Efficiency of Energy Conversion

- If we are more efficient with the energy we already have there will be less pollution, less reliance on foreign oil and increased domestic security.
**Illustration**

An electric motor consumes 100 watts (a joule per second (J/s)) of power to obtain 90 watts of mechanical power. Determine its efficiency?

\[
\text{Efficiency} = \frac{\text{Useful Energy Output}}{\text{Total Energy Input}}
\]

\[
\begin{align*}
\text{Efficiency} &= \frac{90 \text{ W} \times 100}{100 \text{ W}} \\
&= 90\%
\end{align*}
\]

**Efficiency of Some Common Devices**

<table>
<thead>
<tr>
<th>Device</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Motor</td>
<td>90</td>
</tr>
<tr>
<td>Home Oil Furnace</td>
<td>65</td>
</tr>
<tr>
<td>Home Coal Furnace</td>
<td>55</td>
</tr>
<tr>
<td>Steam Boiler (power plant)</td>
<td>89</td>
</tr>
<tr>
<td>Power Plant (thermal)</td>
<td>36</td>
</tr>
<tr>
<td>Automobile Engine</td>
<td>25</td>
</tr>
<tr>
<td>Light Bulb-Fluorescent</td>
<td>20</td>
</tr>
<tr>
<td>Light Bulb-Incandescent</td>
<td>5</td>
</tr>
</tbody>
</table>

**Vehicle Efficiency – Gasoline Engine**

25% of the gasoline is used to propel a car, the rest is lost as heat, i.e. an efficiency of 0.25

Source: Energy Sources/Applications/Alternatives
Heat Engine

- A heat engine is any device which converts heat energy into mechanical energy.
- Accounts for 50% of our energy conversion devices.

Carnot Efficiency

- Maximum efficiency that can be obtained for a heat engine.

\[ \eta (\text{Carnot}) = (1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}) \times 100 \]

Illustration

For a coal-fired utility boiler, the temperature of high pressure steam would be about 540°C and T cold, the cooling tower water temperature would be about 20°C. Calculate the Carnot efficiency of the power plant.
5. Energy Efficiency

**Inference**

A maximum of 64% of the fuel energy can go to generation. To make the Carnot efficiency as high as possible, either $T_{\text{hot}}$ should be increased or $T_{\text{cold}}$ should be decreased.
### Boiler Components

- Chemical Energy Input (100 BTU)
- Thermal Energy (88 BTU)
- Mech. Energy (36 BTU)
- Generator
- Elect. Energy Output (10.26 Wh)

### Overall Efficiency

Overall Efficiency of a series of devices:

\[
\text{Eff} = \frac{\text{E}_{\text{boiler}} \times \text{E}_{\text{turbine}} \times \text{E}_{\text{generator}}}{\text{Chemical Energy} \times \text{Thermal Energy} \times \text{Mechanical Energy}}
\]

- \(\text{E}_{\text{boiler}} = 0.88\)
- \(\text{E}_{\text{turbine}} = 0.41\)
- \(\text{E}_{\text{generator}} = 0.97\)

\[
\text{Eff} = 0.35 \text{ or } 35\%
\]
The efficiency of a system is equal to the product of efficiencies of the individual devices (sub-systems).

**System Efficiency**

<table>
<thead>
<tr>
<th>Step</th>
<th>Step Efficiency</th>
<th>Cumulative Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction of Coal</td>
<td>96%</td>
<td>96%</td>
</tr>
<tr>
<td>Transportation</td>
<td>98%</td>
<td>94% (0.96x0.98)</td>
</tr>
<tr>
<td>Electricity Generation</td>
<td>38%</td>
<td>36% (0.96x0.98x0.38)</td>
</tr>
<tr>
<td>Transportation Elec</td>
<td>91%</td>
<td>33%</td>
</tr>
<tr>
<td>Lighting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incandescent</td>
<td>5%</td>
<td>1.7%</td>
</tr>
<tr>
<td>Fluorescent</td>
<td>20%</td>
<td>6.6%</td>
</tr>
</tbody>
</table>

**Efficiency of a Light Bulb**

<table>
<thead>
<tr>
<th>Step</th>
<th>Step Efficiency</th>
<th>Cumulative Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production of Crude</td>
<td>96%</td>
<td>96%</td>
</tr>
<tr>
<td>Refining</td>
<td>87%</td>
<td>84%</td>
</tr>
<tr>
<td>Transportation</td>
<td>97%</td>
<td>81%</td>
</tr>
<tr>
<td>Thermal to Mech E</td>
<td>25%</td>
<td>20%</td>
</tr>
<tr>
<td>Mechanical Efficiency-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmission</td>
<td>50%</td>
<td>10%</td>
</tr>
<tr>
<td>Rolling Efficiency</td>
<td>20%</td>
<td>6.6%</td>
</tr>
</tbody>
</table>
5. Energy Efficiency

**Efficiency of a Space Heater**

- Electricity = 24%
- Fuel Oil = 53%
- Natural Gas = 70%

**Heat Mover**

- Any device that moves heat "uphill", from a lower temperature to a higher temperature reservoir.
- Examples:
  - Heat pump.
  - Refrigerator.

**Heat Pump Heating Cycle**

Heat Pump Cooling Cycle

Source: http://energyoutlet.com/res/heatpump/pumping.html

Coefficient of Performance (C.O.P)

Effectiveness of a heat pump is expressed as coefficient of performance (C.O.P)

\[ \text{C.O.P} = \frac{T_{\text{hot}}}{T_{\text{hot}} - T_{\text{cold}}} \]

Example

Calculate the ideal coefficient of performance (C.O.P.) For an air-to-air heat pump used to maintain the temperature of a house at 70 °F when the outside temperature is 30 °F.

\[ \text{C.O.P} = \frac{T_{\text{hot}}}{T_{\text{hot}} - T_{\text{cold}}} \]
Solution Cont.

\[ T_{\text{hot}} = 70^\circ F = 21^\circ C = 21 + 273 = 294 K \]
\[ T_{\text{cold}} = 30^\circ F = -1^\circ C = -1 + 273 = 272 K \]
\[ \text{C.O.P} = \frac{294}{294 - 272} = \frac{294}{22} = 13.3 \]

Consequences

- For every watt of power used to drive this ideal heat pump, 13.3 W is delivered from the interior of the house and 12.3 from the outside.
- Theoretical maximum is never achieved in practice. This example is not realistic. In practice, a C.O.P in the range of 2 - 6 is typical.

More C.O.P.’s

Compare the ideal coefficients of performance of the of the same heat pump installed in Miami and Buffalo.
Miami: \( T_{\text{hot}} = 70^\circ F, T_{\text{cold}} = 40^\circ F \)
Buffalo: \( T_{\text{hot}} = 70^\circ F, T_{\text{cold}} = 15^\circ F \)

Miami: \( T_{\text{hot}} = 294^\circ K, T_{\text{cold}} = 277^\circ K \)
Buffalo: \( T_{\text{hot}} = 294^\circ K, T_{\text{cold}} = 263^\circ K \)
C.O.P = \frac{T_{\text{hot}}}{T_{\text{hot}} - T_{\text{cold}}}

\begin{align*}
\text{Miami} & \quad \text{Buffalo} \\
= \frac{294}{(294-277)} & = \frac{294}{(294-263)} \\
= 17.3 & = 9.5
\end{align*}