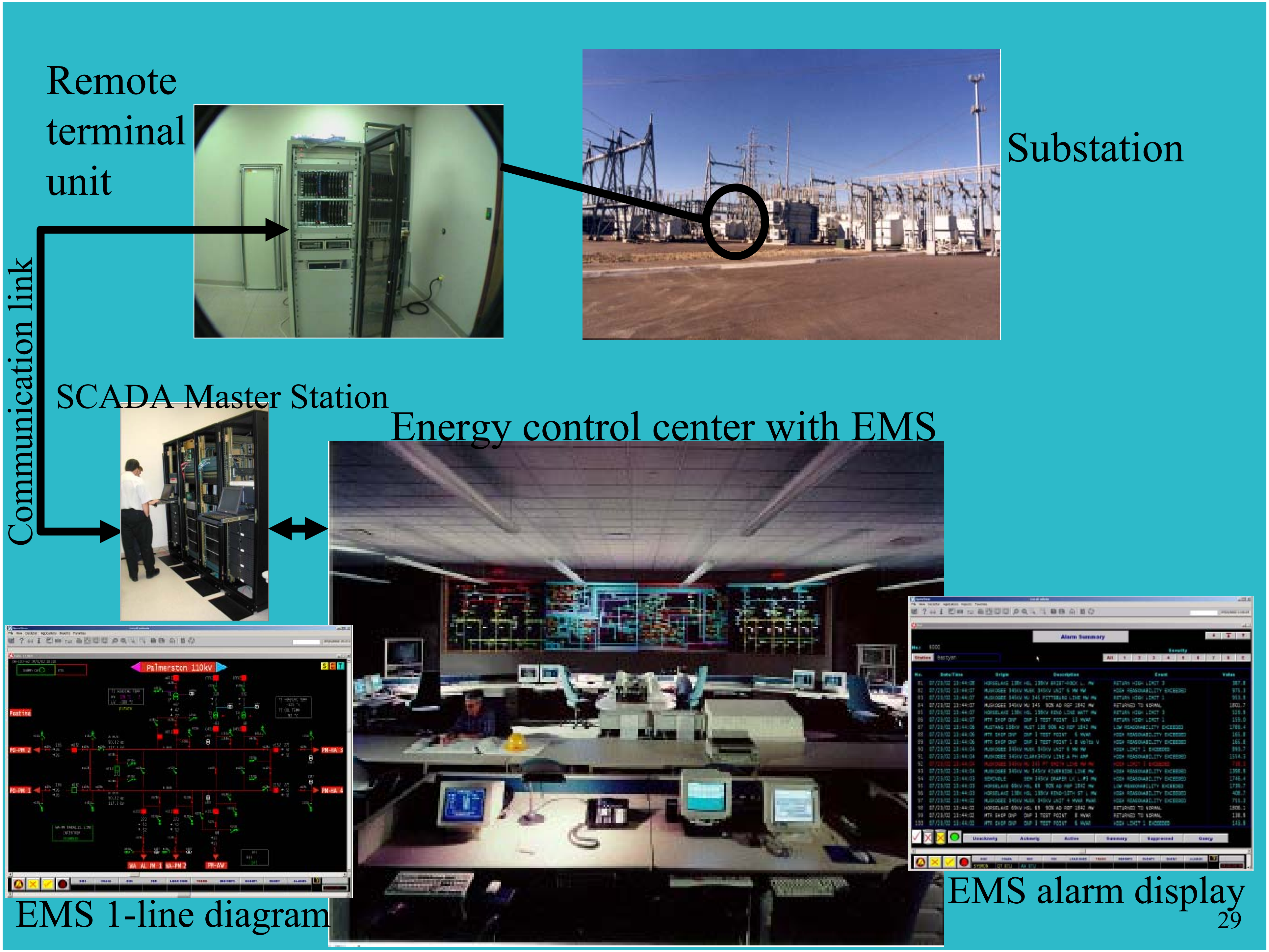


oops!

Substations: where transmission lines meet, & where transformers & protection equipment are located

Energy Control Centers

- Energy Control Center (ECC):
  - SCADA, EMS, operational personnel
  - "Heart" (eyes & hands, brains) of the power system
- Supervisory control & data acquisition (SCADA):
  - Supervisory control: remote control of field devices
  - Data acquisition: monitoring of field conditions
  - SCADA components:
    - » Master Station: System "Nerve Center" located in ECC
    - » Remote terminal units: Gathers data at substations; sends to Master Station
    - » Communications: Links Master Station with Field Devices
- Energy management system (EMS)
  - Topology processor & network configurator
  - State estimator and power flow model development
  - Automatic generation control (AGC), Optimal power flow (OPF)
  - Security assessment and alarm processing


Remote terminal unit
Substation
Communication link
SCADA Master Station
Energy control center with EMS
Palmerston 110kV
Alarm Summary
EMS 1-line diagram
EMS alarm display

More energy control centers




More energy control centers

31

Power systems: What can go wrong?

- Lightning

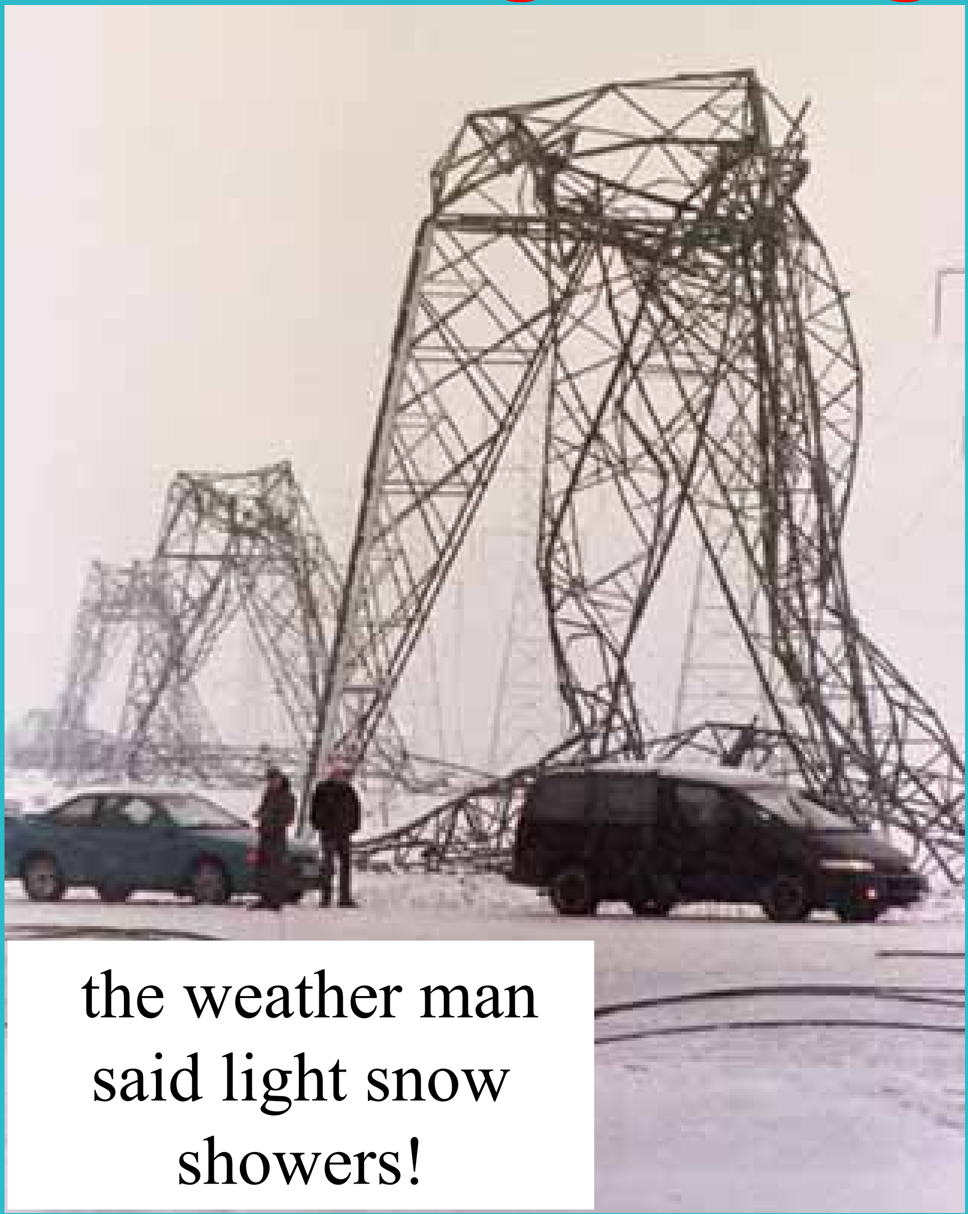

(c) 1995 Dave Crowley www.stormguy.com
Lake Keystone Oct 1995

lightning induced flashover!

Power systems: What can go wrong?

- Lightning
- Wind and snow

hurry up, I can't hold it much longer



the weather man said light snow showers!

it was the wrong sort of snow!

Mon 3 Feb 2003:- no electricity for 70% of Indian state of Bihar

Power systems: What can go wrong?

- Lightning
- Wind, ice, and snow
- Deterioration

(insulation failure)

arc across 400kV insulator

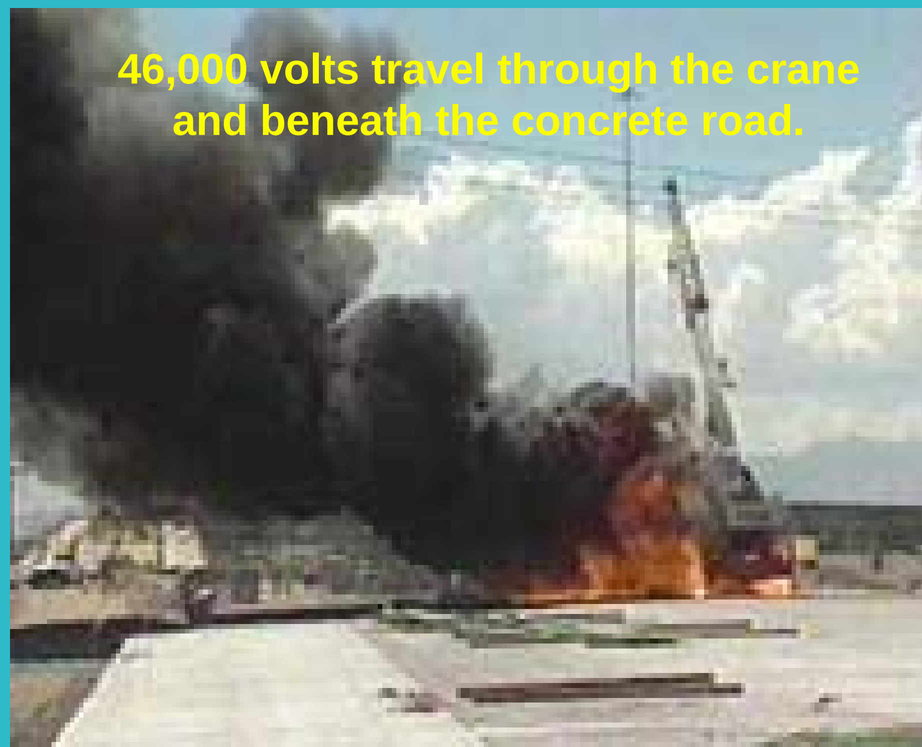
Power systems: What can go wrong?

- Lightning
- Wind and snow
- Deterioration (insulation failure)
- Animals (mainly squirrels & snakes, but sometimes….)

Power systems: What can go wrong?

- Lightning
- Wind and snow
- Deterioration (insulation failure)
- Animals (mainly squirrels & snakes, but sometimes….)
- Vehicles and construction (accidents)

Crane contacts overhead power line during freeway construction.



46,000 volts travel through the crane and beneath the concrete road.

Power systems: What can go wrong?

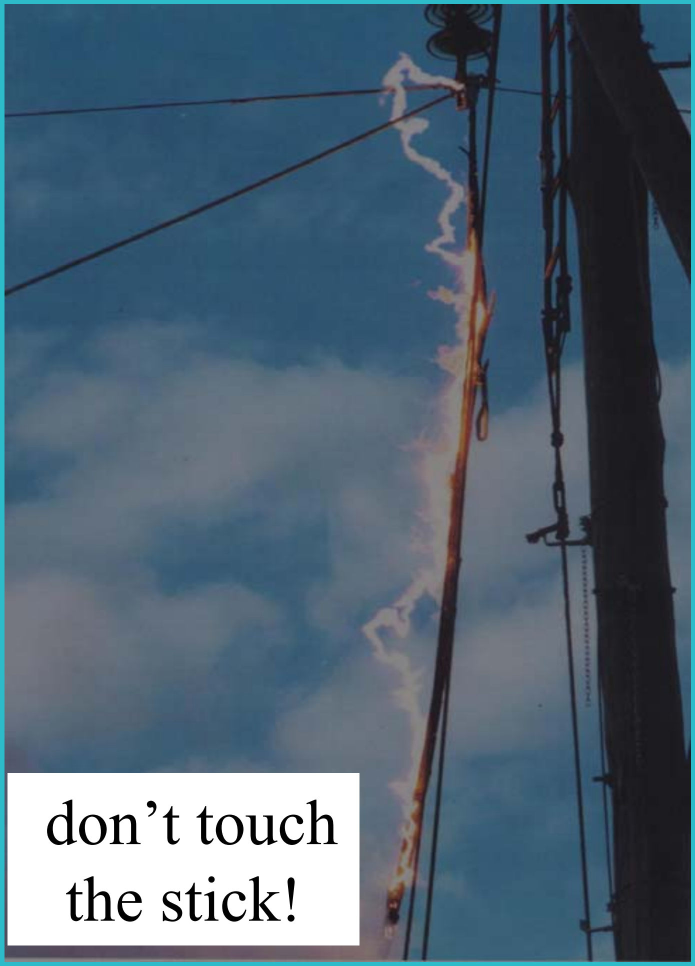
- Lightning
- Wind and snow
- Deterioration (insulation failure)
- Animals (mainly squirrels & snakes, but sometimes….)
- Vehicles and construction (accidents)
- Careless maintenance (mistakes)

I hope you switched it off!

