Electricity Generation and Use

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Mechanical Engineering 496ALT

Alternative Energy

February 17, 2009

California State University Northridge

Assignments and Exams

- First Midterm Exam – Thursday, February 26
  - Open book and notes
  - Covers up to tonight's lecture
  - Like homework assignments
- Reading: Chapter 17 for tonight, Chapter 8 for following two lectures
- Homework tonight and next Tuesday (covered on February 26 midterm)

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Outline

- Review last class
- Electricity demand
- Electricity supply
- Costs of electricity
- Utilities *versus* non-utility producers
- Deregulation of electricity
- Alternative generation approaches

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What kinds of energy stored?

- Fuel containers store fuel energy
- Batteries and supercapacitors store electrical energy
- Flywheels and compressed air systems store mechanical energy
- Thermal energy storage as latent or sensible heat used in heating and cooling systems

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Energy Storage Measures

- Energy per unit mass (kJ/kg; Btu/lb_m)
- Energy per unit volume (kJ/m^3; Btu/ft^3)
- Rate of delivery of energy to and from storage (kW/kg; Btu/hr·kg)
- Efficiency (energy out/energy in)
- Life cycles – how many times can the storage device be used

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Fuel Energy

- Volumetric energy storage in Btu/gallon
  - Gasoline: 109,000 to 125,000
  - Diesel fuel: 128,000 to 130,000
  - Biodiesel: 117,000 to 120,000
  - Natural gas: 33,000 to 38,000 at 3,000 psi, 38,000 to 44,000 at 3,600 psi, and ~73,500 as liquefied natural gas (LNG)
  - 85% ethanol in gasoline: ~80,000
  - 85% methanol in gasoline: 56,000 to 66,000
  - Hydrogen: ~6,500 at 3,000 psi, ~16,000 at 10,000 psi, and ~30,500 as liquid
  - Liquefied petroleum gas (LPG): ~84,000

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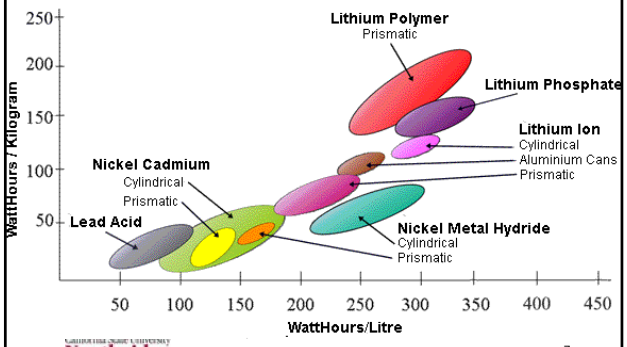
http://www.eere.energy.gov/afdc/altfuel/fuel_comp.html

Battery Properties



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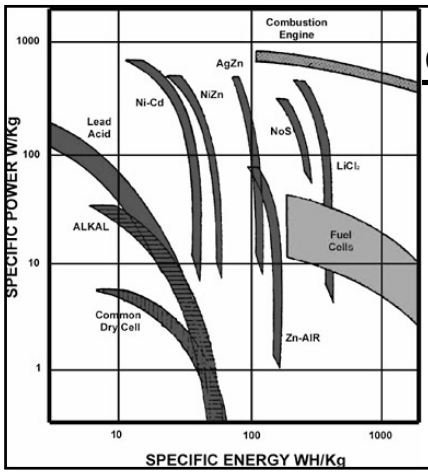
http://www.mpoweruk.com/chemistries.htm



Compare

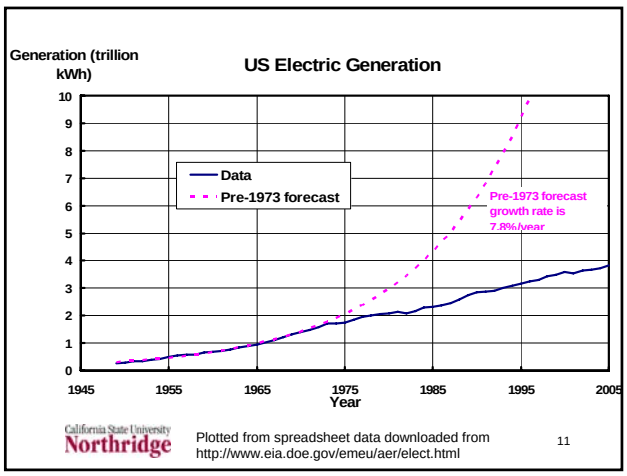
Batteries versus other motive power

http://www.nap.edu/books/0309092612/html/40.html

	Whr/kg	kJ/m^3	Cost $/ kWh	Effi-ciency	Peak W/kg
Lead acid batteries	40	30000	130	80%	250
Nickel-Cadium batteries	50	37500	300	75%	110
Nickel-metal-hydride batteries	80	60000	260	70%	250
Sodium-sulfur batteries	190	143000	330	85%	230
Lithium-ion batteries	100	75000	200	95%	250
Capacitor	11.1	40000		95%	
Inductor	0.556	10000	180	95%	
Pumped hydro	0.000278	1	90	70%	

	Whr/kg	kJ/m^3	Cost $/ kWh	Effi-ciency	Peak W/kg
Lead acid batteries	40	30000	130	80%	250
Sodium-sulfur batteries	190	143000	330	85%	230
Lithium-ion batteries	100	75000	200	95%	250
Lead acid batteries(2)	55.6	30000	54	75%	
Flywheel	55.6	200000		80%	
Liquid hydrocarbon fuels	13888.9	$3.5x10^7$			

