My political leanings are generally

1. Very conservative
2. Conservative
3. Moderate
4. Liberal
5. Very liberal
6. Libertarian
7. Not political
Lecture 9 Thermodynamics III
+ Electrical Power
Entropy and Particles in a box

- Particles start all on left
  - What happens?
    - What are the odds that later we find all of them on the left?
- Just like the coin tossing!

- After mixing, chance of all on the left is \((1/2)^N\)

*It would take work to push all the molecules back to the left side*
Heat Engines

- Heat engines take heat from a hot reservoir and does work and expels heat to the cold reservoir
- Note that the first law says $Q_1 = W + Q_2$
- The 2nd law tells us the amount of work we can get from a temperature difference
- Efficiency = (work output)/(energy in)
Carnot Engine

- The Carnot Engine is an idealized engine that works in a reversible way
  - What is a **reversible** engine?
    - A refrigerator
      - By adding work we can take heat from the cold reservoir and deposits it to the hot reservoir
    - Again – 1st law works
  - \( W + Q_1 = Q_2 \)
    - Notice more heat is delivered than work done!
Real Heat Engines

- Real heat engines always are less efficient than Carnot engines.
- In all heat engines there is waste heat from the 2nd law.
  - Electric motors are not governed by the 2nd – although generally the production of electricity is...
- In real engines there is additional waste heat.
- The Carnot engine gives us a goal.
Real Engine

\[ T_1 \]

\[ Q_1 \]

\[ Q_{\text{waste}} \]

\[ W_{\text{out}} \]

\[ Q_2 \]

\[ T_2 \]
Car Engines

- efficiency of about 25%
  - The efficiency may be as high as 37% at the optimum operating point.
  - Most internal combustion engines waste about 35% of the energy in gasoline as heat lost to the cooling system and another 35% through the exhaust.
  - The rest, about 5%, is lost to friction
Will a car engine run with the exhaust pipe plugged by a potato?

1. Yes
2. Yes, for a while until the engine gets too hot
3. No
Work out $Q_{\text{Waste}}$, $Q_1$, $Q_{2\text{ out}}$
Real Engine – heat recovery
What fraction of our 100 Quads of energy is lost to waste heat

1. 10%
2. 25%
3. 40%
4. 60%
5. 80%
Net Primary Resource Consumption ~97 Quads

Electrical imports* 0.08
Nuclear 8.1
Hydro 2.6 2.5
Biomass/other** 3.2 0.9
Natural gas 19.6 5.7
Net imports 3.6
Coal 22.6 20.0
U.S. petroleum and NGPL 14.9
Imports 24.3

Bal. no. 0.9
Bal. no. 0.3
Bal. no. 0.1
Bal. no. 0.7
Bal. no. 0.5
Bal. no. 0.1
Bal. no. 0.2
Bal. no. 0.7
Bal. no. 0.4
Bal. no. 0.9

Electric power sector 38.2
Electric system energy losses 26.3
Lost energy 56.2
Residential/commercial 19.6
Industrial 19.0
Nonfuel 5.9
Transportation 26.5
Useful energy 35.2

Source: Production and end-use data from Energy Information Administration, Annual Energy Review 2002.
*Net fossil-fuel electrical imports.
**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.
## Electrical Power in Maryland 2006

<table>
<thead>
<tr>
<th>Plant</th>
<th>Primary Energy Source</th>
<th>Company</th>
<th>Net Summer Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chalk Point LLC</td>
<td>Coal</td>
<td>Mirant Chalk Point LLC</td>
<td>2,429</td>
</tr>
<tr>
<td>Calvert Cliffs Nuclear Power Plant</td>
<td>Nuclear</td>
<td>Calvert Cliffs Nuclear PP Inc</td>
<td>1,735</td>
</tr>
<tr>
<td>Morgantown Generating Plant</td>
<td>Coal</td>
<td>Mirant Mid-Atlantic LLC</td>
<td>1,492</td>
</tr>
<tr>
<td>Brandon Shores</td>
<td>Coal</td>
<td>Constellation Power Source Gen</td>
<td>1,286</td>
</tr>
<tr>
<td>Herbert A Wagner</td>
<td>Coal</td>
<td>Constellation Power Source Gen</td>
<td>1,001</td>
</tr>
<tr>
<td>Dickerson</td>
<td>Coal</td>
<td>Mirant Mid-Atlantic LLC</td>
<td>853</td>
</tr>
<tr>
<td>Rock Springs Generation Facility</td>
<td>Gas</td>
<td>CED Operating Co LLC</td>
<td>632</td>
</tr>
<tr>
<td>Conowingo</td>
<td>Hydroelectric</td>
<td>Susquehanna Electric Co</td>
<td>548</td>
</tr>
<tr>
<td>C P Crane</td>
<td>Coal</td>
<td>Constellation Power Source Gen</td>
<td>399</td>
</tr>
<tr>
<td>Perryman</td>
<td>Gas</td>
<td>Constellation Power Source Gen</td>
<td>360</td>
</tr>
</tbody>
</table>
From my electricity bill from PEPCO

### Energy Source (Fuel Mix)
**July 1, 2006 – June 30, 2007**

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>55.2%</td>
</tr>
<tr>
<td>Gas</td>
<td>5.8%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>34.3%</td>
</tr>
<tr>
<td>Oil</td>
<td>0.5%</td>
</tr>
<tr>
<td>Hydroelectric (&gt; 30MW)</td>
<td>0.4%</td>
</tr>
</tbody>
</table>

#### Renewable Energy
- Captured Methane Gas: 1.1%
- Geothermal: 0.0%
- Hydroelectric (< 30MW): 0.7%
- Solar: 0.0%
- Solid Waste: 1.6%
- Wind: 0.1%
- Wood or other Biomass: 0.3%
- Unspecified Renewable: 0.0%

**Total**: 100%

Renewable energy sources subtotal: 3.8%

### Air Emissions
The amount of air pollution associated with the generation of electricity production for Pepco and for the Mid-Atlantic region is shown below.