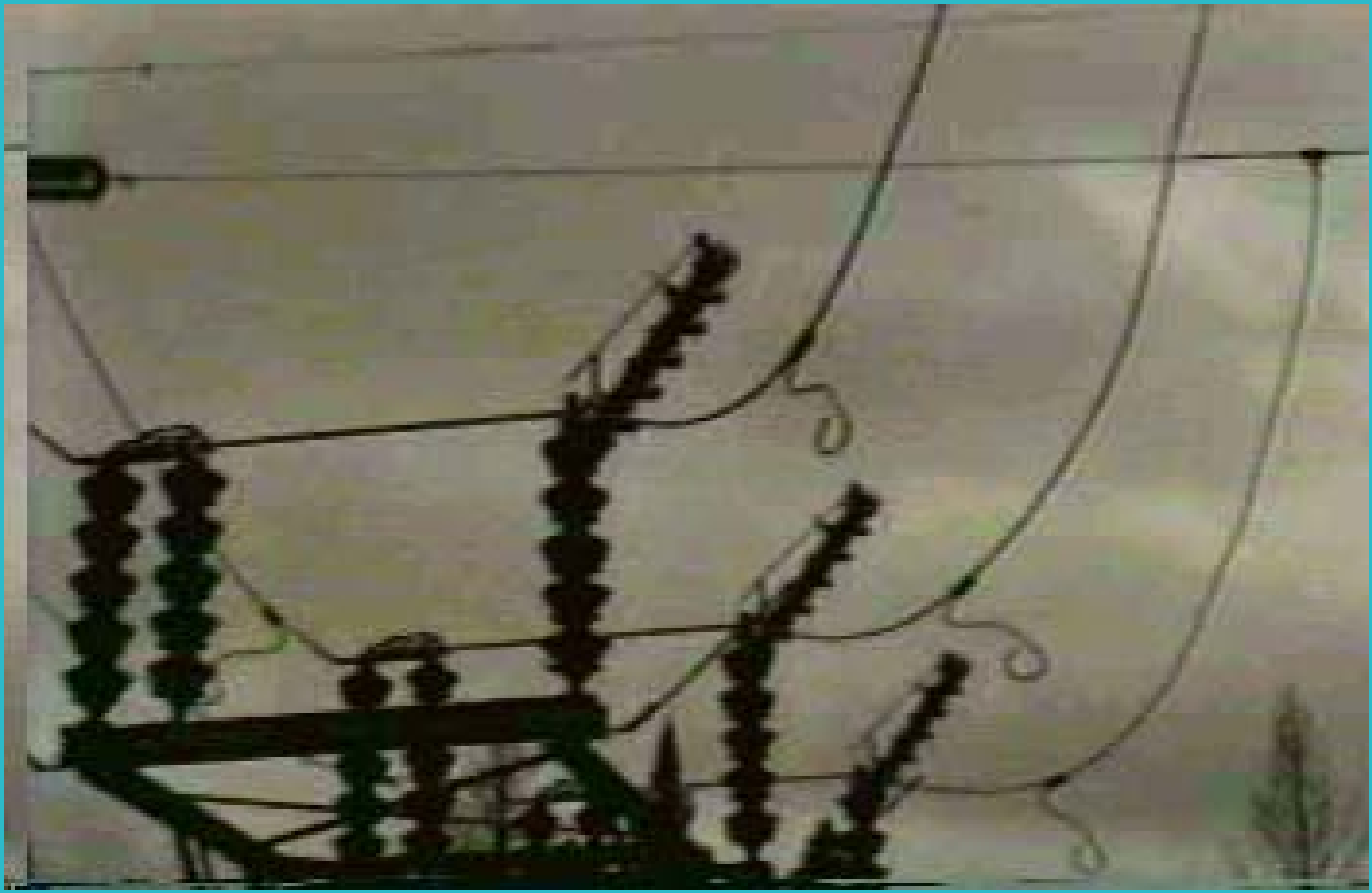
An interesting job….

Power systems: What can go wrong?

- All of the previous situations cause faults.
- Faults are dangerous situations that can hurt people and destroy equipment.
- Protection equipment removes faults:
  - Fuses detect faults and melt a wire. Must be replaced.
  - Relays detect faults and signal circuit breaker to trip.
  - Circuit breakers open lines. Can be re-used.



Staged Faults on
400kV line



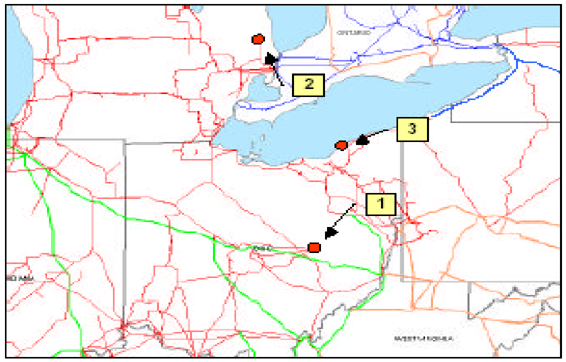

The New York Times
POWER SURGE BLACKS OUT NORTHEAST
HITTING CITIES IN 8 STATES AND CANADA
MIDDAY SHUTDOWNS DISRUPT MILLIONS
The Boston Globe
Great blackout of '03
Outage hits millions in US, Canada
Officials find few answers but grid's fragility
New York takes chaos in stride
Tears, memories in N.H. service for slain pair
Chicago Tribune
50 million lose power
Largest blackout in history hits U.S., Canada cities
Liberia's wait ends; U.S. troops land
Key Al Qaeda figure captured
The Philadelphia Inquirer
POWERLESS
Blackout hits 50 million in U.S., Canada
DAILY NEWS
NEW YORK'S HOMETOWN NEWSPAPER
BLACKOUT
■ 50 MILLION LOSE POWER
■ CITY SWELTERS TO A HALT
■ RUSH-HOUR CHAOS TODAY
LIVE FROM NEW YORK CITY
WCBS
BREAKING NEWS
VOICE OF DARYN KAGAN
NEW YORK
CNN
5:40p ET
AFFIC RUNNING SMOOTHLY; PEDESTRIANS CALMLY DIR
NEW YORK POST
SPECIAL EDITION
PARALYZED
NY'ers stranded by huge blackout

Blackouts

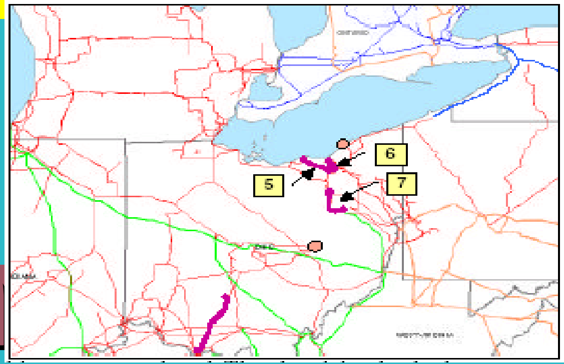
Summary of well-known blackouts

Location	Date	Scale in term of MW or Population	Collapse time
US-NE[1]	10-11/9/65	20,000 MW, 30M people	13 mins
New York[2]	7/13/77	6,000 MW, 9M people	1 hour
France[3]	1978	29,000 MW	26 mins
Japan[4]	1987	8,200 MW	20mins
US-West[5]	1/17/94	7,500 MW	1 min
US-West[5]	12/14/94	9,300 MW	
US-West[5]	7/2/96	11,700 MW	36 seconds
US-West[5]	7/3/96	1,200 MW	> 1 min
US-West[5]	8/10/96	30,500 MW	> 6 mins
Brazil[6]	3/11/99	25,000 MW	30 secs
US-NE[7]	8/14/03	62,000 MW, 50M people	> 1 hour
London[8]	8/28/03	724 MW, 476K people	8 secs
Denmark & Sweden [9][10]	9/23/03	4.85M people	7mins
Italy[11]	9/28/03	27,700 MW, 57M people	27mins

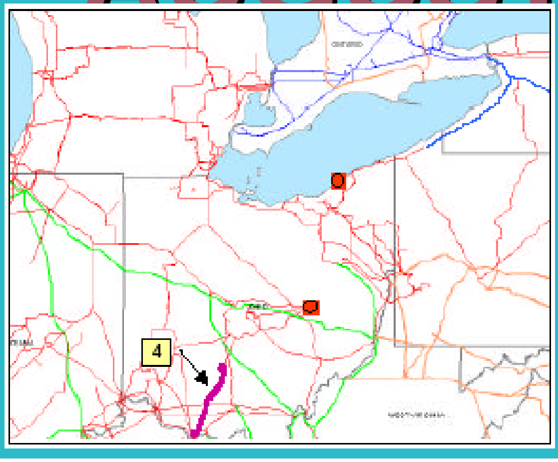
1. 12:05	Conesville Unit 5 (rating 375 MW)	INITIATING EVENT
2. 1:14	Greenwood Unit 1 (rating 785 MW)	
3. 1:31	Eastlake Unit 5 (rating: 597 MW)	
4. 2:02	Stuart – Atlanta 345 kV	SLOW PROGRESSION
5. 3:05	Harding-Chamberlain 345 kV	
6. 3:32	Hanna-Juniper 345 kV	
7. 3:41	Star-South Canton 345 kV	
8. 3:45	Canton Central-Tidd 345 kV	
9. 4:05	Sammis-Star 345 kV	

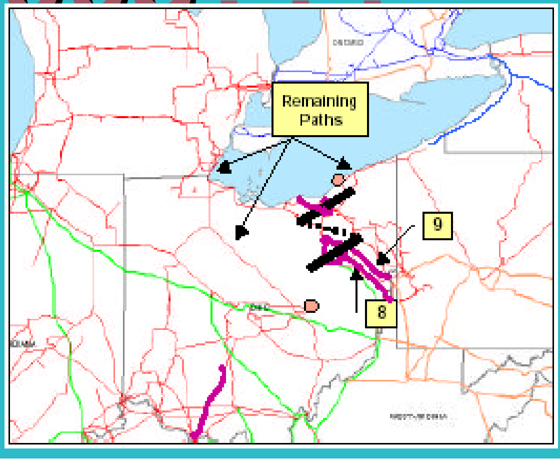


APPE



AUGUST 14, 2003???





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7. 3:41	Star-South Canton 345 kV	
8. 3:45	Canton Central-Tidd 345 kV	
9. 4:05	Sammis-Star 345 kV	
10. 4:08:58	Galion-Ohio Central-Muskingum 345 kV	FAST PROGRESSION (cascade)
11. 4:09:06	East Lima-Fostoria Central 345 kV	
12. 4:09:23-4:10:27	Kinder Morgan (rating: 500 MW; loaded to 200 MW)	
13. 4:10	Harding-Fox 345 kV	
14. 4:10:04 – 4:10:45	20 generators along Lake Erie in north Ohio, 2174 MW	
15. 4:10:37	West-East Michigan 345 kV	
16. 4:10:38	Midland Cogeneration Venture, 1265 MW	
17. 4:10:38	Transmission system separates northwest of De	
18. 4:10:38	Perry-Ashtabula-Erie West 345 kV	
19. 4:10:40 – 4:10:44	4 lines disconnect between Pennsylvania & New York	
20. 4:10:41	2 lines disconnect and 2 gens trip in north Ohio,1868MW	
21. 4:10:42 – 4:10:45	3 lines disconnect in north Ontario, New Jersey, isolates NE part of Eastern Interconnection, 1 unit trips, 820 mw	
22. 4:10:46 – 4:10:55	New York splits east-to-west. New England and Maritimes separate from New York and remain intact.	
23. 4:10:50 – 4:11:57	Ontario separates from NY w. of Niagara Falls & w. of St. Law. SW Connecticut separates from New York, blacks out.	

Immediate causes of the 8/14/03 blackout

1:30 Loss of East Lake generator (over-excitation)

2:02 Loss of Stuart-Atlanta (tree contact)

2:02 MISO system model becomes inaccurate

2:14-3:08 Loss of software in FE control center

3:05 Loss of Harding-Chamberlain (tree contact)

3:32 Loss of Hanna-Juniper (tree contact)

3:41 Loss of Star-S.Canton (tree contact)

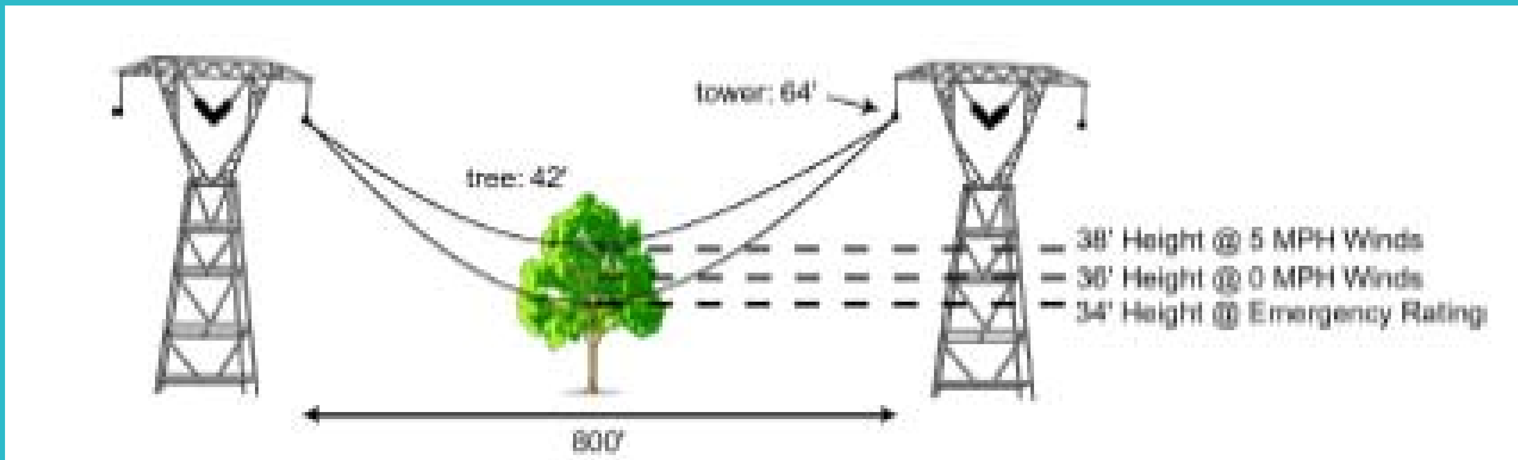
4:06 Loss of Sammis-Star (high overload looked like fault to "zone 3" of the protection system)

Why so much tree-contact?