Unreferenced data obtained in 2002 by L. S. Caretto



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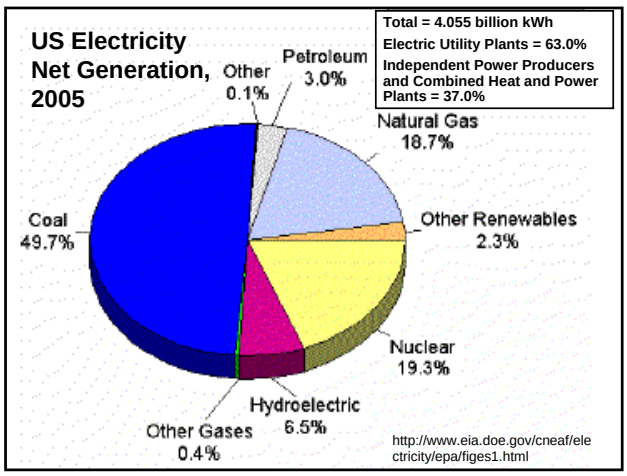
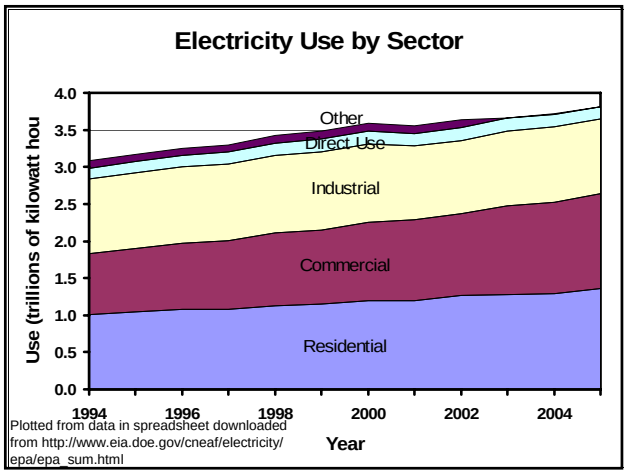
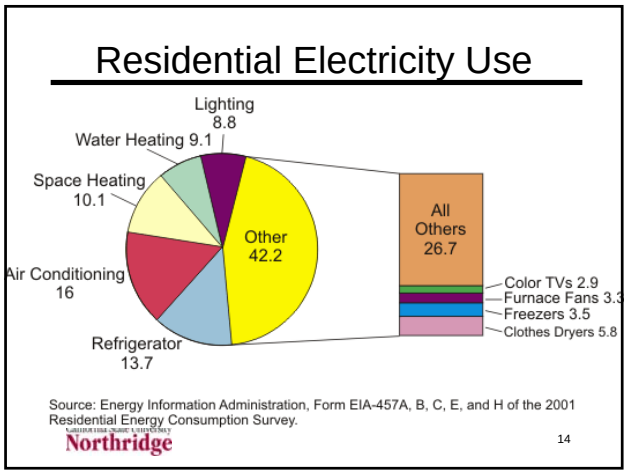
Plotted from spreadsheet data downloaded from http://www.eia.doe.gov/emeu/aer/elect.html



http://www.eia.doe.gov/cneaf/electricity/epa/figes1.html


Electricity Use by Sector
Use (trillions of kilowatt hou
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Other
Direct Use
Industrial
Commercial
Residential
1994
1996
1998
2000
2002
2004
Year
Plotted from data in spreadsheet downloaded from http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html


Residential Electricity Use
Lighting 8.8
Water Heating 9.1
Space Heating 10.1
Air Conditioning 16
Refrigerator 13.7
Other 42.2
All Others 26.7
Color TVs 2.9
Furnace Fans 3.3
Freezers 3.5
Clothes Dryers 5.8
Source: Energy Information Administration, Form EIA-457A, B, C, E, and H of the 2001 Residential Energy Consumption Survey.
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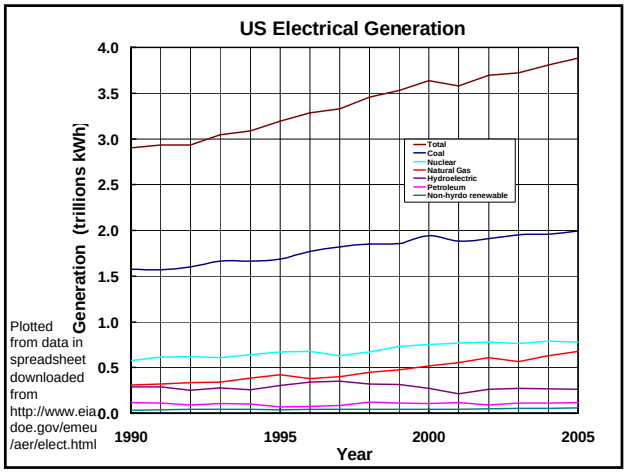
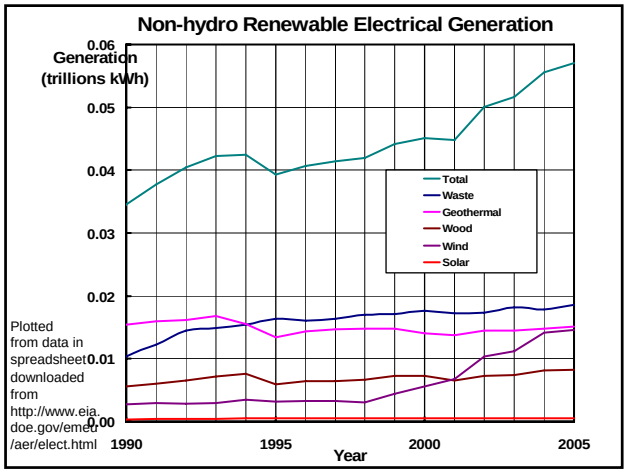
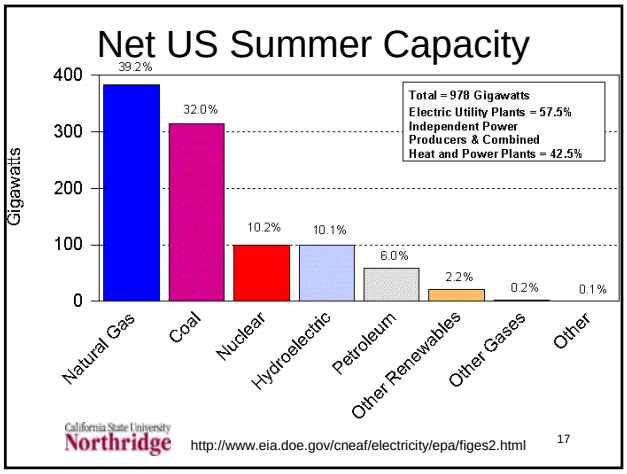

