Combined Heat and Power (CHP)  
Is It Right For Your Facility  

U.S. DOE Industrial Technologies Program  
Webcast Series  
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CHP Decision Making Process

Presented by
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CHP Regional Application Centers
Levels of CHP Site Assessments

- Questionnaire: (overly simplistic)
- Level 1: Screening Analysis
  - 1 to 2 day effort by a Regional Application Center
  - Computer model and/or spread sheet analysis
  - 30% to 50% accurate
- Level 2: Conceptual/Financial Analysis
  - 1 to 3 week effort (depending on size/complexity)
  - Computer aided – 10% to 20% accuracy
- Level 3 Investment Grade (Engineering Company)
CHP Installations

- Significant capital investment (easily 6 figures)
- Usually competes for tight capital funds (not a typical capital project for most companies)
- Each site has unique characteristics (assumptions)
- Each level of analysis has associated costs (several thousands to tens of thousands to several hundred thousands of dollars)
What is Today’s Presentation

- Simply identifying factors that provide an indication of CHP viability
- Mostly qualitative factors – not a level 1 analysis
- Information packets to assist in determining if an analysis is worth while
- Does my facility exhibit some of the key characteristics

- Targeted toward facility managers with some technical background
- Based on

Resource Guide Available for download at

Defining CHP Concept

- **Prime Mover** generates mechanical energy (reciprocating engines, turbines, fuel cells)
- **Generator** converts mechanical energy into electrical energy
- **Waste Heat Recovery** includes one or more heat exchangers that capture and recycle the heat from the prime mover
- **Thermal Utilization** equipment converts the recycled heat into useful heating, cooling, and/or dehumidification
- **Operating Control Systems** insure the CHP components function properly together
The #1 Factor When Identifying a CHP Site

- Can the facility use the waste/recycled heat?
- When the heat is not utilized, the system is operating at ≈ 30% to 35%
- When the heat is being utilized, the system can operate up to 80% to 85%
- Without long hours of operation (>3,000 hrs/yr) with at least 50% usage of the recycled heat (annual basis), the viability of CHP is low.
Impact of Heat Recovery is Critical

32% Efficient Engine Generator

- No Heat Rec.
- 1,500 Btu/kWh
- 3,000 Btu/kWh
- 4,500 Btu/kWh
- 6,000 Btu/kWh

Cost of Electricity ($/kWh) vs. Cost of Gas ($/MMBtu)
Step 1: Understand Your Facility’s Thermal Requirements

- Key Factor for a Viable CHP Application:
  - Ability of the facility to utilize the waste heat (higher the usage, the higher the efficiency)
  - Coincidence of need for electric power & thermal energy (capacity and time of use)

It is More Likely that CHP Makes Sense if >50% of the Available Thermal Energy from the Prime Mover can be Utilized on an Annual Basis
Identify Existing Equipment (thermal load)

- Boilers (steam/water) – Chillers (electric/absorption)
  - Capacity -- Age -- Fuel Type
  - Central Heating/Cooling Plant
  - Type Distribution System (steam, water, air)
  - Steam (operating temp., pressure, flow rates)
  - Water (delivery temperature)
  - Proximity of equipment to potential CHP installation

The Best Time To Install A CHP System Is When Contemplating Replacement of Aging Equipment or Facility Upgrade
Step 2: Understand Your Electric & Fuel Rates

- Review last 12 months of electric and fuel bills:
  - What utility is delivering the energy (electric and gas)?
  - What type of rate structure am I on?
    - Flat charge/rate – energy/demand charges – real time pricing
      - On-peak, off-peak schedules
  - What is the delivered price (electricity and gas)?
  - What is the peak and average demand?
  - What rate are you on so you can look up more info online?

For a First Cut Very Rough Screening of the Viability of CHP, the Cost Differential Between Electricity and Natural Gas “Spark Spread” can be Estimated
Spark Spread

Steps to Determining Spark Spread:

1. Utilize the last 12 months electric and gas utility bills
2. Determine the Average Annual Electric Cost ($/MMBtu)
3. Determine the Average Gas Cost ($/MMBtu)
4. Determine the gas/electric price difference… “Spark Spread”

CHP has more potential for favorable paybacks when the spark spread is >$12/MMBtu.
Example Problem to Determine Spark Spread

Example – Totals From Utility Bills

- Total Electric Consumption – 16,000,000 kWh
- Total Electric Cost - $1,280,000
- Total Natural Gas Consumption – 1,000,000 therms
- Total Natural Gas Cost - $700,000
# Example Problem - Determine Spark Spread