- Trees were overgrown because right-of-ways had not been properly maintained.
- Lines expand and sag due to heat; more prone in summer with high temperature & low winds; more prone with high current.
- Each successive line trip requires that the power it was carrying be transferred to flow elsewhere, resulting in increased power on remaining lines.

Figure 5.10. Cause of the Hanna-Juniper Line Loss

This August 14 photo shows the tree that caused the loss of the Hanna-Juniper line (tallest tree in photo). Other 345-kV conductors and shield wires can be seen in the background. Photo by Nelson Tree.



Another influence: insufficient reactive power

Another contribution to the blackout was insufficient reactive power in the Cleveland area, i.e., the reactive power (vars) in the Cleveland area generation was insufficient to meet the reactive power demand of its motors. Conditions that make a system prone to this include:

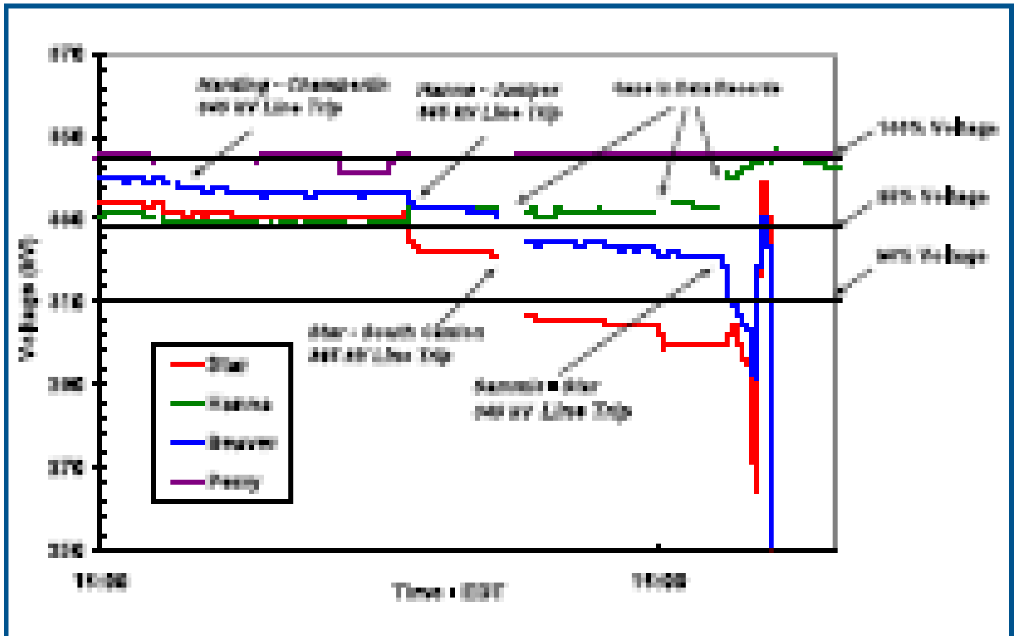
- High load, especially induction motors (air conditioners)
- Loss of generation in load-intensive area and/or loss of transmission into that load-intensive area

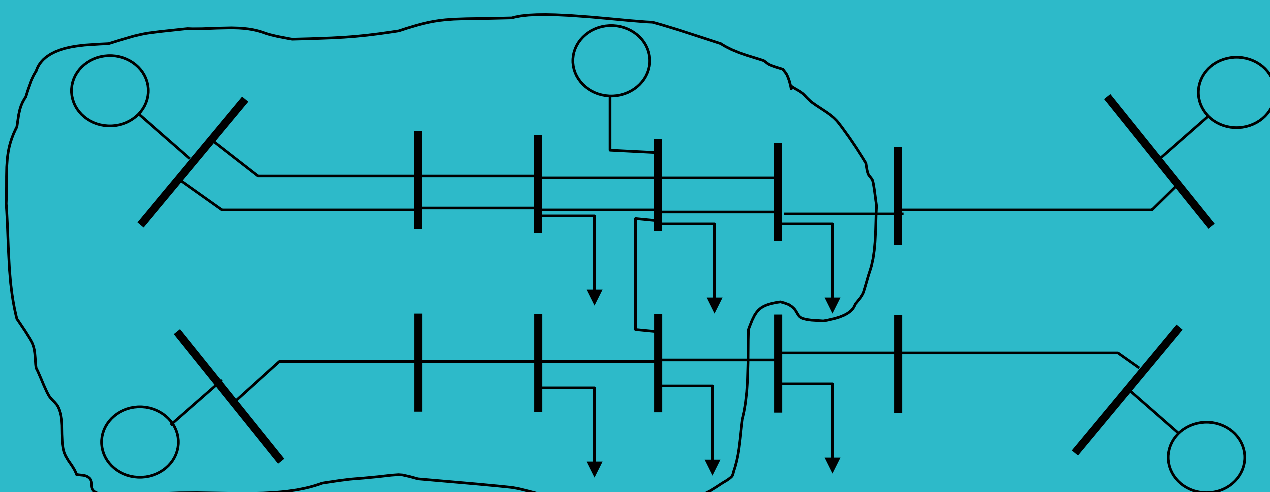
This results in voltage decline in the load-intensive area, and because P~VI, when voltage V declines, current I must increase in order to maintain the same power P.

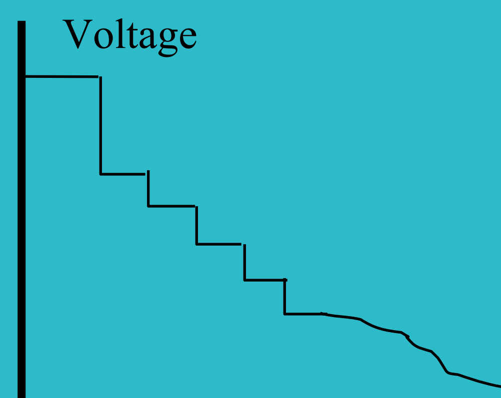
When I goes up, lines load up more heavily.

Another influence: insufficient reactive power

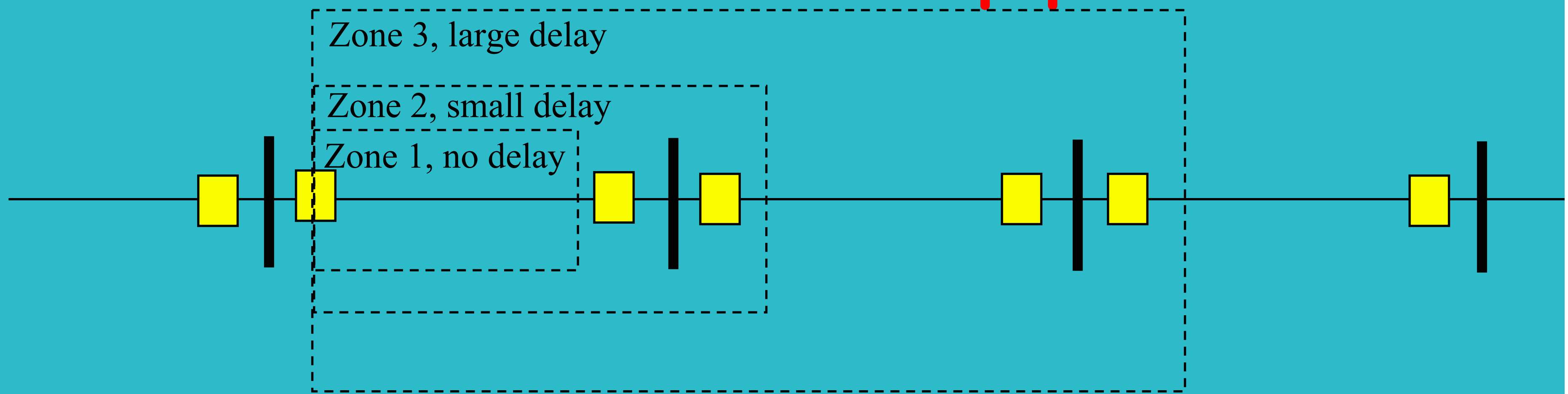
Figure 5.6. Voltages on FirstEnergy's 345-kV Lines: Impacts of Line Trips







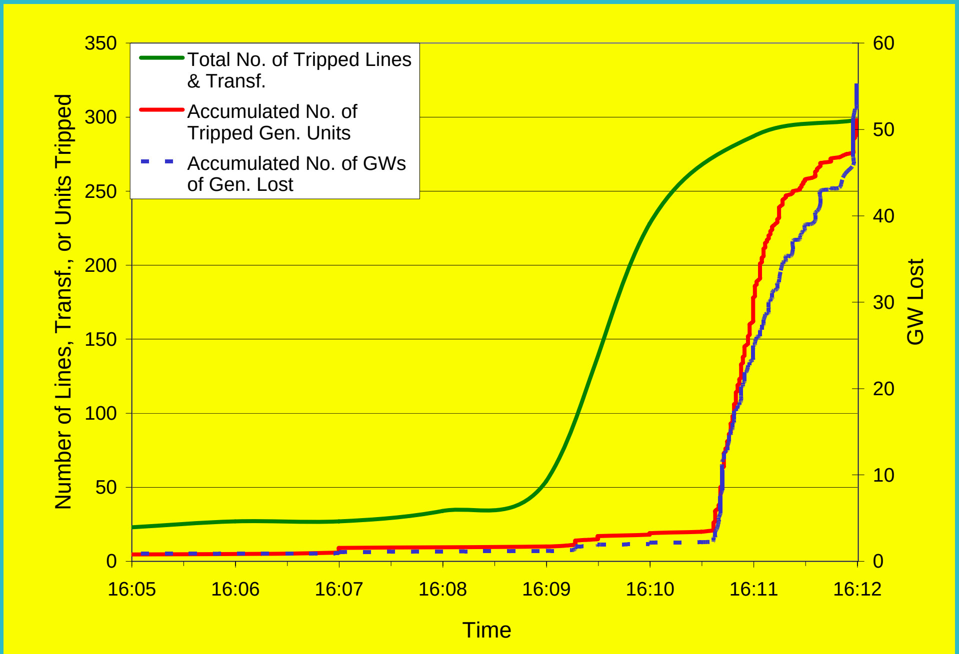
Another influence: Backup protection



- Relays sense V/I and trip if it is too low; good approach because fault conditions are low voltage, high current.
- Relays are directional; trip only for faults "looking" in one direction.
- Zone 1 trips instantly; trip zone for primary protection
- Zone 2 has small delay. Zone 3 has large delay; these are trip zones for "backup" protection

Why did the cascade happen (events 10-23)

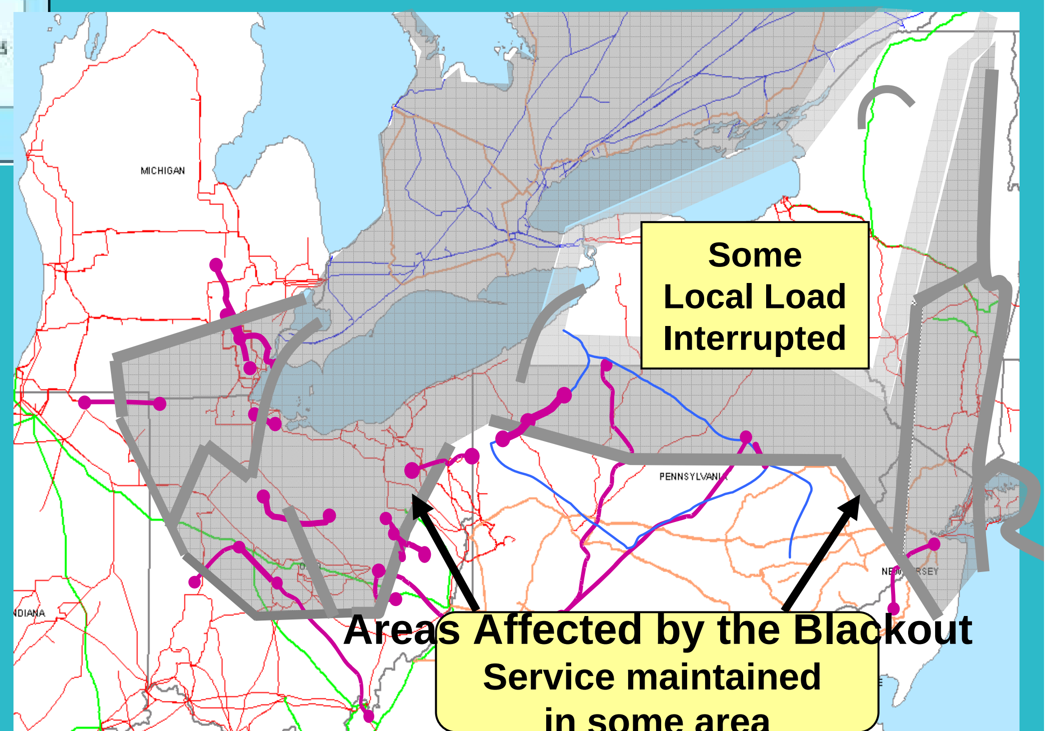
- Oscillations in voltages and currents, and/or very high currents caused many transmission line zone 2,3 protection systems to see what appeared to be faults & trip the line.