US Electrical Generation
Generation (trillions kWh)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Total
Coal
Nuclear
Natural Gas
Hydroelectric
Petroleum
Non-hyrdo renewable
1990
1995
2000
2005
Year
Plotted from data in spreadsheet downloaded from http://www.eia.doe.gov/emeu/aer/elect.html


Non-hydro Renewable Electrical Generation
Generation (trillions kWh)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Total
Waste
Geothermal
Wood
Wind
Solar
1990
1995
2000
2005
Year
Plotted from data in spreadsheet downloaded from http://www.eia.doe.gov/emeu/aer/elect.html


Net US Summer Capacity
Gigawatts
400
300
200
100
0
39.2%
32.0%
10.2%
10.1%
6.0%
2.2%
0.2%
0.1%
Total = 978 Gigawatts
Electric Utility Plants = 57.5%
Independent Power Producers & Combined Heat and Power Plants = 42.5%
Natural Gas
Coal
Nuclear
Hydroelectric
Petroleum
Other Renewables
Other Gases
Other
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http://www.eia.doe.gov/cneaf/electricity/epa/figes2.html
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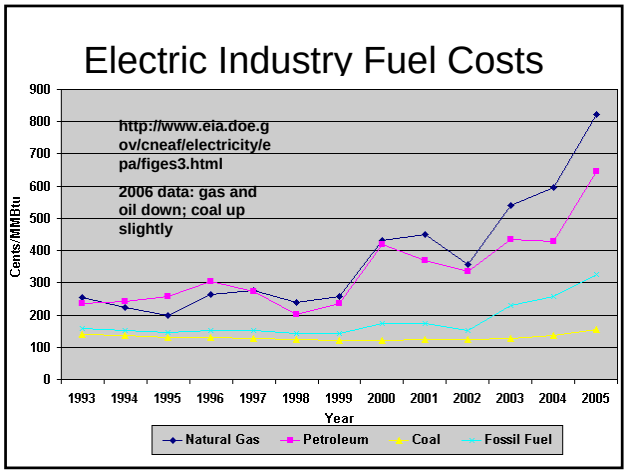
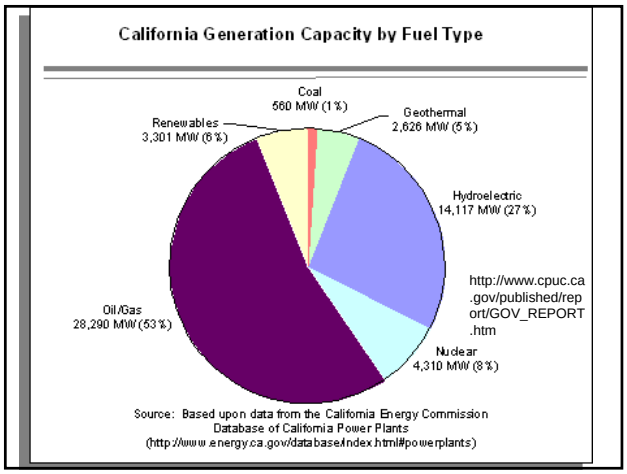
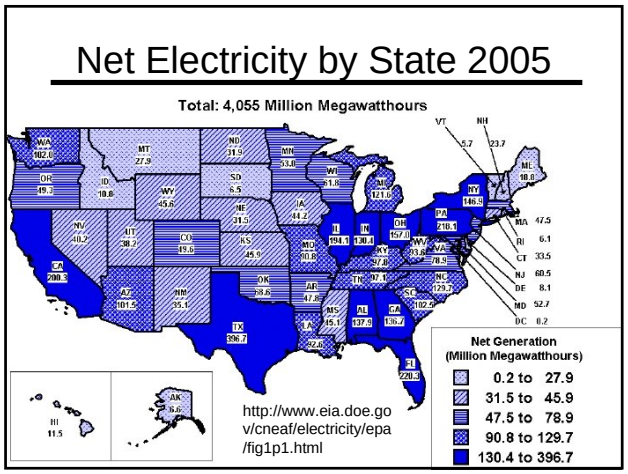
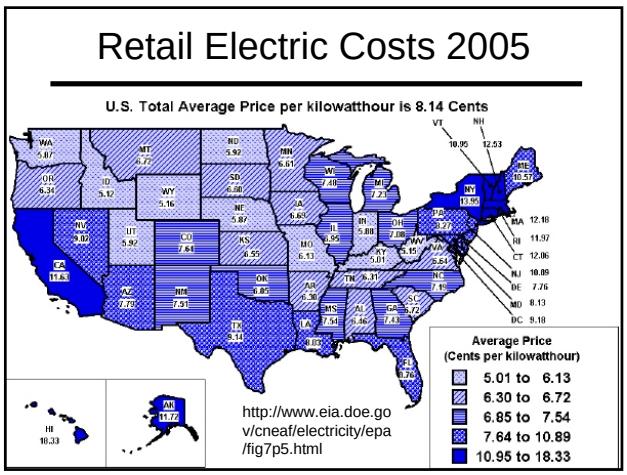
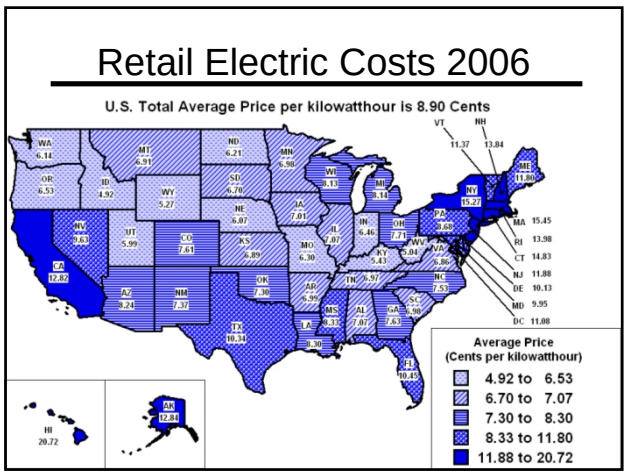
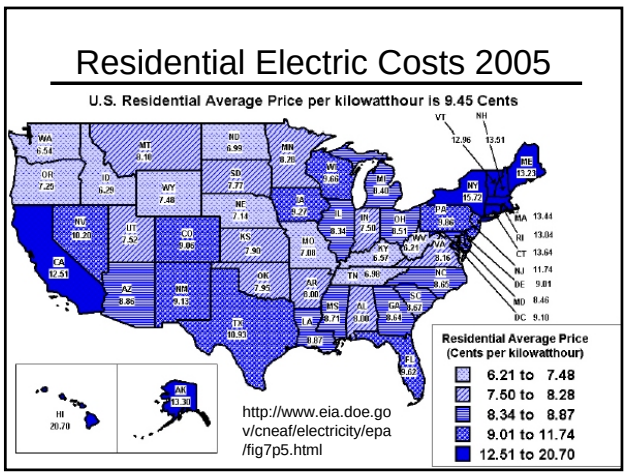