1. **Determine the Average Annual Electric Cost ($/MMBtu):**
   - **a.** Sum the total cost for electricity from the last 12 months of bills:  
     - Total Cost $1,280,000
   - **b.** Sum the number of kWh utilized over the last 12 months of bills:  
     - Total kWh 16,000,000 kWh
   - **c.** Divide the Total Cost by the Total kWh:  
     - Average Annual Electric Cost $0.080 /kWh
   - **d.** Multiply the Average Annual Electric Cost ($/kWh) by 293 to convert to $/MMBtu:  
     - Average Annual Electric Cost $23.44 /MMBtu

2. **Determine the Average Gas Cost ($/MMBtu):**
   - **a.** Sum the total cost for gas from the last 12 months of bills:  
     - Total Cost $700,000
   - **b.** Sum the number of Therms utilized over the last 12 months of bills:  
     - Total Therms 1,000,000 Therms
   - **c.** Divide the Total Cost by the Total Therms:  
     - Average Annual Gas Cost $0.70 /Therm
   - **d.** Multiply the Average Annual Gas Cost ($/Therm) by 10 (for NG) to convert to $/MMBTU:  
     - Average Annual Gas Cost $7.00 /MMBtu

3. **Determine the “Spark Spread”:**
   - **a.** Average Annual Electric Cost (1.d.) $/MMBtu  
     - $23.44 /MMBtu
   - **b.** Minus Average Annual Gas Cost (2.d.) $/MMBtu  
     - $7.00 /MMBtu
   - **c.** Spark Spread  
     - $16.44

4. **Is the “Spark Spread” >$12/MBtu?**  
   - Yes / No  
     - Yes
Bio-Gas Fuels

- Landfill Gas
  - Normally long term contract at specific rate (spark spread)

- Digester Gas
  - Often times considered “free” gas – bi-product of the digester
  - Animal Waste – Food Processing – Waste Water Treatment

Must Remember to Include the Cost of Gas Cleanup
Step 3: Prime Mover Selection / Sizing

- **Reciprocating Internal Combustion Engines:**
  - Most common for CHP <5 MW
  - Good for hot water/low pressure steam applications

- **Gas Turbines (Combustion Turbines)**
  - Generally used for larger applications (>4MW) where a lot of high pressure steam is required per unit of electric power
Micro-turbines
- Compact in size, brought on line quickly, fuel flexibility
- Usually below 200kW unless multiple units utilized
- Good for hot water

Fuel Cells
- Electrochemical Reaction (like a battery)
- Up to 250kW modules (can be stacked)
- Base load only, very quiet, environmentally clean
- Expensive Option
Steam Turbines

- One of the oldest prime mover technologies still in use
- Condensing Turbines: Industrial waste heat streams to produce steam that can drive a steam turbine
- Backpressure Turbine: Captures the energy lost through a pressure reducing valve (PRV)
Thermal-to-Power Ratio (T/P) of the facility can assist in knowing what prime mover to select

1. Determine Thermal Use
   a. Sum the number of Therms utilized over the last 12 months of bills:
      Total Therms 1,000,000
   b. Multiply the Total Therms by 100,000 to get Thermal Btu:
      Total Thermal Energy Purchased \(100 \times 10^9\) Btu
   c. Multiply the Total Thermal Energy Purchased by Boiler/Equipment Efficiency (typically 0.8)
      Total Thermal Energy Delivered/Used \(80 \times 10^9\) Btu

2. Determine Electrical Use
   a. Sum the number of kWh utilized over the last 12 months of bills:
      Total kWh 16,000,000
   b. Multiply the Total kWh by 3413 to get Btu
      Total Electric \(55 \times 10^9\) Btu

3. Determine T/P Ratio
   Divide Total Thermal (Btu) by Total Electric (Btu):
   T/P Ratio 1.46

<table>
<thead>
<tr>
<th>T/P Ratio</th>
<th>Consider Prime Mover</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 to 1.5</td>
<td>engines</td>
</tr>
<tr>
<td>1 to 10</td>
<td>gas turbines</td>
</tr>
<tr>
<td>3 to 20</td>
<td>steam turbines</td>
</tr>
</tbody>
</table>
Sizing the CHP System

- Most times size for the base thermal load (provides the highest efficiency & longest operation).
- Many commercial, institutional buildings seem to size best at ≈ 60% to 65% of peak electric demand.
- Digester Gas: Often times considered “free gas” – consider sizing for max. electricity given available volume of digester gas (selling back to utility).
### Prime Mover Recoverable Useful Heat