- As a few generators tripped, load>gen imbalance caused underfrequency and lower voltages.
- Generators tripped for 1 of following reasons:
  - Underfrequency
  - Out-of-step
  - Under-voltage
  - Over-voltage
  - Overexcitation

Units tripped and areas outaged

The blackout outaged parts of 8 states & Ontario.



The blackout shut down 263 power plants (531 units)

Total cost: ~10 billion $.

Half of DOE annual budget

Twice NSF annual budget

Final List of Main Causes

◆ There was inadequate situational awareness at First Energy (FE). FE did not recognize/understand the deteriorating condition of its system.

◆ FE failed to adequately manage tree growth in its transmission rights-of-way.

◆ Failure of the interconnected grid's reliability organizations (mainly MISO) to provide effective real-time diagnostic support.

◆ FE and ECAR failed to assess and understand the inadequacies of FE's system, particularly with respect to voltage instability and the vulnerability of the Cleveland-Akron area, and FE did not operate its system with appropriate voltage criteria.

- No long-term planning studies w/ multiple contingencies or extreme conditions
- No voltage analyses for Ohio area and inappropriate operational voltage criteria
- No independent review or analysis of FE's voltage criteria and operating needs
- Some of NERC's planning & operational requirements were ambiguous

A few of the 46 Recommendations

1. Make reliability standards mandatory and enforceable, with penalties for noncompliance.

2. Develop a regulator-approved funding mechanism for NERC and the regional reliability councils, to ensure their independence from the parties they oversee.

3. Strengthen the institutional framework for reliability management in North America.

4. Clarify that prudent expenditures and investments for bulk system reliability (including investments in new technologies) will be recoverable through transmission rates.

8. Shield operators who initiate load shedding pursuant to approved guidelines from liability or retaliation.

11. Establish requirements for collection and reporting of data needed for post-blackout analyses.

12. Commission an independent study of the relationships among industry restructuring, competition, and reliability.

13. DOE should expand its research programs on reliability-related tools and technologies.

16. Establish enforceable standards for maintenance of electrical clearances in right-of-way areas.

19. Improve near-term and long-term training and certification requirements for operators, reliability coordinators, and operator support staff.

21. Make more effective and wider use of system protection measures.

23. Strengthen reactive power and voltage control practices in all NERC regions.

24. Improve quality of system modeling data and data exchange practices.

26. Tighten communications protocols, especially for communications during alerts and emergencies. Upgrade communication system hardware where appropriate.

33. Develop and deploy IT management procedures.

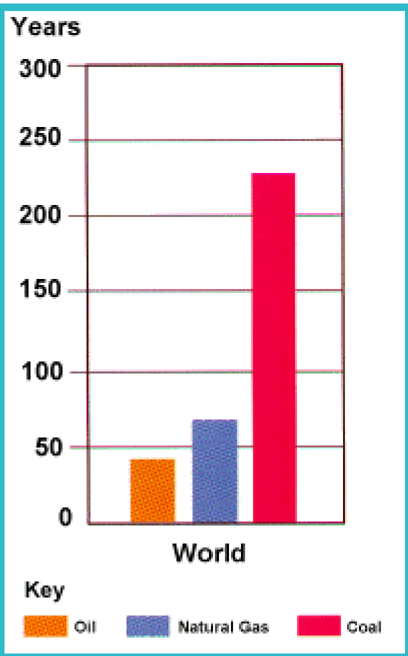
The Future of Energy

- Renewables
- Distributed generation
- The hydrogen economy
- Superconductivity
- Electric vehicles
- New nuclear
- Sustainability

Renewable Energy

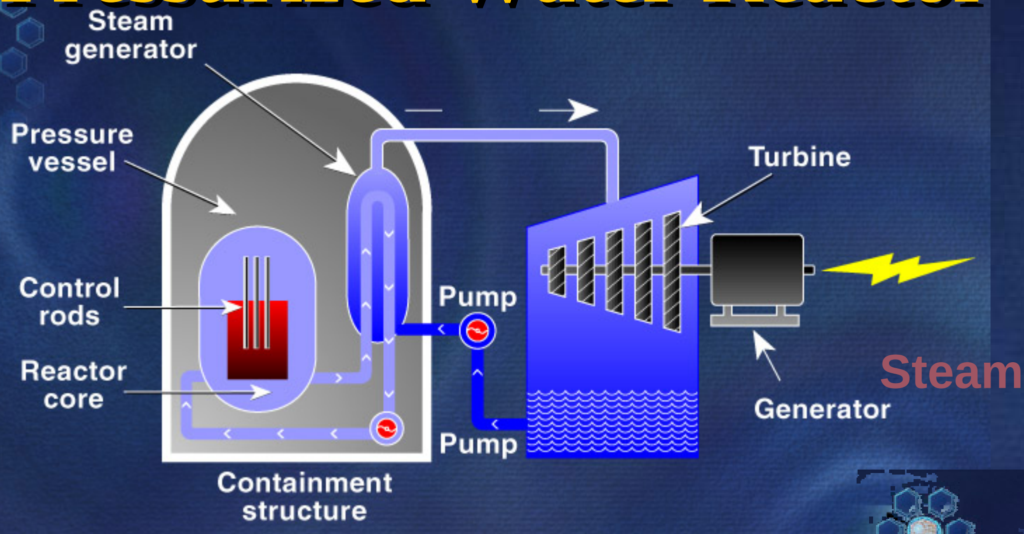
Geothermal

It's Just Steam!

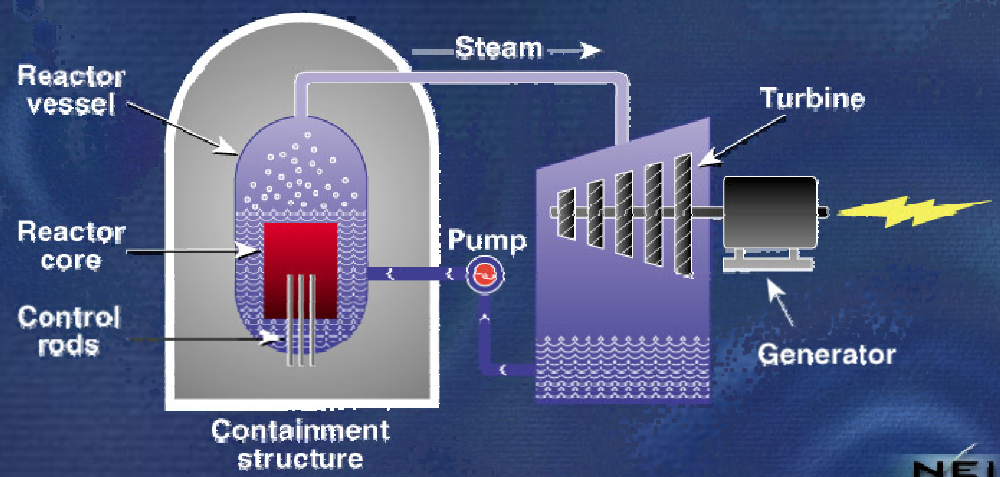


The chart shows the length of time that these remaining reserves would last if production continues at the 1996 level.

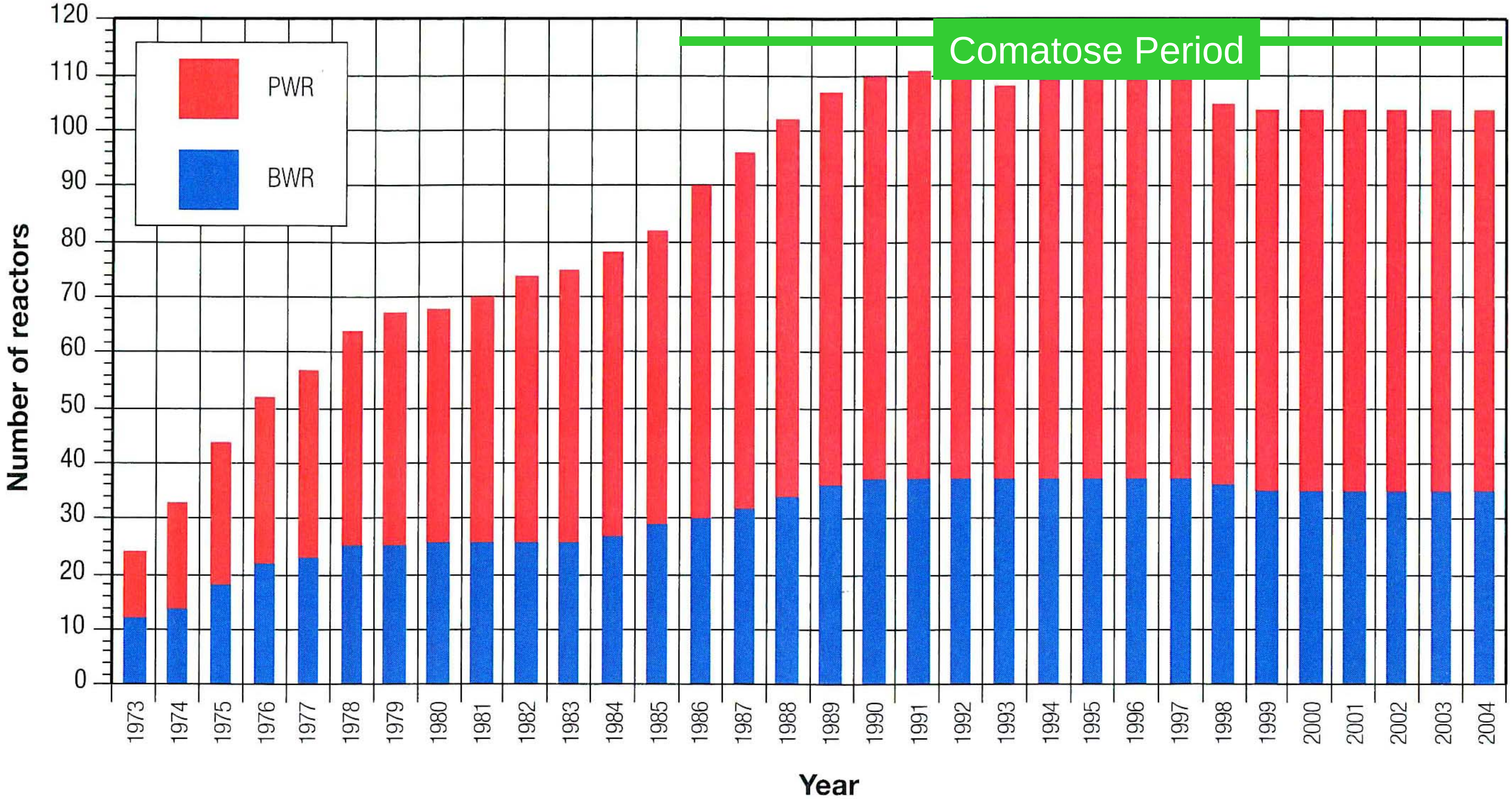
Pressurized Water Reactor



Boiling Water Reactor



Number of Operating Power Reactors in the United States – 1973-2004



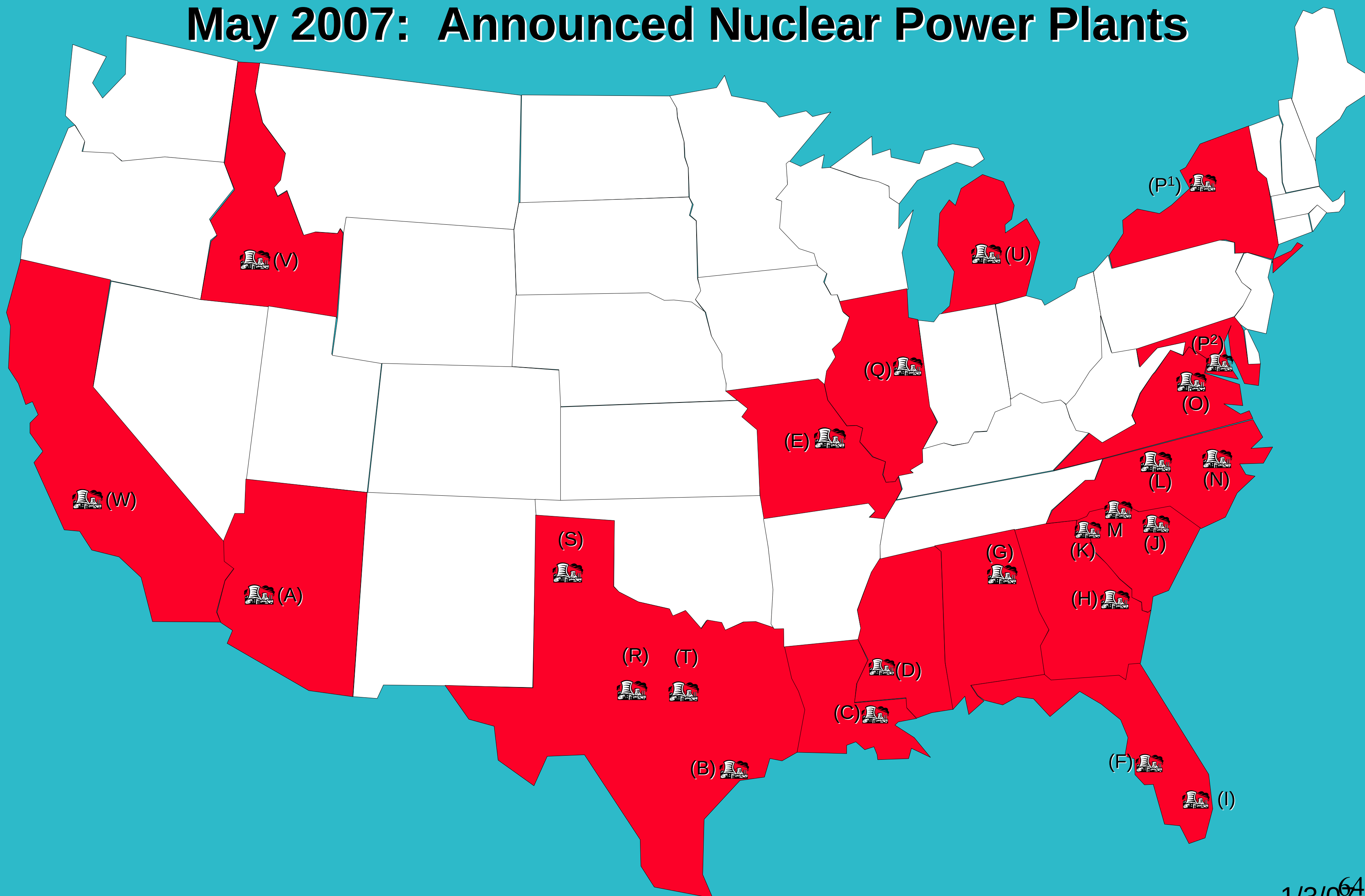
(Source: NUREG-0713, Vol. 26 [October 2005])