Electric Industry Fuel Costs
Cents/MMBtu
900
800
700
600
500
400
300
200
100
0
http://www.eia.doe.gov/cneaf/electricity/epa/figes3.html
2006 data: gas and oil down; coal up slightly
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Natural Gas
Petroleum
Coal
Fossil Fuel

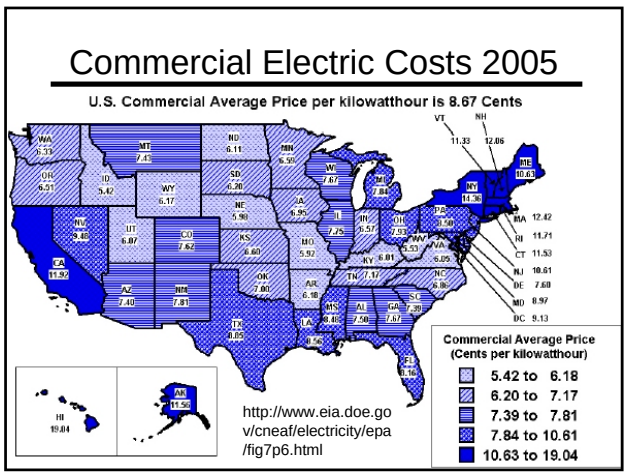

California Generation Capacity by Fuel Type
Coal
560 MW (1%)
Geothermal
2,626 MW (5%)
Renewables
3,301 MW (6%)
Hydroelectric
14,117 MW (27%)
Oil/Gas
28,290 MW (53%)
Nuclear
4,310 MW (8%)
http://www.cpuc.ca.gov/published/report/GOV_REPORT.htm
Source: Based upon data from the California Energy Commission
Database of California Power Plants
(http://www.energy.ca.gov/database/index.html#powerplants)


Net Electricity by State 2005
Total: 4,055 Million Megawatthours
Net Generation
(Million Megawatthours)
0.2 to 27.9
31.5 to 45.9
47.5 to 78.9
90.8 to 129.7
130.4 to 396.7
http://www.eia.doe.gov/cneaf/electricity/epa/fig1p1.html

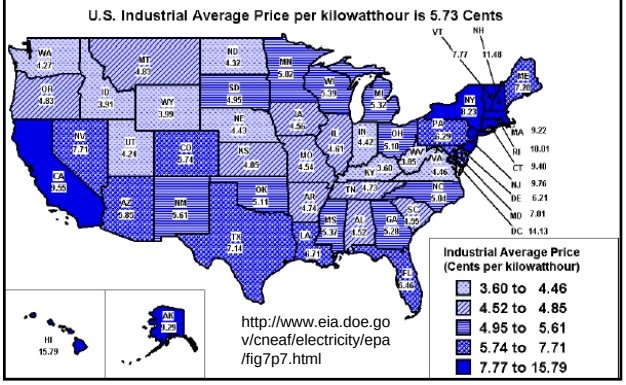

Retail Electric Costs 2005
U.S. Total Average Price per kilowatthour is 8.14 Cents
Average Price
(Cents per kilowatthour)
5.01 to 6.13
6.30 to 6.72
6.85 to 7.54
7.64 to 10.89
10.95 to 18.33
http://www.eia.doe.gov/cneaf/electricity/epa/fig7p5.html


Retail Electric Costs 2006
U.S. Total Average Price per kilowatthour is 8.90 Cents
Average Price
(Cents per kilowatthour)
4.92 to 6.53
6.70 to 7.07
7.30 to 8.30
8.33 to 11.80
11.88 to 20.72


Residential Electric Costs 2005
U.S. Residential Average Price per kilowatthour is 9.45 Cents
Residential Average Price
(Cents per kilowatthour)
6.21 to 7.48
7.50 to 8.28
8.34 to 8.87
9.01 to 11.74
12.51 to 20.70
http://www.eia.doe.gov/cneaf/electricity/epa/fig7p5.html