#### Pounds Emitted per Megawatt Hour of Electricity Generated

<table>
<thead>
<tr>
<th></th>
<th>Pepco</th>
<th>Mid-Atlantic Regional Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur Dioxide (SO₂)</td>
<td>7.8</td>
<td>7.8</td>
</tr>
<tr>
<td>Nitrogen Oxides (NOₓ)</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>1,238</td>
<td>1,242</td>
</tr>
</tbody>
</table>

CO₂ is a “greenhouse gas,” which may contribute to global climate change. SO₂ and NOₓ released into the atmosphere react to form acid rain. NOₓ also reacts to form ground level ozone, an unhealthful component of “smog.”
U.S. Electric Power Industry Net Generation

- Coal: 78%
- Nuclear: 18%
- Gas: 4%
- Other Renewables: 2.4%
- Hydroelectric: 7.0%
- Natural Gas: 20.0%
- Petroleum: 1.6%
- Other Gases: 0.4%
- Nuclear: 19.4%
- Other: 0.3%

Total = 4,065 Billion KWh
Electric Utility Plants = 61.1%
Independent Power Producers & Combined Heat and Power Plants = 38.9%

Maryland: Coal 78%
Peak Power

- You have a peak power of say 2kW (when you are using your hair dryer)
- Your neighbor also has a peak power of 2kW.
- What is the typical peak power of the two of you?

Ave 1700 – Std Dev. 300
Ave 1700 – Std Dev. 130
Peak Power

- Customers use 1000W hairdryers between 7 and 8 AM for 5 minutes. How much power should I plan for?

One customer…
Peak Power

- Customers use 1000W hairdryers between 7 and 8 AM for 5 minutes. How much power should I plan for?

Five customers…
Peak Power

- Customers use 1000W hairdryers between 7 and 8 AM for 5 minutes. How much power should I plan for?

Fifty customers…
Peak Power

- Customers use 1000W hairdryers between 7 and 8 AM for 5 minutes. How much power should I plan for?

500 customers...
Peak Power

- Customers use 1000W hairdryers between 7 and 8 AM for 5 minutes. How much power should I plan for?

5000 customers…
Customers use 1000W hairdryers between 7 and 8 AM for 5 minutes. How much power should I plan for?

Average ~ (5/60)*1000*5000 = 417,000
Standard deviation = 25,000

5000 customers...
What season is peak electric demand?

1. Summer
2. Fall
3. Winter
4. Spring
Peak Demand Discussion

- Uncorrelated demand
- Correlated demand
- Excess capacity
- Economy of scale
- Energy Storage
  - Pumped hydropower
  - Compressed Air
  - Batteries
  - Flywheels
  - Superconducting magnets
  - Capacitors
- Trade offs of generating cost (for peak demand)
Flywheels
Capacitors

Charge $+Q$
Plate area $A$
Electric field $E$
Plate separation $d$

Charge $+Q$
Electric field $E$
Dielectric
Polarized molecules

Charge $-Q$
Hydroelectric storage

Raccoon Mt. Tennessee - build a lake on top of a mountain
1000 ft. above generator

When there is little demand

When there is a lot of demand
Renewable energy

Solar - only produces during the day
Wind - only produces when windy

We cannot have too much of solar and wind without storage...
Fuel Costs for Electricity Generation

![Graph showing fuel costs for electricity generation from 1993 to 2006. The graph compares natural gas cost, petroleum cost, coal cost, and fossil fuel cost. The costs are measured in cents per MMBtu, and the years are marked on the x-axis. The costs show a general trend of increase over the years.]
The US Power Grid
The US Power Grid
Losses in Power Transmission

- \( V = IR \)
- Power transmitted is \( P = VI \)
- Power dissipated by \( P = I^2R \)
- \( P_{\text{loss}} = I^2R = \frac{P^2}{V^2}R \)
- So for fixed power transmitted the higher the voltage the lower the current and the less the loss.
- Modern Transmission runs at 380KV to 735KV
How to tell transmission line voltages...


Miles of AC and DC Transmission Lines in the U.S. in 2002

<table>
<thead>
<tr>
<th>Voltage (kV)</th>
<th>AC Miles</th>
<th>DC Voltage (kV)</th>
<th>DC Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>230</td>
<td>76,762</td>
<td>250-300</td>
<td>930</td>
</tr>
<tr>
<td>345</td>
<td>49,250</td>
<td>400</td>
<td>852</td>
</tr>
<tr>
<td>500</td>
<td>26,038</td>
<td>450</td>
<td>192</td>
</tr>
<tr>
<td>765</td>
<td>2,453</td>
<td>500</td>
<td>1,333</td>
</tr>
<tr>
<td>Total AC</td>
<td>154,503</td>
<td>Total DC</td>
<td>3,307</td>
</tr>
</tbody>
</table>

Total AC/DC 157,810

Electrical Usage

U.S. Peak Load, 1986-2006

Capacity Margin, 1995-2006

U.S. Peak Load by NERC Region, 2006

North American Electric Reliability Council Map for the United States
Capacity Factor

The amount of energy that a power plant actually generates compared to its maximum rated output, expressed as a percentage.