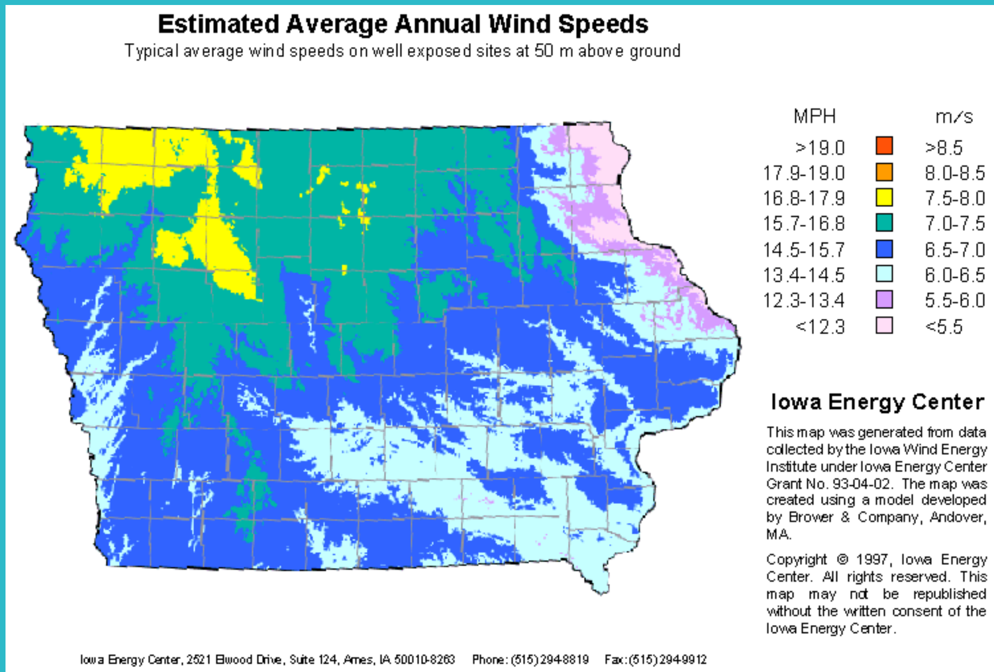
Why New Nuclear Now?

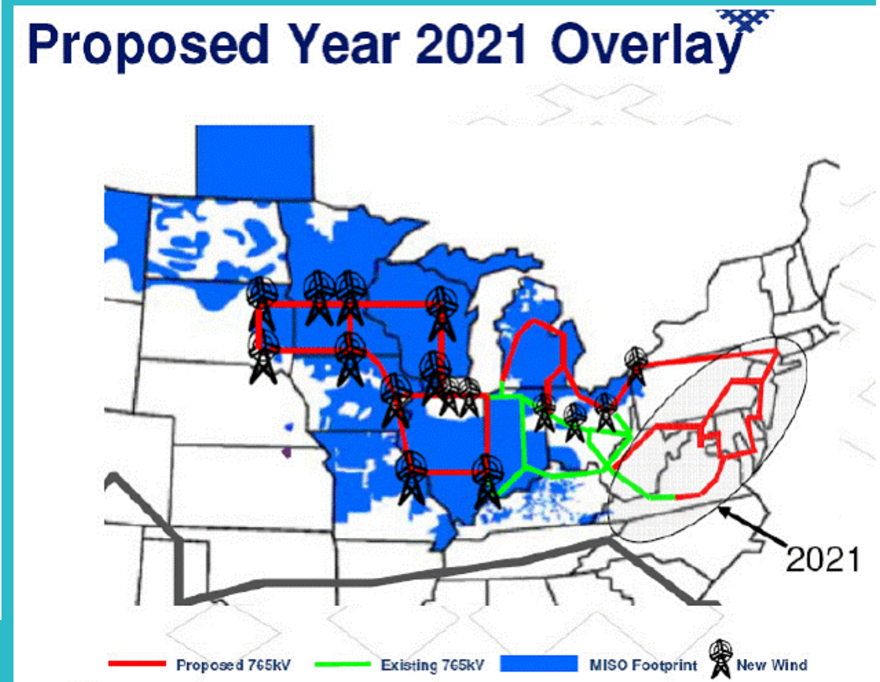
- Rising political concern over carbon emissions and global warming
- Energy Policy Act of 2005 (EPAct 2005)
  - Loan Guarantees – 80% of P&I cost – first 6 plants
  - Production Credit – capped at $125 MM per year for 8 years (1.8 cents/Kwhr); 6000 Mw national limit
  - Standby Support:
    - » Upto $500 MM – plants 1&2 (100% of delay costs)
    - » Upto $250 MM – plants 3 – 6 (50% of delay costs)
- NP 2010 Program (50% sharing of cost of engineering on 2 new designs)
- Proactive attitude between NRC & Industry

PROPOSED NUCLEAR POWER PLANTS

May 2007: Announced Nuclear Power Plants





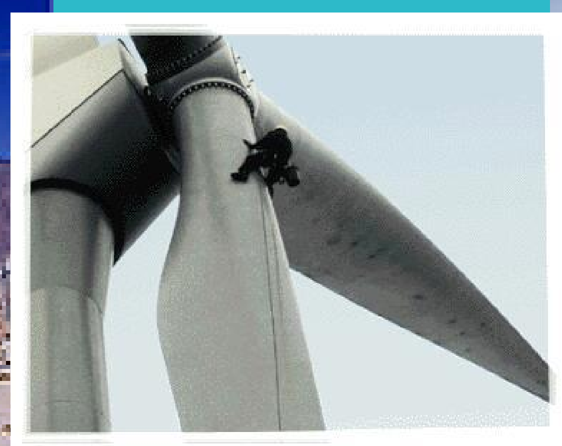


Wind energy potential in Iowa is very good. Iowa is currently #3 in nation in terms of installed wind, but

- needs storage/backup
- needs transmission

THE TOP TWENTY STATES for wind energy potential, as measured by annual energy potential in the billions of kWhs, factoring in environmental and land use exclusions for wind class of 3 and higher.

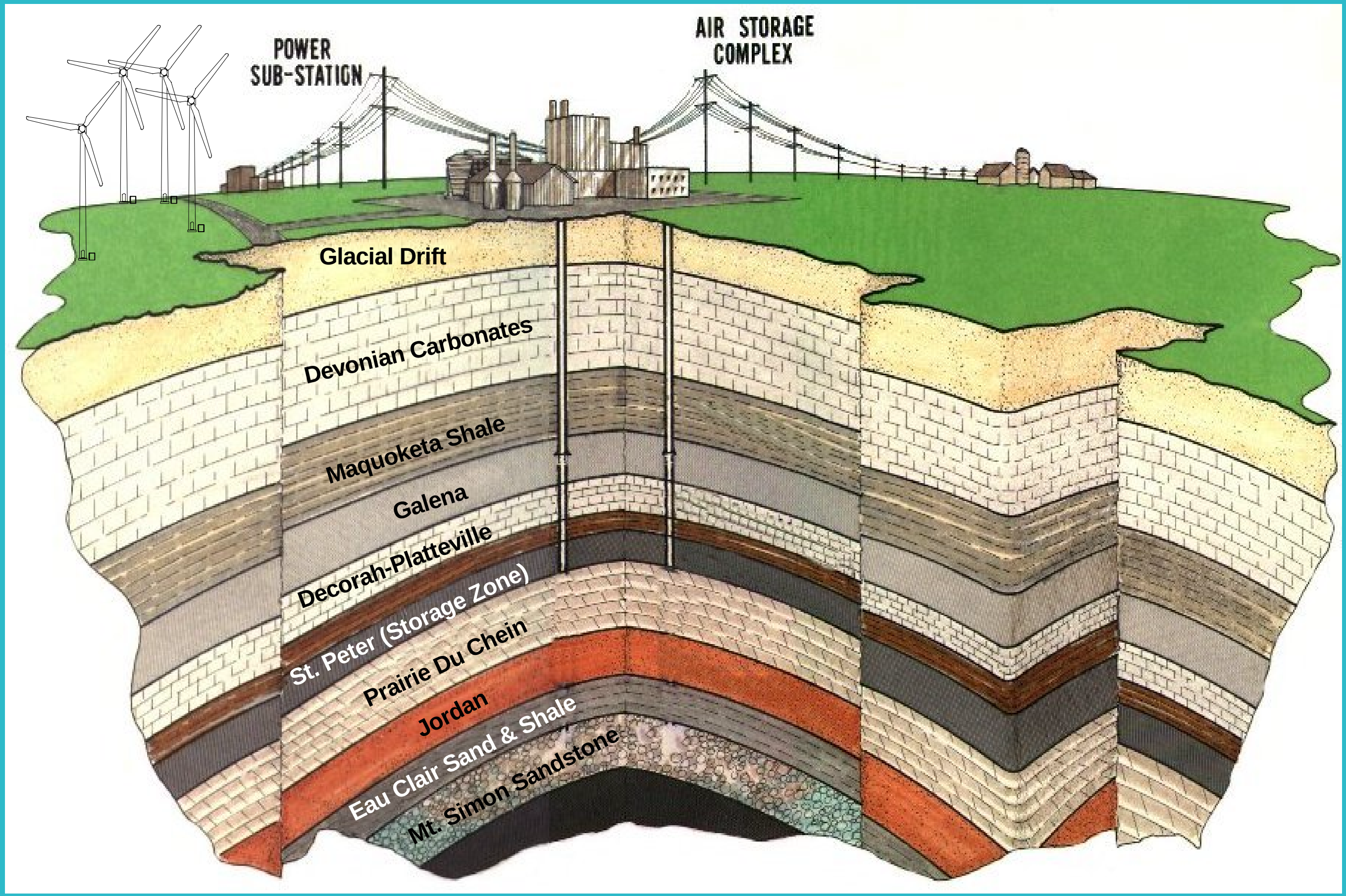
1	North Dakota	1,210	11	Colorado	481
2	Texas	1,190	12	New Mexico	435
3	Kansas	1,070	13	Idaho	73
4	South Dakota	1,030	14	Michigan	65
5	Montana	1,020	15	New York	62
6	Nebraska	868	16	Illinois	61
7	Wyoming	747	17	California	59
8	Oklahoma	725	18	Wisconsin	58
9	Minnesota	657	19	Maine	56
10	Iowa	551	20	Missouri	52




Wind







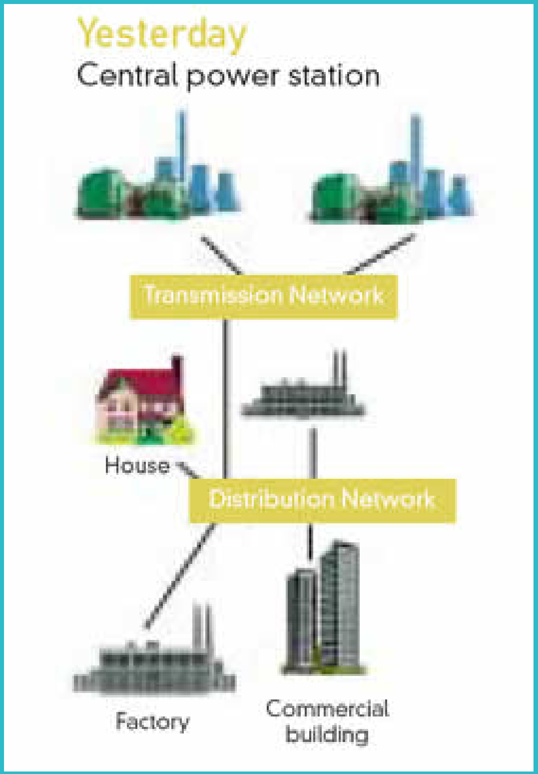
Compressed air-energy storage uses off-peak energy from wind and other sources to replace 2/3 of the natural gas used in a combustion turbine generator

