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)

Outline

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

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

Energy Storage Measures

- Energy per unit mass (kJ/kg; Btu/lb<sub>m</sub>)
- Energy per unit volume (kJ/m<sup>3</sup>; Btu/ft<sup>3</sup>)
- 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

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

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

![Battery Properties Diagram](http://www.mpoweruk.com/chemistries.htm)

### Compare

**Batteries versus other motive power**

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

### Battery Properties Table

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Whr/kg</th>
<th>kJ/m³</th>
<th>Cost $/kWh</th>
<th>Efficiency</th>
<th>Peak W/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead acid batteries</td>
<td>40</td>
<td>30000</td>
<td>130</td>
<td>80%</td>
<td>250</td>
</tr>
<tr>
<td>Nickel-Cadmium batteries</td>
<td>50</td>
<td>37500</td>
<td>300</td>
<td>75%</td>
<td>110</td>
</tr>
<tr>
<td>Nickel-metal-hydride batteries</td>
<td>80</td>
<td>60000</td>
<td>260</td>
<td>70%</td>
<td>250</td>
</tr>
<tr>
<td>Sodium-sulfur batteries</td>
<td>190</td>
<td>143000</td>
<td>330</td>
<td>85%</td>
<td>230</td>
</tr>
<tr>
<td>Lithium-ion batteries</td>
<td>100</td>
<td>75000</td>
<td>200</td>
<td>95%</td>
<td>250</td>
</tr>
<tr>
<td>Capacitor</td>
<td>11.1</td>
<td>40000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inductor</td>
<td>0.556</td>
<td>10000</td>
<td>180</td>
<td>95%</td>
<td></td>
</tr>
<tr>
<td>Pumped hydro</td>
<td>0.000278</td>
<td>1</td>
<td>90</td>
<td>70%</td>
<td></td>
</tr>
</tbody>
</table>

Unreferenced data obtained in 2002 by L. S. Careto

### US Electricity Net Generation, 2005

- Total = 4,055 billion kWh
- Electric Utility Plants = 63.0%
- Independent Power Producers and Combined Heat and Power Plants = 37.0%

![US Electricity Net Generation Pie Chart](http://www.eia.doe.gov/energyexplained/images/us-electricity-net-generation2005_large.png)

**Generation (trillion kWh)**

![Graph of US Electric Generation](http://www.eia.doe.gov/emeu/aer/elect.html)

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

Electricity Use by Sector

Residential
Commercial
Industrial
Direct Use
Other

Use (trillions of kilowatt hours)

0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

Year

Plotted from data in spreadsheet downloaded from http://www.eia.doe.gov/cneaf/electricity/epa/esa_sum.html

Residential Electricity Use

Lighting 8.8
Space Heating 10.1
Air Conditioning 16
Refrigerator 13.7
Other 42.2

Source: Energy Information Administration, Form EIA-860/86A, B, C, E, and H of the 2001 Residential Energy Consumption Survey

US Electrical Generation

Total
Coal
Natural Gas
Hydroelectric
Nuclear
Petroleum
Non-hydro renewable

Generation (trillions kWh)

Year

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

Non-hydro Renewable Electrical Generation

Waste
Geothermal
Wood
Wind
Solar

Generation (trillions kWh)

Year

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

Net US Summer Capacity

Natural Gas
Coal
Hydroelectric
Nuclear
Petroleum
Other Renewables
Other Gases
Other

Cig.equiv.

0
100
200
300
400

2022
2021
2020
2019
2018
2017
2016
2015
2014
2013
2012
2011
2010
2009
2008
2007
2006
2005
2004
2003
2002
2001
2000
1999
1998
1997
1996
1995
1994

Plotted from data in spreadsheet downloaded from http://www.eia.doe.gov/cneaf/electricity/epa/figes2.html

Electric Industry Fuel Costs

Natural Gas
Petroleum
Coal
Fossil Fuel

2006 data: gas and oil down; coal up slightly

http://www.eia.doe.gov/emeu/laer/elect.html
**Electricity generation and use**

**Industrial Electric Costs 2005**

Industrial Average Price (Cents per kilowatthour)

- 3.60 to 4.46
- 4.62 to 4.85
- 4.95 to 5.61
- 6.74 to 7.71
- 7.77 to 10.79

http://www.eia.doe.gov/cneaf/electricity/epa/fi07p7.html

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**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**

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  - CA energy, peak MW growth: 1.25%, 1.35%
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**SCE’s 2006 Energy Sources**

- Natural Gas: 55%
- Coal: 17%
- Hydro: 17%
- Nuclear: 17%
- Fuel Oils: 5%

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**SCE’s 2006 Renewable Resources**

- Wind: 39%
- Biomass: 8%
- Solar: 2%
- Small Hydro: 5%
- Geothermal: 56%

2006 Renewable Procurement Percentage = 16.8%
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

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

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
  - http://www.eia.doe.gov/emeu/electricity/page/prim2toc2.html

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
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

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)

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

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)
The California Experience II

- Price caps drive 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

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

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

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
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

Electric Reliability Council Regions

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

California Climate vs. Demand

y = 610.72x - 15120
R² = 0.8484

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
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