Commercial Electric Costs 2005
U.S. Commercial Average Price per kilowatthour is 8.67 Cents
Commercial Average Price
(Cents per kilowatthour)
5.42 to 6.18
6.20 to 7.17
7.39 to 7.81
7.84 to 10.61
10.63 to 19.04
http://www.eia.doe.gov/cneaf/electricity/epa/fig7p6.html

Industrial Electric Costs 2005



Electricity Load

- Power demand varies by day and hour
  - CA energy, peak MW growth: 1.25%, 1.35%
- Renewable Portfolio Standards require utilities to have renewable generation
  - 20% of retail sales by December 31, 2010 in California (transmission problems?)
  - Papers from WCS AWMA October 2007 conference in next five slides
    - CA Energy Commission – Dave Ashuckian
    - SC Edison – James Woodruff

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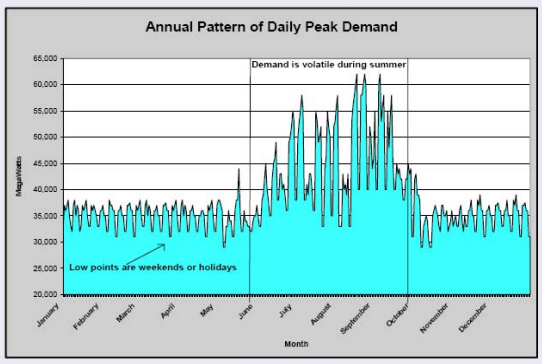
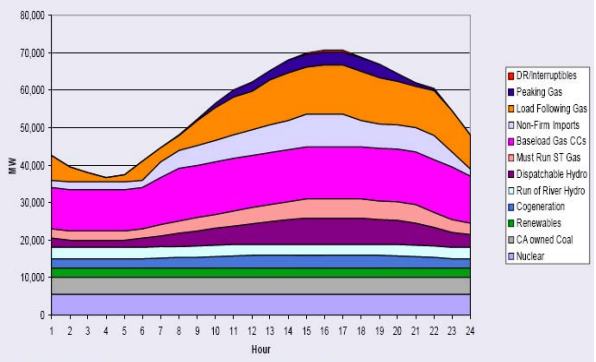
Typical Annual Electricity Demand



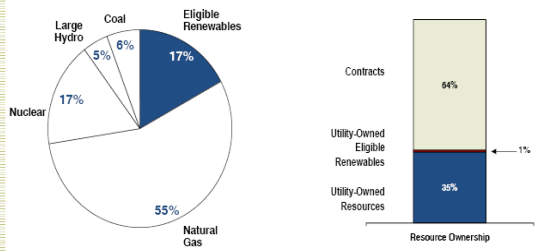
Energy Commission October 18, 2007 3

Typical Resources used on a Peak Day

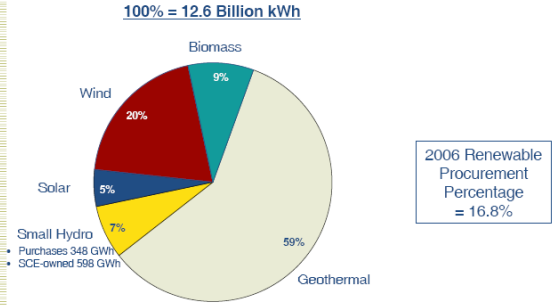


Energy Commission October 18, 2007 5

SCE's 2006 Energy Sources

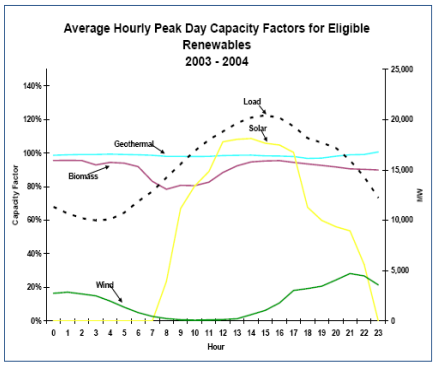


SCE's 2006 Renewable Resources



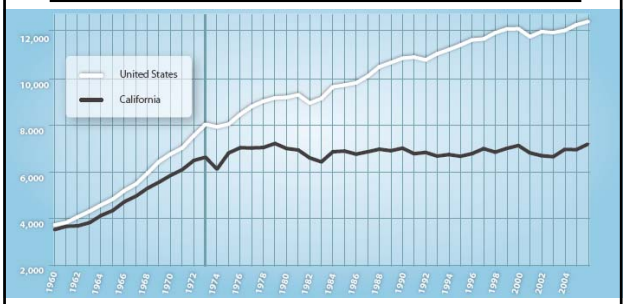
Page: 3

Renewable Delivery Compared to Load



Page: 8

Electricity Sales (kWh/person)



http://www.energy.ca.gov/2007publications/CEC-100-2007-008/CEC-100-2007-008-CMF.PDF Figure ES-2

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A Brief History

- Initial development of industry
  - Generation mostly by investor-owned, regulated monopolies
  - Some publicly owned utilities and rural cooperatives
  - Large industries generate for their own use
- PURPA 1978 brings in other generators
- EPAct 1992 deregulates generation at Federal level

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Who Makes Electricity?

