1. Calculate the entropy change for a reversible heat engine, and

2. Calculate the entropy loss for a reversible heat engine.

Answer: Consider the process in two stages; 1) you transfer heat in, and 2) you transfer heat and work out. Use the result from Carnot to show that the change in entropy is zero. This leads to the result that the exergy lost is also zero.

\[ \Delta S = S_2 - S_1 = \frac{1}{T_o} \left[ (E_2 - E_1) - (B_2 - B_1) \right] = \frac{Q_L}{T_L} - \frac{Q_H}{T_H} \]

\[ B_{\text{lost}} = Q_H - Q_L + T_o \Delta S - W \]

3. Show that maximum amount of work that can be obtained from a system in reference to the environment at standard conditions, \( T_o, P_o \) is

\[ B = (H - T_o S) - (H - T_o S)_o \]

Answer: this system is almost identical to the one done in class. The problem is just “reversed” be sure to keep track of signs.

4. Calculate the maximum work one can obtain from oxidizing H2

\[ 2H_2(g) + O_2(g) \rightarrow 2H_2O(g) \quad \Delta B = +457 \text{ kJ}, \text{ or } 114 \text{ MJ/kg hydrogen} \]

5. Calculate the minimum work required to obtain H2 from water.

Reverse the above reaction but start with liquid water, \( \Delta B = -474 \text{ kJ}, \text{ or } 119 \text{ MJ/kg of hydrogen} \)

6. Calculate the minimum work to reduce iron using hydrogen, use

\[ 3\text{Fe}_2\text{O}_3 + \text{H}_2 = 2 \text{Fe}_3\text{O}_4 + \text{H}_2\text{O} \quad (1) \]

\[ \text{Fe}_3\text{O}_4 + \text{H}_2 = 3 \text{FeO} + \text{H}_2\text{O} \]

\[ \text{FeO} + \text{H}_2 = \text{Fe} + \text{H}_2\text{O} \]

Now assume the H2 comes from the electrolysis of water and add this too.
7. What is the minimum work required for photosynthesis?

\[ 6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2 \]

8. What is the maximum work one could obtain from auto-respiration?

\[ 6CO_2 + 6H_2O \leftarrow C_6H_{12}O_6 + 6O_2 \]

9. What is the maximum work one could obtain from burning the following fuels with oxygen: octane? methane? methanol? hydrogen? How much CO\(_2\) is generated for each?

### Calculated Exergy and Reported Heating Values

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Calculated Max Exergy (MJ/kg*)</th>
<th>CO(_2) generated (gCO(_2)/MJ)</th>
<th>Fuel</th>
<th>Heat of Combustion (MJ/kg)</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>33</td>
<td>112</td>
<td>Coal anthracite</td>
<td>18-29, 30-33</td>
<td>Smil BCCA</td>
</tr>
<tr>
<td>Octane</td>
<td>46</td>
<td>68</td>
<td>Gasoline</td>
<td>46-47</td>
<td>Smil</td>
</tr>
<tr>
<td>Methane</td>
<td>49</td>
<td>56</td>
<td>Nat. gas</td>
<td>33-37, 38-50</td>
<td>Smil Web</td>
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<tr>
<td>Oil</td>
<td>42</td>
<td>75</td>
<td>Fuel oil</td>
<td>42-44</td>
<td>Smil</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>114</td>
<td>0</td>
<td></td>
<td>114</td>
<td>Smil</td>
</tr>
<tr>
<td>Methanol</td>
<td>21</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10. Calculate the exergy lost due to steady state heat transfer as shown below.

\[ Q \quad T_1 \quad T_2 \quad Q \]
The exergy in is: \( B_1 = Q(1 - T_0/T_1) \)

The exergy out of the law is: \( B_2 = Q(1 - T_0/T_2) \)

The exergy lost is: \( \Delta B = T_0 Q(1/T_2 - 1/T_1) \)