(1) **Problem 8.2 (Messenger and Abtahi)** (50pts)
Determine the present electricity cost for which the $600 refrigerator (described in M&A, p361, and Session 20, slides 20-22) will have the same LCC as the $800 unit, assuming all other parameters to be the same.

The Life Cycle Cost (LCC) is equal to the initial cost \( (C_i) \) + annual electricity use \( (E_{annual}) \) in kWh/year times the electricity cost \( (C_{elec}) \) in $/kWh times the cumulative present worth factor \( (P_a) \)

The Cumulative Present Worth Factor is:

\[
P_a = \frac{1 - x^n}{1 - x} = 11.16
\]

where \( x \) is given by:

\[
x = \frac{1+i}{1+d} = \frac{1+0.05}{1+0.03} = 1.019
\]

So, equating LCCs:

\[
C_{i,A} + E_{annual,A}C_{elec,P_A} = C_{i,B} + E_{annual,B}C_{elec,P_A}
\]

\[
C_{elec} = \frac{C_{i,B} - C_{i,A}}{P_A(E_{annual,A} - E_{annual,B})}
\]

or

\[
C_{elec} = \frac{800 - 600}{11.16(1800 - 1200)} = 0.030$/kWh
\]

That's 3 cents/kWh – there is no place in the US where electricity volumetric costs are this low!!
Problem 8.13 (Messenger and Abtahi) (50 pts)

A battery storage system is to be designed to provide a storage capacity of somewhere between 440 and 555 Ah at 48V at a C/20 discharge rate. Four battery types are under consideration:

<table>
<thead>
<tr>
<th>Battery</th>
<th>Volts</th>
<th>Capacity (Ah)</th>
<th>Type</th>
<th>Lifetime (Year)</th>
<th>Weight (lb)</th>
<th>Cost Each ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6</td>
<td>220</td>
<td>Flooded</td>
<td>5</td>
<td>56</td>
<td>66</td>
</tr>
<tr>
<td>B</td>
<td>12</td>
<td>255</td>
<td>AGM</td>
<td>8</td>
<td>168</td>
<td>356</td>
</tr>
<tr>
<td>C</td>
<td>12</td>
<td>180</td>
<td>AGM</td>
<td>8</td>
<td>135</td>
<td>301</td>
</tr>
<tr>
<td>D</td>
<td>12</td>
<td>555</td>
<td>Gel</td>
<td>12</td>
<td>564</td>
<td>1941</td>
</tr>
</tbody>
</table>

Assume an interest inflation rate of 2% and a discount rate of 5% and a 24 year system lifetime. Perform an LCC for the four battery types and discuss other considerations that may influence the choice of batteries. If the site were a homeowner, what would you recommend? Why? If the site were a remote communication system, what would you recommend? Why?

So first calculate the number of batteries (of each type) to achieve a storage system with \( V = 48 \) V, and \( 440 \text{Ah} < Q < 550 \text{Ah} \):

- **Battery A, 6 V**
  - 8 batteries in series produces 48 V, but only 220 Ah, so 2 parallel strings of 8 in series will produce 440Ah – 16 batteries total
  - Lifetime is 5 years, so they will have to be replaced at year 5, year 10, year 15, and year 20

- **Battery B, 12 V**
  - 4 batteries in series produces 48 V, but only 255 Ah, so 2 parallel strings of 4 in series will produce 510Ah – 8 batteries total
  - Lifetime is 8 years, so they will have to be replaced at year 8 and year 16

- **Battery C, 12 V**
  - 4 batteries in series produces 48 V, but only 180 Ah, so 3 parallel strings of 4 in series will produce 540Ah – 12 batteries total
  - Lifetime is 8 years, so they will have to be replaced at year 8 and year 16

- **Battery D, 12 V**
  - 4 batteries in series produces 48 V, and 555 Ah, so 1 string of 4 in series will suffice – 4 batteries total
  - Lifetime is 12 years, so they will have to be replaced at year 12
The present worth factor to be applied to the battery cost at replacement time is given by:

\[ F_{PW,n} = \left( \frac{1+i}{1+d} \right)^n = \left( \frac{1+0.02}{1+0.05} \right)^n = 0.971^n \]

So, for example, Battery A replaced at year 5 has a present worth of $1056 times (0.971)^5 or $1056 times 0.866 or $914. Repeat this for all battery replacements at the appropriate time. Sum the present values to get the Life Cycle Cost.

**Analysis:**
So a homeowner might look for the lowest cost system and pick Battery A, but she would have to deal with lots of battery maintenance (water top-off); she might conclude that maintenance is too burdensome and pick Battery B in spite of the extra cost.

The manager of a remote communication system might be most motivated to choose the longest lifetime battery to reduce the replacement service calls, so Battery D perhaps

<table>
<thead>
<tr>
<th>Battery A (16)</th>
<th>Battery B (8)</th>
<th>Battery C (12)</th>
<th>Battery D (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Years</strong></td>
<td><strong>PW</strong></td>
<td><strong>PW</strong></td>
<td><strong>PW</strong></td>
</tr>
<tr>
<td>0</td>
<td>$1,056</td>
<td>$1,056</td>
<td>$3,612</td>
</tr>
<tr>
<td>5</td>
<td>$1,056</td>
<td>$914</td>
<td>$3,612</td>
</tr>
<tr>
<td>8</td>
<td>$2,848</td>
<td>$2,259</td>
<td>$3,612</td>
</tr>
<tr>
<td>10</td>
<td>$1,056</td>
<td>$790</td>
<td>$2,864</td>
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<tr>
<td>12</td>
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<td>$684</td>
<td>$7,764</td>
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<tr>
<td>15</td>
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<td>$684</td>
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<td>$1,791</td>
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<td>$591</td>
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<tr>
<td><strong>Totals</strong></td>
<td><strong>$4,035</strong></td>
<td><strong>$6,898</strong></td>
<td><strong>$8,748</strong></td>
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<td></td>
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<td><strong>$13,247</strong></td>
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</tbody>
</table>