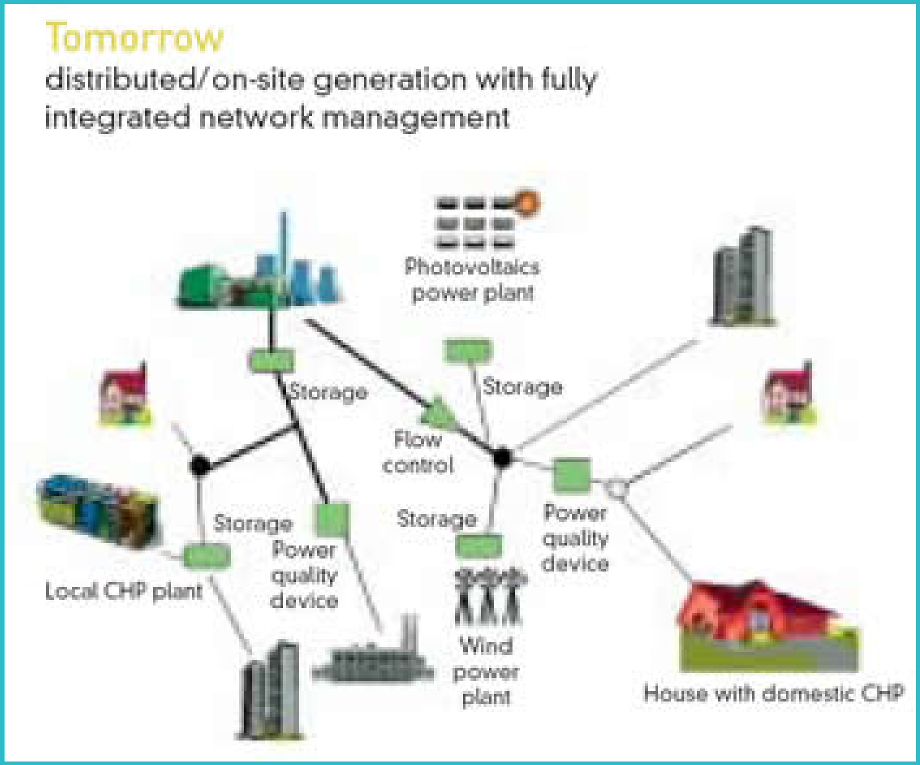
Cost comparison for different energy sources

Energy source	Operating cost range (cents/kWhr)	Installed cost range ($/kW-peak)
Solar (photovoltaics)	20-40	6000-10000
Fuel cells	10-15	3000-4000
Wind	5-10	1500-3000
Fossil-fired	2-7	500-1000

Distributed Generation

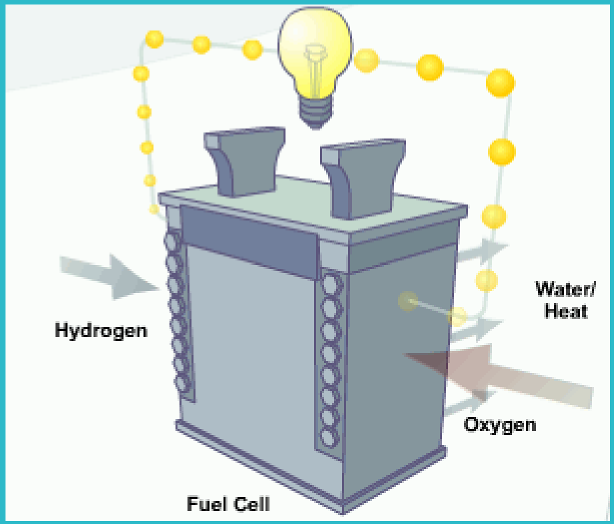
•**Distributed Generation: generation of energy close to the point of use.**
•**DG typically ranges from 1 kilowatt to 5 Megawatts in capacity, contrasting with Central Generation, which is associated with large 500 to 3000 MW generating plants usually located remote end-use location.**
• **DG resources include wind, solar, fuel cells, cogeneration, and microturbines (gas, propane, fuel-oil).**





The Hydrogen Economy

- In electrolysis, electric current is applied to water to produce hydrogen & oxygen.
- Fuel cells reverse this process: hydrogen & oxygen are combined to produce electricity &water.
- Fuel cells are similar to batteries in that both utilize chemical process to produce electricity, but they are different in that batteries store the chemicals and must be recharged whereas fuel cells do not store, but they must be refueled.
- Hydrogen can be extracted from a variety of hydro-carbon fuels such as methanol, ethanol, natural gas, gasoline, propane, and landfill gas.
- Fuel cells can be combined with solar and/or wind in an effective way. As long as wind is blowing and/or sun is shining, wind and solar are used to supply electricity to an electrolysis process to produce hydrogen, which is stored.



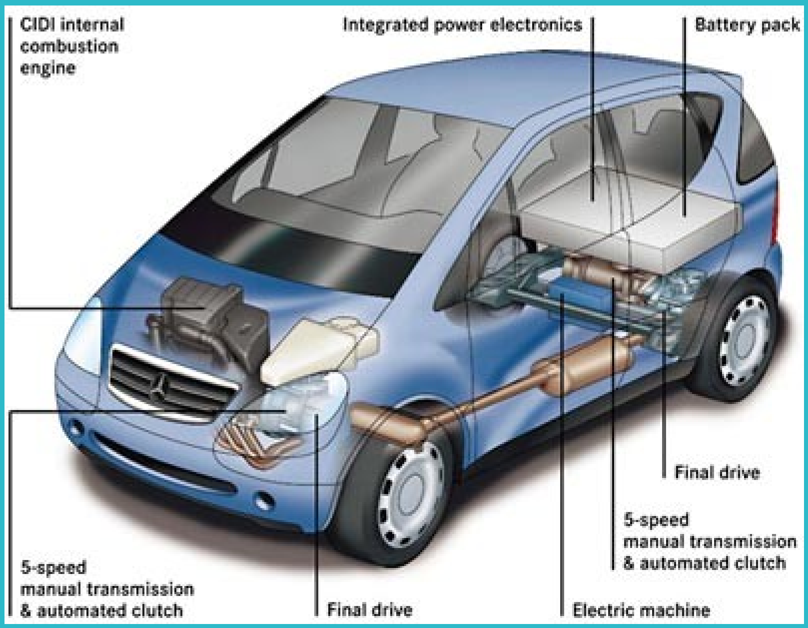
- The *hydrogen economy* is a term given to the idea that we may replace our dependence on fossil-fired power production and petroleum-based transportation with hydrogen-fueled systems.

Electric, hybrid, & fuel cell vehicles

- Electric vehicles use an electric motor powered by batteries.

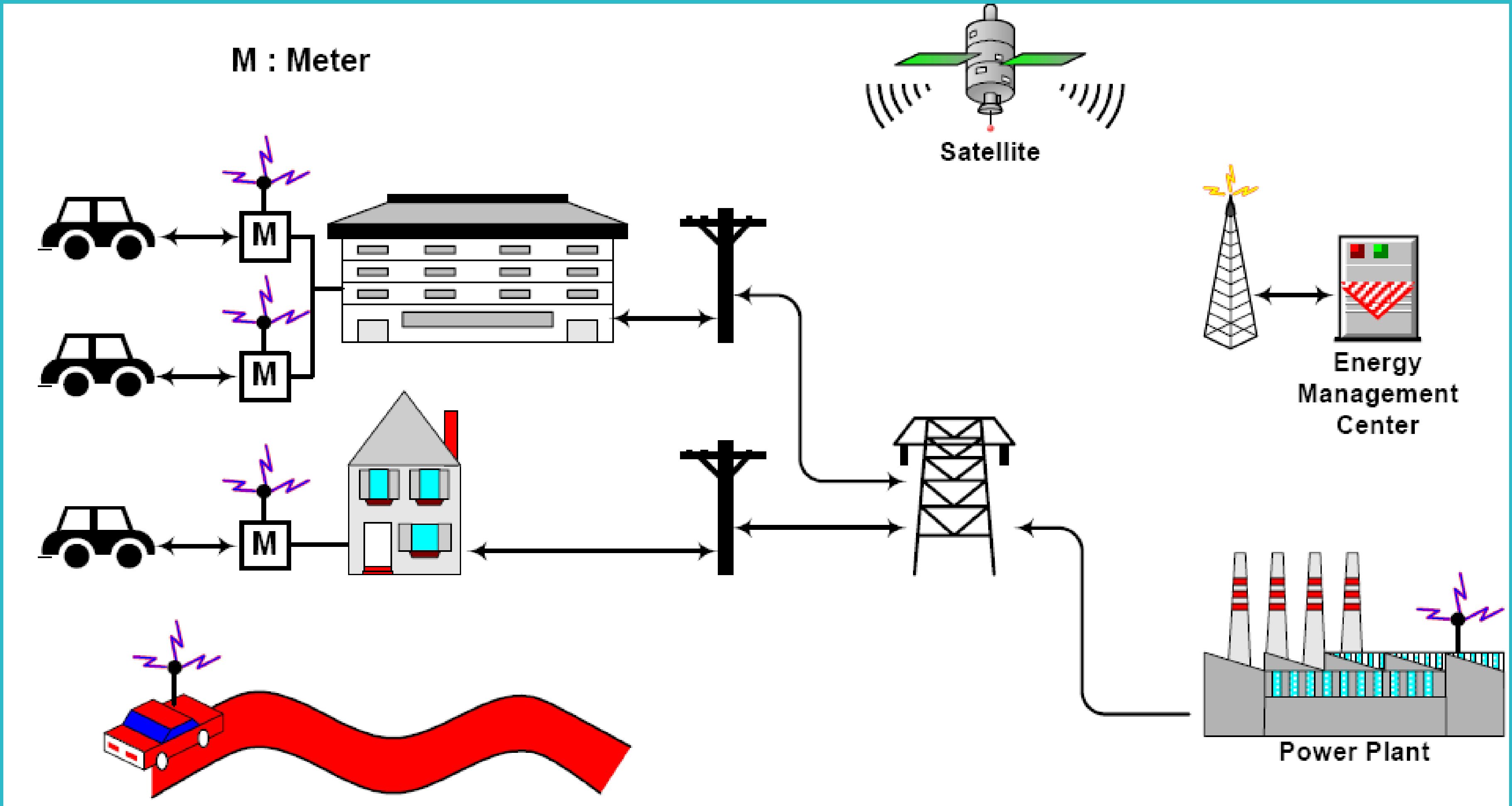
- Hybrid vehicles use an internal combustion engine (ICE) & an electric motor (powered by a battery). In the parallel hybrid, either the ICE or the electric motor can power the transmission. In the series hybrid, the ICE turns a generator & the generator either powers the electric motor or recharges the batteries.

GM EV1



- Fuel cell vehicles use a fuel cell to power an electric motor.

Plug-in Vehicles: a potentially revolutionizing idea



For the first time ever, this is integration of the 2 systems we use to consume energy: vehicular & electric.

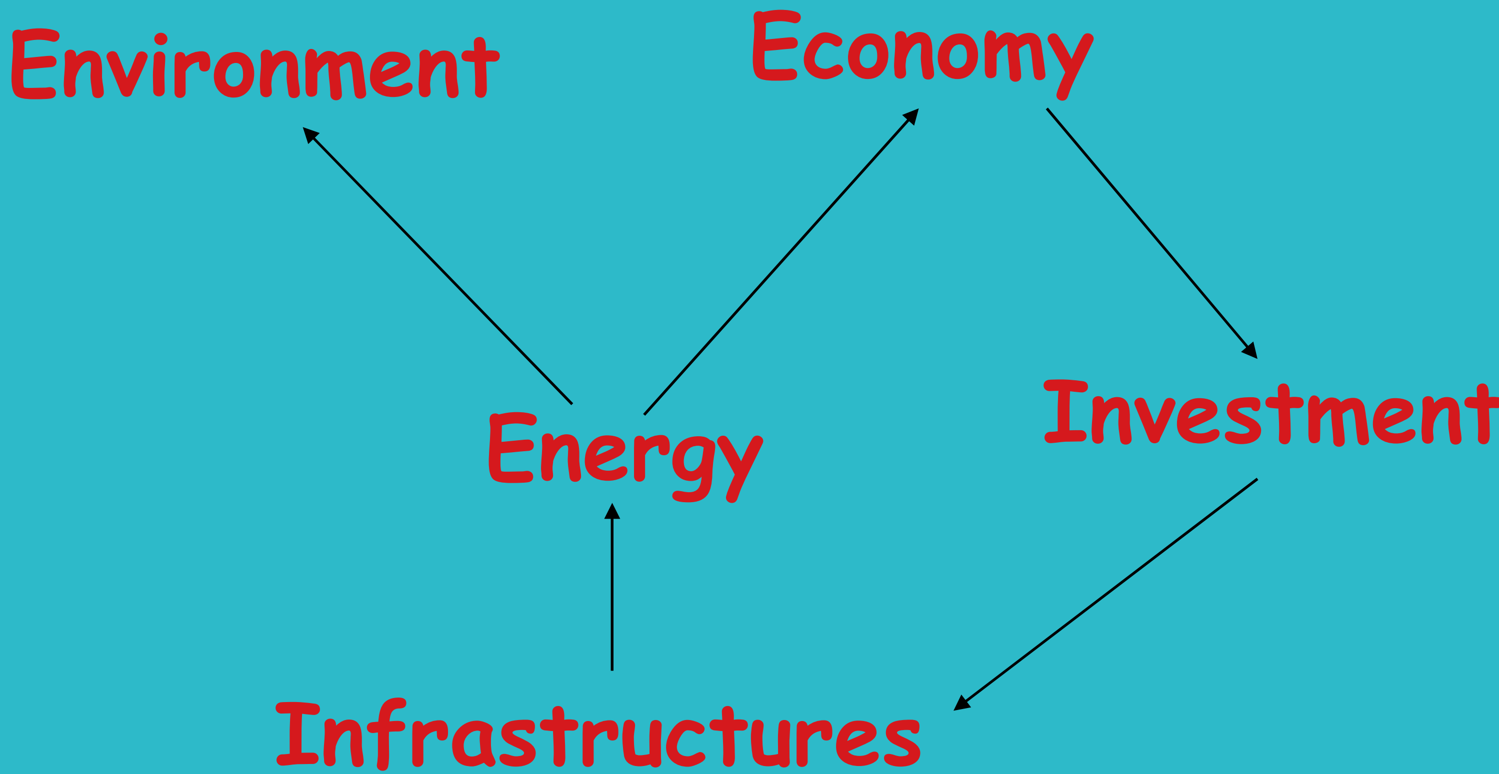
Superconductivity

Benefit: 0 resistance, 0 losses.

