Questions?
Comments?
Gottfried talk: Ferguson lecture
11 am in Graham Chapel
“Science meets politics - from
Thomas Jefferson to George W. Bush”

Energy: Coal and Electric Power
Global Carbon Cycle

Schematic representation
Detour

Fossil fuels

[Diagram showing the process of carbon dioxide being produced through photosynthesis by plants, which then decay into dead plants and animals, ultimately leading to fossil fuels.]
Detour (same)

Fossil fuels
Fossil Fuel formation

Optimal conditions:

• Abundant growth of living organisms
  – Abundant light
  – Warmth
  – Moisture
    Swamps / river deltas / lakes / shallow seas
• Minimize return of CO₂ to the atmosphere
  Water: covers & protects remains from atmospheric oxygen
• Most likely: fossil fuels from algae / plankton / higher plants
Origin of Oil

- Decaying algae / plankton
  - Methane (\(\text{CH}_4\))
- Kerogen
  - [fats, oils, waxes; long carbon chains]
  - flooding, burying, heat
- Petroleum (Crude Oil)
  - [Several hundred compounds; 5-20 carbons per molecule]
  - Higher T
- Natural Gas (Mostly methane; few % 2-5 C/molecule)
Lignin

Higher plants contain large amounts of lignin
Complex molecule responsible for structural & mechanical rigidity of plants
C in cross-linked rings

Heat & pressure

- compress lignin
- rigid material

COAL!
## Types of coal

<table>
<thead>
<tr>
<th>Type</th>
<th>Age (MY)</th>
<th>Carbon</th>
<th>Heat (Btu/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite</td>
<td>60</td>
<td>65-75%</td>
<td>7,000</td>
</tr>
<tr>
<td>Sub bituminous</td>
<td>100</td>
<td>72-76%</td>
<td>10,000</td>
</tr>
<tr>
<td>Bituminous</td>
<td>300</td>
<td>76-90%</td>
<td>12,000-15,000</td>
</tr>
<tr>
<td>Anthracite</td>
<td>350</td>
<td>90-95%</td>
<td>~15,000</td>
</tr>
</tbody>
</table>

### Content of coal

- C: 65-96%
- H: 2-5%
- N: 1-2%
- O: 1-30%
- S: 0-5%
How do we get coal?

- **Surface mining (strip mining)**
  - Very productive: 30-40 tons per worker per day
  - 60% of US production
  - Environmentally damaging

- **Underground mining**
  - 8 Tons per worker per day
  - ~100 US deaths per year
  - Black lung disease
# Deaths per GigaWatt-Yr

<table>
<thead>
<tr>
<th></th>
<th>Extraction</th>
<th>Transport</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td>0.3</td>
<td>2.3</td>
<td>2.6</td>
</tr>
<tr>
<td>Deep</td>
<td>1.7</td>
<td>2.3</td>
<td>4.0</td>
</tr>
<tr>
<td>Oil</td>
<td></td>
<td></td>
<td>0.4</td>
</tr>
<tr>
<td>Natural Gas</td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>Nuclear</td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
</tbody>
</table>
Coal power plant

Schematic
Coal plant in more detail
1000 pounds of coal story

Start with 1000 lbs of coal

- 1 lb = 13,000 Btu
- $E_{\text{coal}} = 13,000,000$ Btu

Boiler

$E_{\text{boiler}} = 0.88 \times E_{\text{coal}}$

$E_{\text{boiler}} = 11,440,000$ Btu

$E_{\text{smokestack}} = 0.12 \times E_{\text{coal}}$

$E_{\text{smokestack}} = 1,560,000$ Btu

$\square = 88\%$
Turbine

Condenser

\[ E_{\text{turbine}} = 0.47 \times E_{\text{boiler}} \]
\[ = 5,377,000 \text{ Btu} \]

Condenser

\[ E_{\text{condenser}} = 0.53 \times E_{\text{boiler}} \]
\[ = E_{\text{boiler}} - E_{\text{turbine}} \]
\[ = 6,063,000 \text{ Btu} \]

Generator

Friction

\[ E_{\text{generator}} = 0.99 \times E_{\text{turbine}} \]
\[ = 5,323,000 \text{ Btu} \]
\[ = 5,323,000 \text{ Btu} \times \frac{1 \text{ kW-hr}}{3,413 \text{ Btu}} \]
\[ = 1,560 \text{ kW-hr} \]

Useful Energy = 1,560 kW-hr
Role of 2\textsuperscript{nd} law

- $\Delta_{\text{turbine}}$ is weak link in $\Delta_{\text{total}}$
  but
- 2\textsuperscript{nd} Law constrains $\Delta_{\text{turbine}}$

$$\Delta_{\text{turbine}} < \Delta_{\text{reversible}} = 1 - \frac{T_c}{T_h}$$

If $T_c = 15 \text{ C (59 F)} = 288 \text{ K}$
and $T_h = 300 \text{ C} = 573 \text{ K}$

$$\Delta_{\text{reversible}} = 1 - \frac{288}{573} = 0.5$$
Total efficiency

\[ \eta_{\text{total}} = \eta_{\text{boiler}} \times \eta_{\text{turbine}} \times \eta_{\text{generator}} \]
\[ = (0.88) \times (0.47) \times (0.99) \]
\[ = 0.409 \]

\[ E_{\text{generator}} = \eta_{\text{total}} \times E_{\text{coal}} \]
\[ = 0.409 \times 13,000,000 \text{ Btu} \]
\[ = 5,323,000 \text{ Btu} \]
Convert

- 1 lb = 1 hour of A/C

Why?
- 1,000 lbs coal \( \equiv \) 1,560 kW-hr
- 1 lb of coal \( \equiv \) 1,560 W-hr
- An A/C window unit might draw 1,600 W

Therefore

1 lb of coal = 1 hour of A/C
Emissions

- 1,000 lbs of coal
- 50 lbs of SO$_2$
  - scrubbers
  - 5 lbs to atmosphere
- 2,600 lbs of CO$_2$
- 100 lbs of ash
  - 1 lb to atmosphere
  - 99 lbs solid waste
  [landfill]
Power

\[ P = \frac{E}{t} \quad \text{or} \quad t = \frac{E}{P} \]

Consider a 1,000 MegaWatt plant

[650,000 A/C units]

It uses 1,000 lbs of coal in

\[ t = \frac{1.56 \text{ MW-hr}}{1,000 \text{ MW}} = 1.56 \times 10^{-3} \text{ hr} \]

\~ 5 seconds!

1 day = 17 million lbs = 8,500 tons

also 25 tons of \( \text{SO}_2 \)

21,000 tons of \( \text{CO}_2 \)

850 tons of ash
Plant details

Typical outputs for conversion of 1000 pounds of coal into electric energy.

- Sulfur oxides = 5 lb
- Carbon dioxide = 2600 lb
- Ash = 1 lb
- Heat energy = 1,560,000 Btu

1000 lb fuel

Energy into turbine = 11,440,000 Btu

Energy into generator = 5,377,000 Btu

Electric energy out = 5,323,000 Btu

or 1560 kWh

Heat rejected to environment = 6,063,000 Btu
Steam engine

Piston

Turning wheel to do work

Cold

pump
Units

- 1 ton = 2,000 lbs
- 1 metric ton = 1,000 kg = 2,204.6 lbs
- 1 metric ton = tonne