- Traditional electric utilities
  - 239 investor owned utilities supply about 75% of ultimate customers
  - 2,009 publicly owned utilities
  - 912 consumer owned rural electric cooperatives
  - 10 Federal electric utilities
- About 2,110 non-utility power producers as shown on next chart

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http://www.eia.doe.gov/cneaf/electricity/page/prim2/toc2.html

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Non-utility Electric Producers

- Facilities qualifying under 1978 Public Utility Regulatory Policies Act (PURPA)
- Cogeneration facilities producing steam and electricity, doing other business
- Independent power producers who sell electricity wholesale
- Exempt wholesale generators under 1992 Energy Policy Act (EPACT)
- http://www.eia.doe.gov/cneaf/electricity/page/prim2/toc2.html

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Government Agencies

- Federal Energy Regulatory Commission (FERC) regulates interstate transmission of electricity, oil and gas
- State public utilities commissions regulate investor-owned utilities in state
- State Independent System Operators (ISO) operates transmission ines
- California Energy Commission (CEC) one-stop permits for new power plants

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What is PURPA?

- Public Utility Regulatory Policies Act 1978
  - Requires utilities to change rate structures from earlier ones that encouraged use
    - Costs per kWh declined with use based on model valid from 1950-1970
  - Convert from oil to gas
  - Require utilities to purchase power from qualified facilities (QFs) who generated it
    - Includes, solar, wind and biomass generation
    - Among requirements to be a QF is the production of electricity and heat with stipulated efficiency

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Effects of PURPA

- Started the development of a new industry: non-utility power producers
- Merged well with development of stationary gas turbine technology for cogeneration
- California incentives linked to PURPA made it an international leader for solar and wind electricity (about 85% of world wind and 95% of world solar in 1990)

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1992 Energy Policy Act

- Required owners of transmission lines to accept power from other generators for ultimate customers ("wheeling")
- Federal Energy Regulatory Commission passed enabling regulations in 1996
- California legislature passed restructuring legislation same year
- History of deregulation has been mixed

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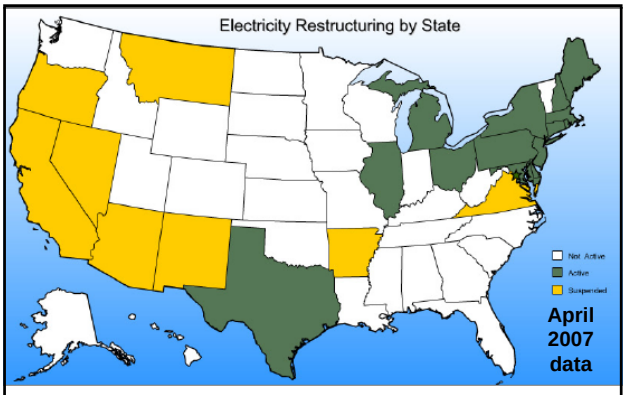

http://www.eia.doe.gov/cneaf/electricity/page/restructuring/restructure_elect.html

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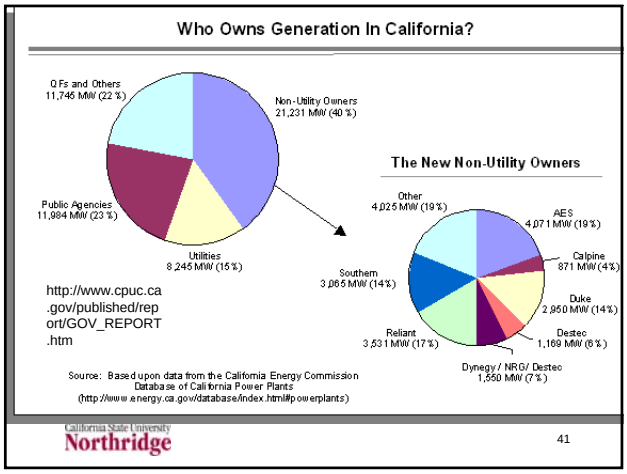

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The California Experience

- Law passed in 1996
  - 10% decrease in rates mandated until utilities paid off existing debt
- Open market started March 31, 1998
- Average wholesale price was $19.73/MWh compared to $24/MWh before deregulation
- SDG&E first to raise prices on July 1, 1999
  - Wholesale price increases to $500/MWh in May 2000 (billed to SDG&E customers)

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The California Experience II

- Price caps drives electricity sales outside of California
  - Aluminum smelters made more money by shutting down and selling electricity
- Wholesale price escalations not felt by LADWP, SCE, and PG&E customers
  - Companies losing 20 to 30 cents on each kWh they sold
  - PG&E bankrupt, SCE close to it

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The California Experience III

- January 17, 2001 governor directs DWR to enter into long-term contracts
  - Contract price was $70/MWh when wholesale spot price was about $300/MWh
  - Later spot prices declined to $35/MWh
- Price increases due to manipulations by companies like Enron and real cost increases because of price increases in natural gas

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The California Experience IV

- What went wrong?
  - Manipulation by power suppliers
  - Fuel cost increases
  - Customers shielded from price increases
    - When customers had to pay higher prices, electricity use decreased
  - Lack of new power plants to meet demand
    - Capacity increases not provided
- Current status http://www.ferc.gov/industries/electric/indus-act/wec.asp

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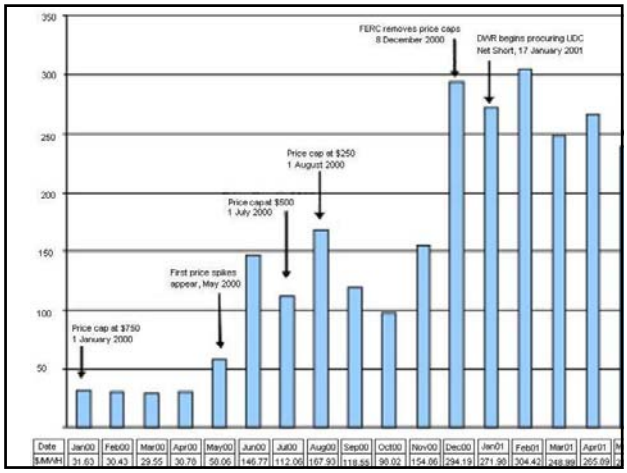