Cost: Special compounds used in conductors that must be cooled with liquid nitrogen to -321° F.

Superconducting transmission lines, motors, generators, & transformers are promising.

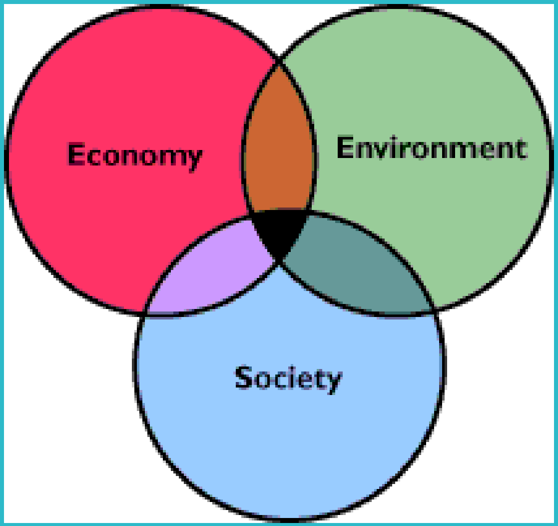
Three E's and Two I's



But what about sustainability….?

One definition of sustainability:
"Sustainability is an economic state where the demands placed upon the environment by people and commerce can be met without reducing the capacity of the environment to provide for future generations. It can also be expressed in the simple terms of an economic golden rule for the restorative economy: leave the world better than you found it, take no more than you need, try not to harm life of the environment, make amends if you do." Paul Hawkin, “The Ecology of Commerce”

There are other definitions, but central is
making “good” decisions
with “right” understanding
of the interconnections among economy, society, and environment



In regards to sustainability, what specific application areas come to mind?

At least the following

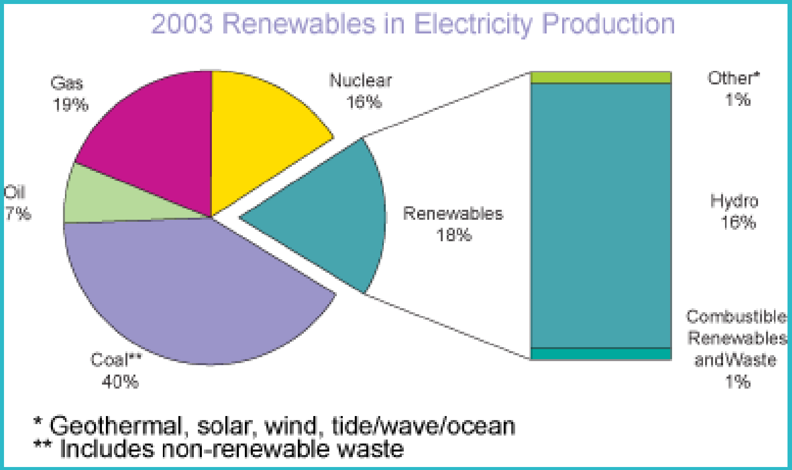
- Agriculture
- Economic development
- Population
- Ecological diversity
- Climate change
- Energy

I will talk about sustainability in energy (since I am not very qualified to talk about the others).

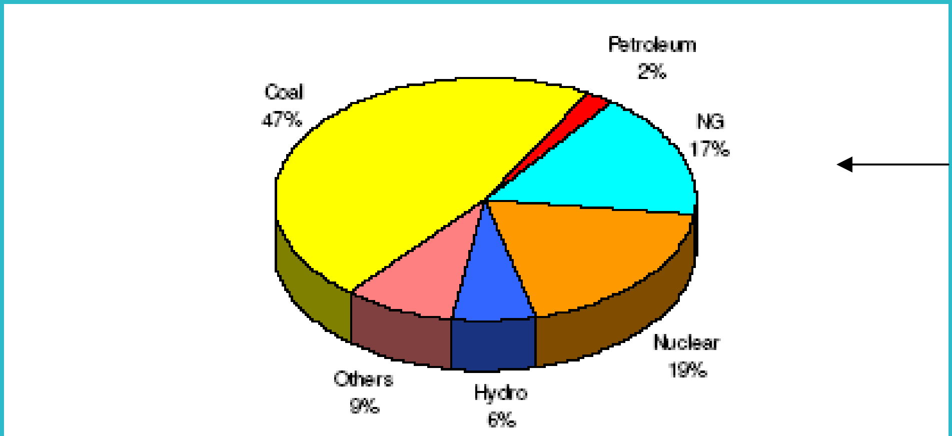
Even more narrowly, I will talk about sustainability in electric energy production leaving out home heating & transportation fuels.

Electric Energy Sources

World



75%



US Electricity Production, for 2002

83%

The "big 3"

- Coal
- Natural Gas
- Nuclear

Comments on the "big 3"

- Coal: Plenty of it, but…emissions
- Gas: Cleaner, but… limited supply
- Nuclear: Plenty of it, but…radioactive waste

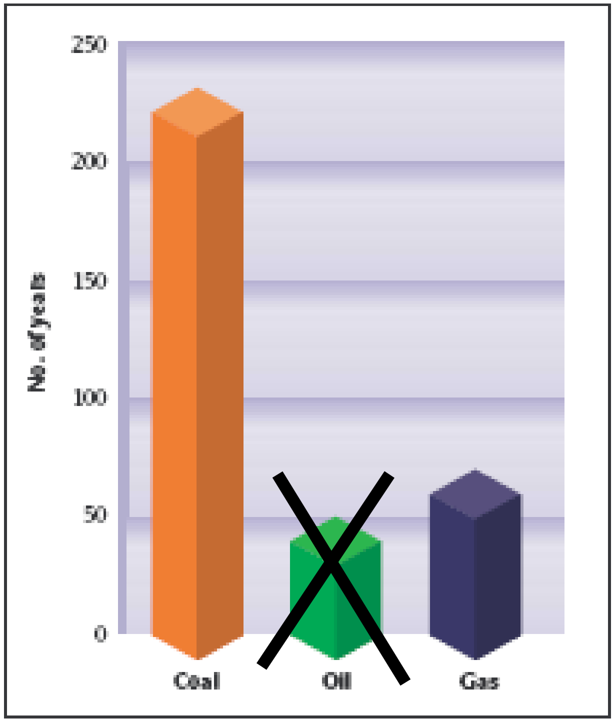


Figure 3: Reserves to production ratio, in years, 2000.

Source: BP Statistics 2001.

Big 3 +…Renewables

“Big 3” energy technologies

- Coal
- Gas
- Nuclear

Renewable energy technologies

- Hydro
- Wind
- Biofuels
- Fuel cells (hydrogen)
- Solar
- Geothermal
- Tidal

Does “renewable”=“sustainable”?

Renewable: capable of being replenished.

Sustainable: capable of being maintained at length without interruption or weakening

To indicate that an energy form is renewable is immediately testable. Each of the listed energies are “capable of being replenished.”

➔Energies are renewable or not.

Sustainability is different – it requires understanding the energy form(s) together with the needs they will fulfill, and the social, economic, & environmental implications.

➔Policies are sustainable or not.

A sustainable policy must include both groups

Use of coal derivatives

Fuel trans-portation

Power plant efficiency

Emissions

Radioactive waste

An Energy Portfolio

- Coal
- Gas
- Nuclear
- Hydro
- Wind
- Biofuels
- Fuel cells
- Solar
- Geothermal
- Tidal

Cogeneration

Combined-cycle units

Distributed generation

Super-conductivity

Lighting efficiency

Motor efficiency

Price-responsive end-use

Conservation

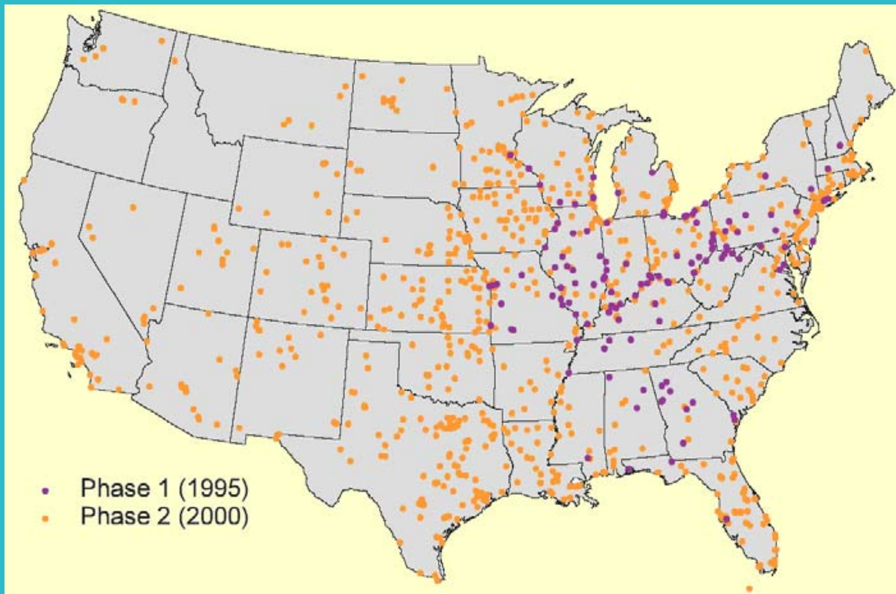
Electric vehicles

Storage

Gasification

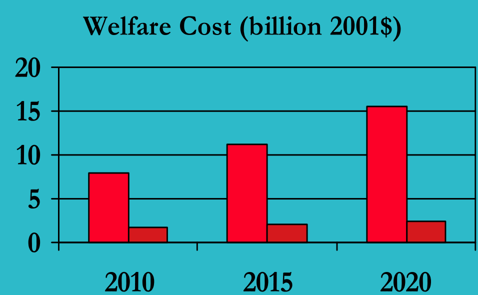
Issues with emissions

1990 Clean Air Act: EPA established cap-&-trade mechanism to control SO_2 emissions. Generation owners allocated freely tradable emission allowances.

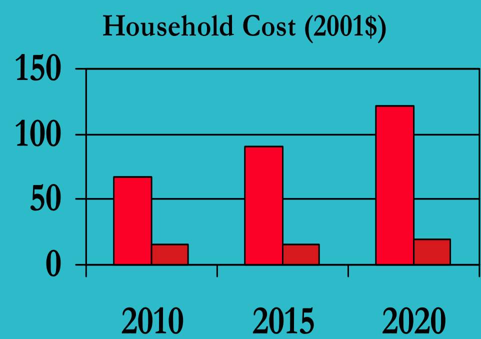


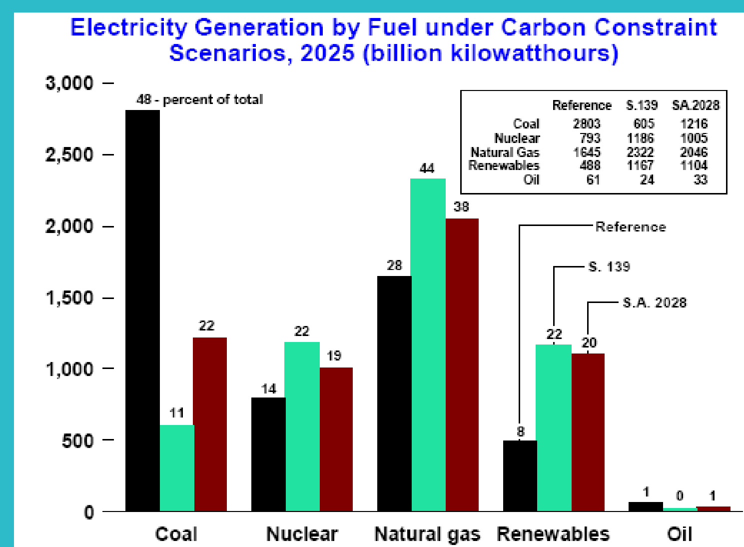
Fed action limiting other green-house gases, Lieberman-McCain S.139/HR4067 (2003), (later revised as S.A. 2028), “Climate Stewardship Act”: cap & trade on carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydro-fluoro-carbons (HFC), perfluorocarbons (PFC), sulfur hexafluoride (SF6). Failed 43-55

Total loss to economy, billions 2001$, for implementation of S. 139 ➡



Total loss per household, 2001$, for implementation of S. 139 ➡





II. Maryland Adopts Historic Global Warming Law Mandating Greenhouse Gas Reductions from Power Plants (3/31/06)

In a major victory against global warming, the Maryland General Assembly gave final approval Friday to the strongest power-plant cleanup bill ever passed by a legislative body in America. In addition to dramatically reducing nitrogen, sulfur and mercury pollution, the Maryland Healthy Air Act requires that the state join the Regional Greenhouse Gas Initiative (RGGI), a consortium of eastern states committed to mandatory CO2 reductions from power plants.

After a two-year campaign led by the Chesapeake Climate Action Network and a coalition of other environmental, faith, and health groups, the so-called 4-pollutant bill passed by veto-proof majorities in both Maryland houses.
Aides to Republican governor Robert Ehrlich say the governor does not intend to veto the bill.

"Maryland leaders took a historic step today in acknowledging the crisis of global warming and deciding to do something about it," said Mike Tidwell, director of the Chesapeake Climate Action Network. "While leaders in Washington say carbon reductions are impossible, the capital itself now borders a region stretching from Maryland to Maine where reductions are in fact happening."

The carbon dioxide component of the bill, bitterly opposed by all the Maryland utilities, mandates that the state take all necessary steps to join the RGGI process. Maryland will thus reduce by 10 percent the CO2 emissions from it coal-fired power plants in accordance with the "model rule“ established by ME, NY, NH, VT, DE, CT, and NJ. Significantly, Maryland will become only the second "coal" state to join RGGI, i.e. a state producing a majority of its electricity from coal.

No state in America has passed legislation that reduces all four power plant pollutants in such an aggressive way. It is our hope that other states will now follow Maryland's lead and that the federal government will quickly supercede all such efforts with its own tough and comprehensive greenhouse gas reduction measures.