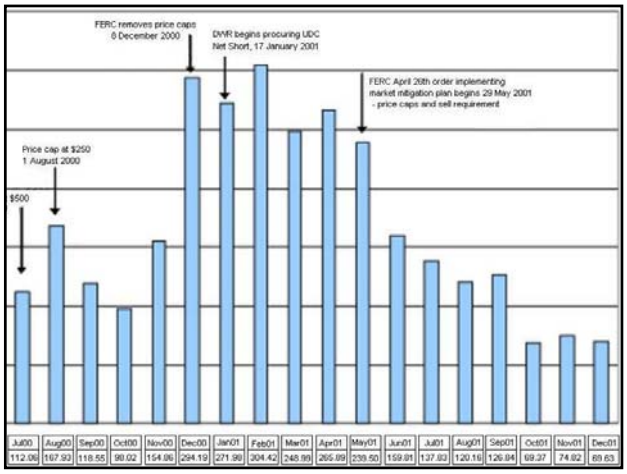

The Pennsylvania Experience

- Legislation did not require utilities to divest generation facilities and allowed long-term contracts
- State is net exporter of electricity
- Originally considered success story, just the opposite of California
- Subsequent price increases – utilities control large fraction of generation
- Prices still lower than before deregulation

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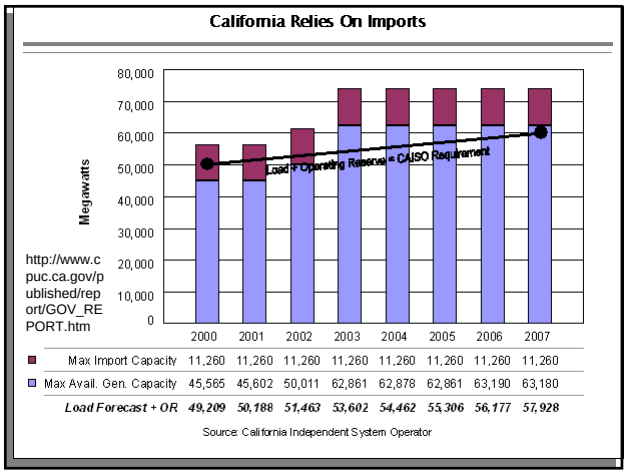

http://www.cpuc.ca.gov/published/report/GOV_REPORT.htm

Reliability Councils

- Set up to share power in a region
- Link producers to produce system reliability
  - ERCOT – Electric Reliability Council of Texas
  - FRCC – Florida Reliability Coordinating Council
  - MRO – Midwest Reliability Organization
  - NPCC – Northwest Power Coordinating Council
  - RFC – Reliability First Corporation
  - SERC – Southern Electric Reliability Council
  - SPP – Southwest Power Pool
  - WECC – Western Energy Coordinating Council

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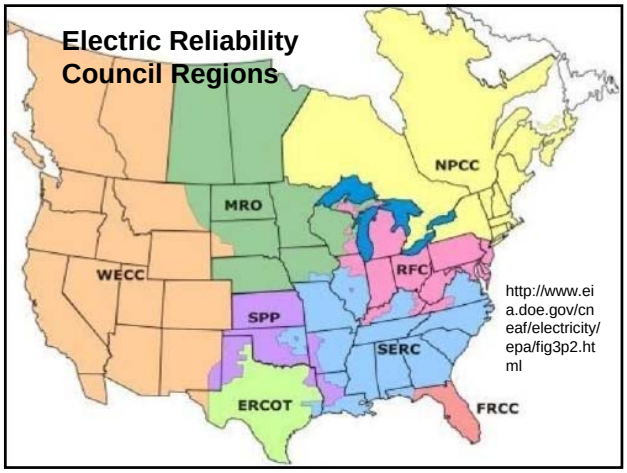
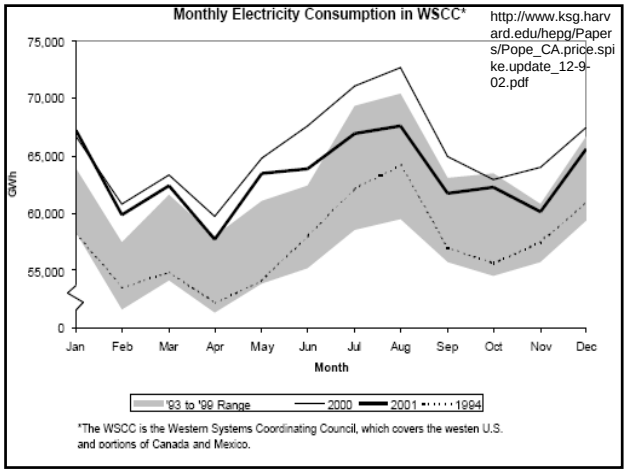
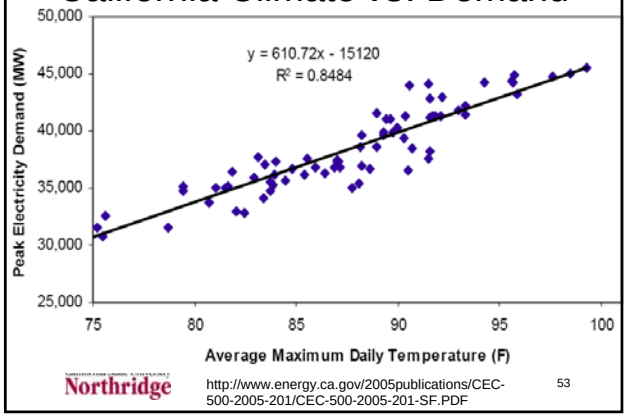


http://www.eia.doe.gov/cneaf/electricity/epa/fig3p2.html



http://www.ksg.harvard.edu/hepg/Papers/Pope_CA.price.spike.update_12-9-02.pdf

California Climate *vs*. Demand



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http://www.energy.ca.gov/2005publications/CEC-500-2005-201/CEC-500-2005-201-SF.PDF