April 2006: Tuesday saw a tectonic shift in the climate-change debate during an all-day Senate conference on global-warming policy. A group of high-powered energy and utility executives for the first time issued this directive to Washington: Bring on the carbon caps! Sens. Pete Domenici (left) and Jeff Bingaman brought energy execs to Capitol Hill for a climate chat.

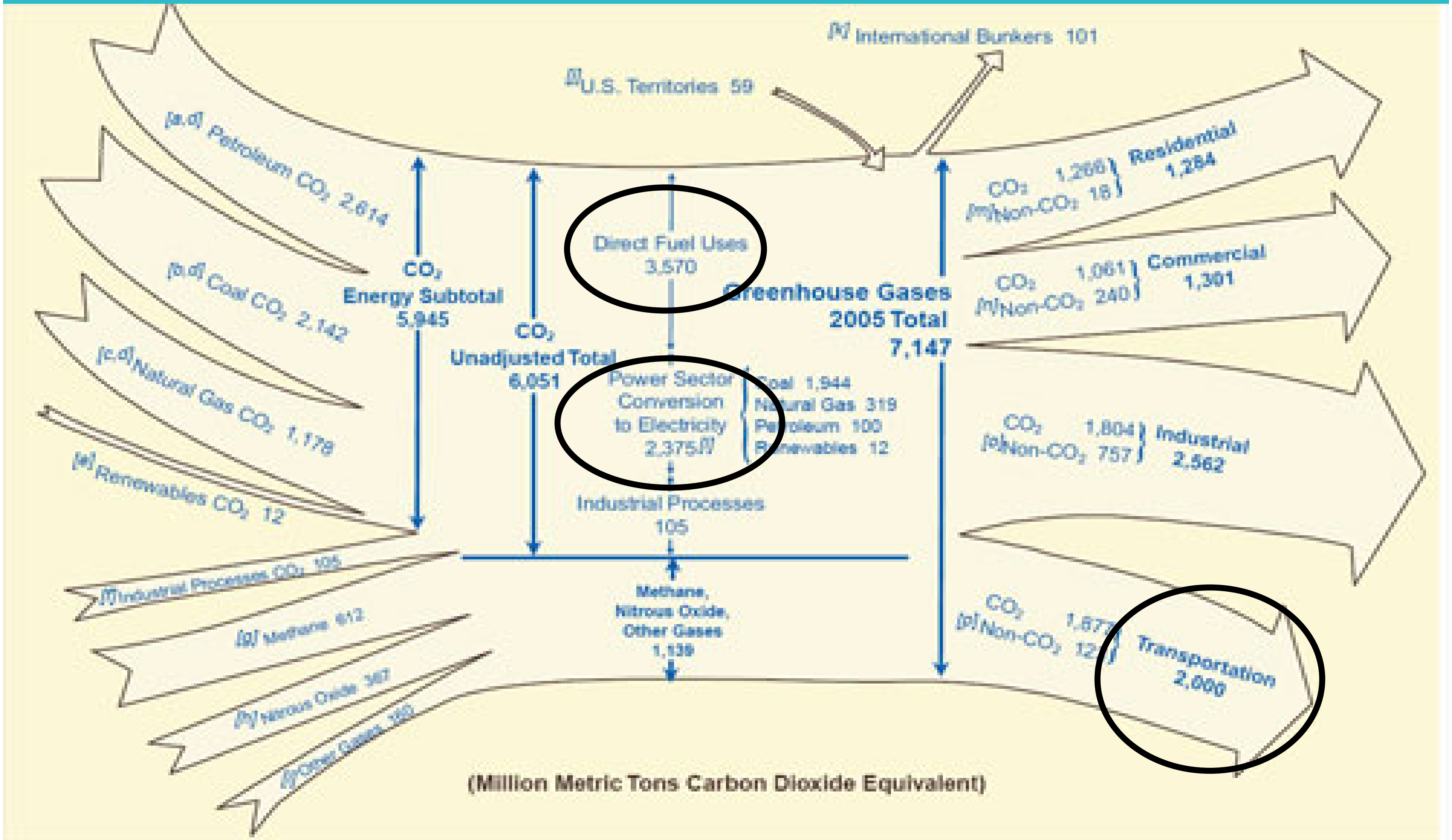
The Energy and Natural Resources Committee heard statements from leaders representing eight big energy companies, including General Electric, Shell, and the two largest owners of utilities in the U.S., Exelon and Duke Energy. Six of the eight said they would either welcome or accept mandatory caps on their greenhouse-gas emissions. Wal-Mart too spoke in favor of carbon caps. The two outliers from the energy sector, Southern Company and American Electric Power, delivered pro forma bids for a voluntary rather than mandatory program, but they, too, broke with tradition by implicitly acknowledging that regulations may be coming, and offering detailed advice on how they should be designed.

Many industry players are increasingly concerned about the inconsistent patchwork of climate regulations that are being proposed and adopted throughout the U.S., from the Regional Greenhouse Gas Initiative that seven Northeastern states put forward in December to plans for greenhouse-gas caps unveiled in California this week. Worried companies say federal regulations would bring stability and sureness to the market.

"GE supports congressional action now," David Slump, the top marketing executive in GE's energy division, said at the hearing.

"It is critical that we start now," said Elizabeth Moler, an executive vice president for Exelon. "We need the economic and regulatory certainty to invest in a low-carbon energy future."

CO2: 2375mmt Electric, 2000mmt Transportation

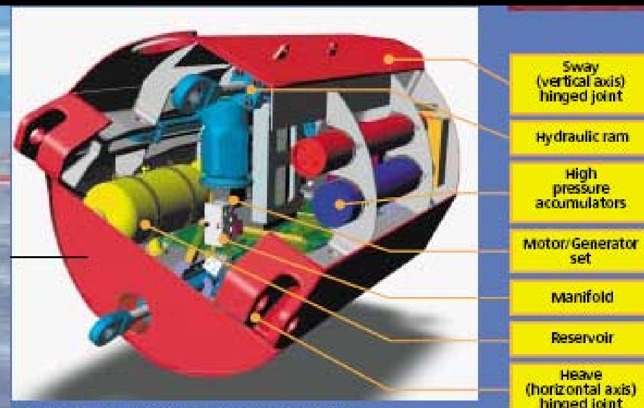


Direct fuel use includes auto & home heating

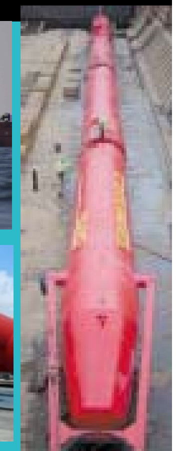
The world's largest landfill gas recuperation plant

The Bandeirantes landfill site, 30 kilometres from the centre of São Paolo, is huge. The waste, created over the past 20 years, is up to 100 metres deep in places. Since 1 January 2004, the Dutch-Brazilian joint venture Biogás has been generating electricity from Bandeirantes landfill gas. Perforated tubes run through the waste to catch the gas and lead it to one of the 24 turbines of 925 kW each. With a total capacity of 23 MW, the plant been producing 170,000 MWh a year. This makes it the largest landfill gas recuperation plant in the world.

World's largest offshore wave power plant



Internal view of a Pelamis Power Conversion Module



The Pelamis P-750 Wave Energy Converter is the result of six years of extensive testing, modelling and development by Ocean Power Delivery Ltd. The machine is a semi-submerged, articulated structure composed of cylindrical sections linked by hinged joints. The wave-induced motion of these joints is resisted by hydraulic rams, which pump high-pressure oil through hydraulic motors via smoothing accumulators. The hydraulic motors drive electrical generators to produce electricity. Power from all the joints is fed down a single umbilical cable to a junction on the sea bed. Several devices can be connected together and linked to shore through a single seabed cable. A novel joint configuration is used to induce a tuneable, cross-coupled resonant response, which greatly increases power capture in small seas. Control of the restraint applied to the joints allows this resonant response to be ‘turned-up’ in small seas where capture efficiency must be maximised or ‘turned-down’ to limit loads and motions in survival conditions. The machine is held in position by a mooring system, comprising of a combination of floats and weights which prevent the mooring cables becoming taut. It maintains enough restraint to keep the Pelamis positioned but allows the machine to swing head on to oncoming waves. Reference is achieved by spanning successive wave crests. The Pelamis is designed to be moored in waters approximately 50-70m in depth (typically 5-10km from the shore) where the high energy levels found in deep swell waves can be accessed. The design of the Pelamis has been independently verified by WS Atkins according to (DNV) offshore codes and standards. first fullscale pre-production prototype has been built and is being tested at the European Marine Energy Centre in Orkney.

The world's largest dry biomass power generation plant

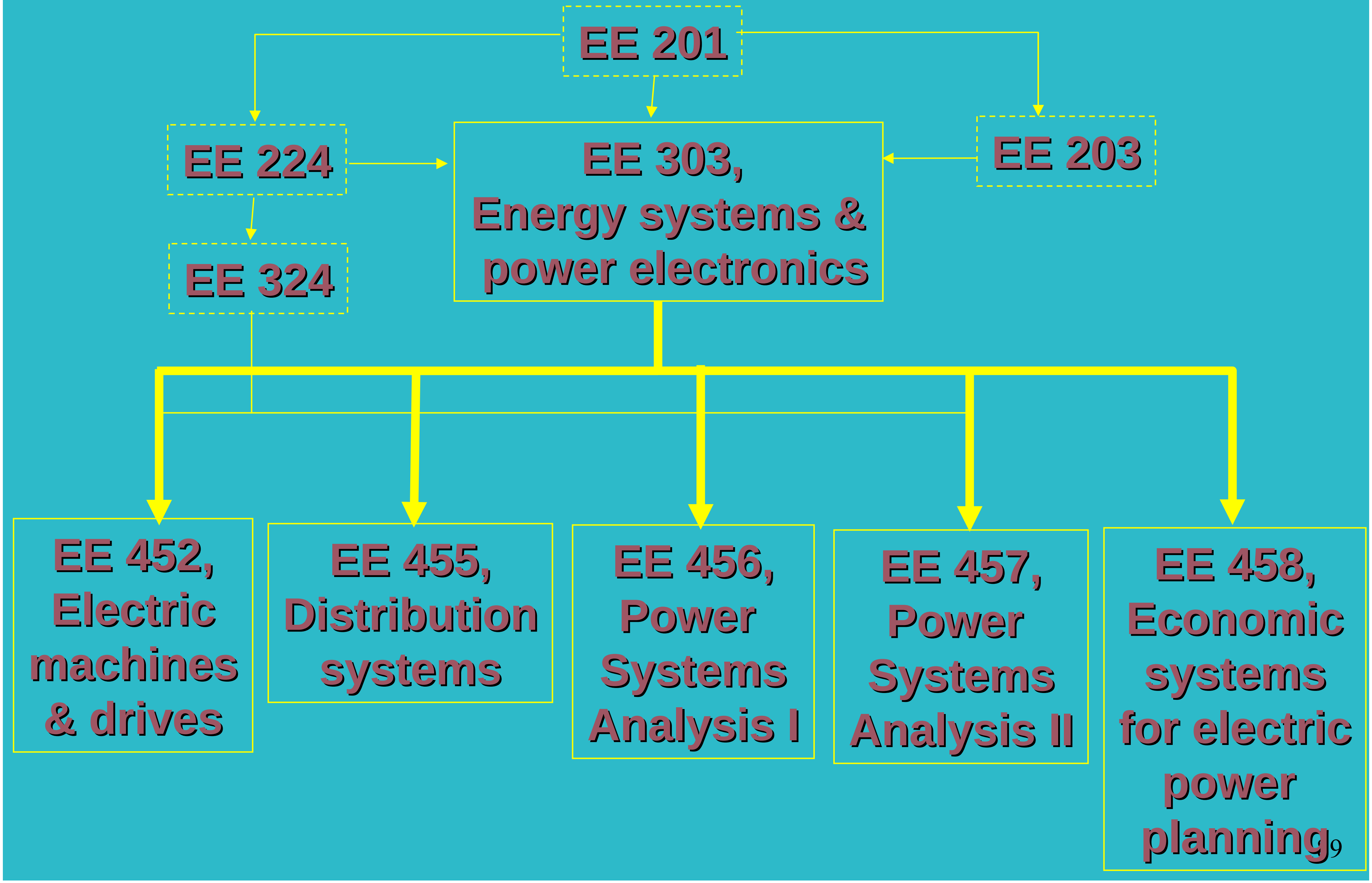
Pietersaari, Finland

Pietersaari on the west coast of Finland hosts what is believed to be the world largest dry biomass fired cogeneration plant. The plant, operated by Alhomens Kraft AB, has a capacity of 240 MW of electrical power, 100 MW process steam, and 60 MW district heating. It burns biofuels such as bark, sawdust, wood chips, and cut peat, along with 10% coal or oil. Commercial operation of the unit began in December 2001.

Some questions for discussion

1. What does a "good" *sustainability decision* look like?
2. In what ways do you expect to find yourself being responsible for making sustainability decisions?
3. What is the "right understanding"?
4. What can you do while you are at ISU to provide yourself with the "right understanding" to contribute towards "good" decisions?
5. What priority levels should be placed on
   a. Environment
   b. Economics
   c. Reliability (absence of interruptions, price stability)

The Electric Power + Energy Systems Group has excellent series of courses to prepare you for an exciting career….



For whom might you work? (below - mainstream comp only)

- Electric utilities: Big/small, everywhere
- Independent system operators (ISOs)
- Manufacturers: GE, ABB, Square D, Toshiba, Mitsubishi, Schweitzer
- Consultants: Black&Veatch, Burns&McDonnell, HD Electric,
- Software vendors: Siemens, Areva, OSI
- Transmission companies: American Transmission Company
- Generation companies: Numerous
- Power marketers: Aquila, Cargill, Cinergy, Mirant, etc.