LADWP Electricity Rates

- Residential normal meter: $0.07288/kWh
- Residential time-of-service meter
  - Monday–Friday, 1–5 pm: $0.14377/kWh
  - Monday–Friday, 10 am–1 pm: $0.08793/kWh
  - All other times: $0.03780/kWh
- Other services have demand charge (per kW) but lower service charge
  - High season (June to October) extra
  - Also have different rates for interruptible or non-interruptible

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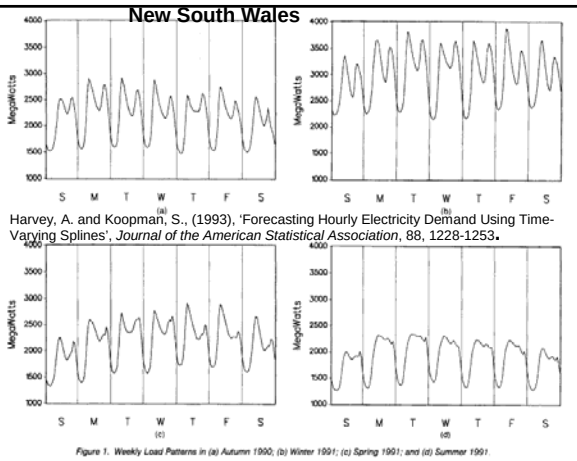
http://www.ladwp.com/ladwp/cms/ladwp001646.jsp



Harvey, A. and Koopman, S., (1993), 'Forecasting Hourly Electricity Demand Using Time-Varying Splines', *Journal of the American Statistical Association*, 88, 1228-1253.

Figure 1. Weekly Load Patterns in (a) Autumn 1990; (b) Winter 1991; (c) Spring 1991; and (d) Summer 1991.

Electric Plants

- Base load plants run continuously
  - Produce load that is required 24/7
  - Most efficient plants
- Peak load plants
  - Used to satisfy demand peaks
  - Often gas turbines that are less efficient
  - Hydroelectric plants run as peak plants because of limited resource
- Distributed Generation – large users generate their own power

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Analysis of Alternatives

- Following charts from paper by Oxford Environmental Change Institute
- Conclude that alternative and energy supplies can, when properly planned, meet needs for peak power
  - Based on models of supply and demand
  - Wind, solar photovoltaic, and domestic combined heating and power (dCHP)
    - dCHP not a renewable, but an alternative

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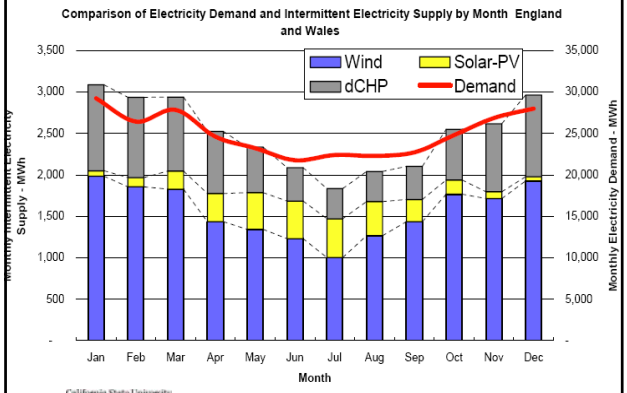

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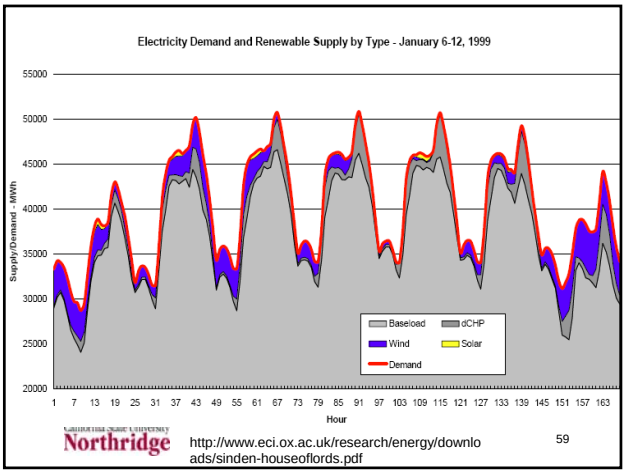
http://www.eci.ox.ac.uk/research/energy/downloads/sinden-houseoflords.pdf



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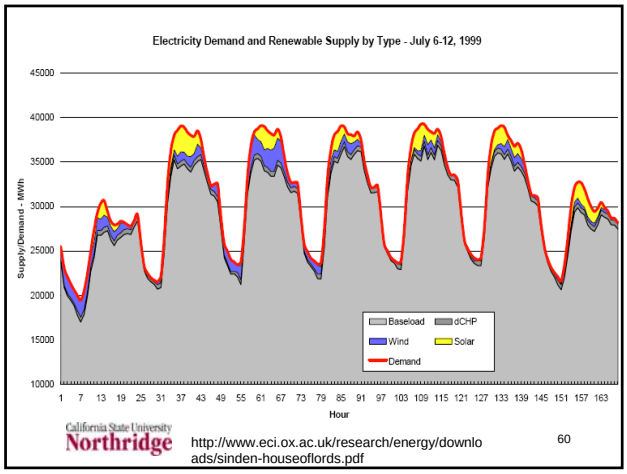
http://www.eci.ox.ac.uk/research/energy/downloads/sinden-houseoflords.pdf



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http://www.eci.ox.ac.uk/research/energy/downloads/sinden-houseoflords.pdf