<table>
<thead>
<tr>
<th>RECIPIROCATING IC ENGINES</th>
<th>Capacity Range (kW)</th>
<th>Electric Generation Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 – 500</td>
<td>500 – 2,000</td>
</tr>
<tr>
<td>% of LHV of Fuel</td>
<td>24 – 28</td>
<td>28 – 38+</td>
</tr>
<tr>
<td>Heat Rate, Btu/kWh</td>
<td>14,000 – 12,000</td>
<td>12,000 – 9,000</td>
</tr>
<tr>
<td>Recoverable Useful Heat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot Water (@ 160°F), Btu/h per kW</td>
<td>4,000 – 5,000</td>
<td>4,000 – 5,000</td>
</tr>
<tr>
<td>Steam (@ 15 psig), lbs/h per kW</td>
<td>4 – 5</td>
<td>4 – 5</td>
</tr>
<tr>
<td>Steam @125 psig, lbs/h per kW</td>
<td>3-4</td>
<td>3-4</td>
</tr>
<tr>
<td>Installed Cost, $/kW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(with Heat Recovery)</td>
<td>1,800 – 1,400</td>
<td>1,400 – 1,000</td>
</tr>
<tr>
<td>O&amp;M Costs, $/kWh</td>
<td>0.015 – 0.012</td>
<td>0.012 – 0.010</td>
</tr>
<tr>
<td>NOx Emission Levels, lbs/MWH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rich Burn w/3-way catalyst</td>
<td>≈0.5 (30-40)</td>
<td>≈0.5 (30-40)</td>
</tr>
<tr>
<td>Lean Burn w/SCR treatment</td>
<td>≈0.5 (2-6)</td>
<td>≈0.5 (2-6)</td>
</tr>
</tbody>
</table>

Similar Charts Available for All other Prime Movers in Resource Guide Book
Meeting Cooling Requirements with Prime Mover Recoverable Heat

- How much absorption cooling can be delivered from a prime mover?
- How much electricity is offset by an absorption chillers?

<table>
<thead>
<tr>
<th>Capacity Range (kW)</th>
<th>Single-Effect</th>
<th>Double-Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>COP</td>
<td>0.6-0.67</td>
<td>0.9-1.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heat Source</th>
<th>Single-Effect</th>
<th>Double-Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Temperature, °F</td>
<td>180</td>
<td>350</td>
</tr>
<tr>
<td>Hot Water Flow Rate, lbs/h per RT</td>
<td>1,000</td>
<td>400</td>
</tr>
<tr>
<td>Steam Flow Rate, lbs/h per RT</td>
<td>18</td>
<td>10-11</td>
</tr>
<tr>
<td>Steam Pressure, psig</td>
<td>15</td>
<td>115-125</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Integration w/ Waste Heat from:</th>
<th>Single-Effect</th>
<th>Double-Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reciprocating engines, RT/kW</td>
<td>0.22 - 0.28</td>
<td>0.3-0.4</td>
</tr>
<tr>
<td>Combustion turbines, RT/kW</td>
<td>0.28 - 0.33</td>
<td>0.4-0.5</td>
</tr>
<tr>
<td>Microturbines, RT/kW</td>
<td>0.33 - 0.45</td>
<td>NA</td>
</tr>
</tbody>
</table>

| Average Electric Power Offset   | 0.6kW/RT      | 0.6kW/RT      |

<table>
<thead>
<tr>
<th>Installed Cost ($/RT)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>100 RT</td>
<td>1000</td>
<td>1200</td>
</tr>
<tr>
<td>500 RT</td>
<td>700</td>
<td>900</td>
</tr>
<tr>
<td>1,000 RT</td>
<td>650</td>
<td>850</td>
</tr>
<tr>
<td>2,000 RT</td>
<td>500</td>
<td>700</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>O&amp;M Costs ($/RT/yr)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>100 RT</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>500 RT- 2,000 RT</td>
<td>16-28</td>
<td>17-25</td>
</tr>
</tbody>
</table>
Step 4: Approximating System Costs

- Installed and O&M cost estimates for each CHP prime mover with heat recovery for standard installations:

<table>
<thead>
<tr>
<th></th>
<th>Installed Costs</th>
<th>O&amp;M Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reciprocating Engines</td>
<td>$1,000 to $1,800 per kW</td>
<td>$0.010 to $0.015 per kWh</td>
</tr>
<tr>
<td>Gas Turbines</td>
<td>$800 to $1,500 per kW</td>
<td>$0.005 to $0.008 per kWh</td>
</tr>
<tr>
<td>Microturbines</td>
<td>$1,000 to $2,000 per kW</td>
<td>$0.010 to $0.015 per kWh</td>
</tr>
</tbody>
</table>

- Absorption Chillers -- $500 to $1,000/RT (dependent on size)

Further Breakdown of Installation Costs Provided in the Rules-of-Thumb Tables in the Resource Guide
- **Landfill Gas and/or Biogas Cleanup**
  - Consider Moisture, Siloxanes, Hydrogen Sulfide, Carbon Dioxide
  - Can add up to 50% of the installed costs of the project
  - Energy requirements can add up to 10% of generation
  - O&M costs can add up to $0.015 per kWh generated

- **Other factors affecting installation costs:**
  - Permitting
  - Difficulty of thermal tie in
  - Difficulty of electric tie in (# of electric feeds, interconnect issues)
  - O&M costs (estimates in Resource Guide)
Step 5: Understanding Basic Economics (Sample Problem)

Determine if CHP makes sense using the facility provided numbers below and the CHP Resource Guide…

- Maximum Electric Demand – 2,500 kW
- Total Electric Consumption – 16,000,000 kWh
- Total Electric Cost - $1,280,000
- Total Natural Gas Consumption – 1,000,000 therms
- Total Natural Gas Cost - $700,000
- Operating Schedule – 8,760 hours
Steps to Solving the Problem

- Determine…
  - average electric demand
  - average price of purchased electricity
  - average natural gas consumption
  - average price of natural gas

- Then…
  - Size the CHP system (match electric and thermal loads)
  - Determine energy savings, installed costs, and simple payback
Steps to Solving the Problem

• Solution Steps…
  – Ave. hourly electric demand = 16,000,000 kWh / 8760 hrs = 1,826 kW
  – Ave. price of purchased electricity = $1,280,000 / 16,000,000 kWh = $0.080 /kWh
  – Ave. hourly natural gas consumption = 1,000,000 therms / 8760 hrs = 114 therms/hr
    = 11.4 MMBtu/hr = 11,400,000 btu/hr
  – Ave. price of natural gas = $700,000 / 1,000,000 = $0.70 /therms = $7.0 /MMBtu

• Sizing CHP System…
  – If we size the CHP system to 60% of the maximum electric demand (1,500 kW), how much heat can we recover?
    • 1,500 kW * 4,500 btu/hr/kW = 6,750,000 btu/hr
    • This recoverable heat amounts to 74% of the total heat load, therefore, this is an acceptable and conservative match for the electric and thermal load
Steps to Solving the Problem

- **Annual Energy Generation…**
  - Annual Electric Generation = 1,500 kW * 8,760 hrs = 13,140,000 kWh
  - Annual Thermal Generation = 6.75 MMBtu/hr * 8760 hrs = 59,130 MMBtus
  - Annual Fuel Consumed = 13,140,000 kWh * 3413 Btu/kwh / 32% (LHV) / 0.905 = 154,858,000,000 btus = 154,858 MMBtus

- **Annual Energy Revenue…**
  - Electric Revenue = $0.080 /kWh * 13,140,000 kWh = $1,051,200
  - Thermal Revenue = 59,130 MMBtus / 80% * $7.0 /MMBtu = $517,388

- **Annual Energy Expenses…**
  - Fuel Expenses = 154,858 MMBtus * $7.0 /MMBtu = $1,084,005
  - O&M Costs = 13,140,000 kWh * $0.011 /kWh = $144,540
  - Standby Charge = $3 /kW installed * 1,500 kW * 12 months = $54,000
Steps to Solving the Problem

- Total Revenue = $1,051,200 + $517,388 = $1,568,588
- Total Expenses = $1,084,005 + $144,540 + $54,000 = $1,282,545
- Total Savings = $286,043

- Installed Costs = 1,500 kW * $1,200 /kW = $1,800,000

- Simple Payback = $1,800,000 / $286,043 = 6.3 years
Considerations of Example Problem

- What is this solution telling me?
- What other factors need to be considered?
  - Credit for backup generation, carbon credits, government grants, etc.

**Energy Price Sensitivity Analysis**
- 10% electric increase = 4.6 year payback
- 20% electric increase = 3.6 year payback
- 10% natural gas increase = 7.8 year payback
- 20% natural gas increase = 10.4 year payback
- 10% elec & 10% nat gas increase = 5.4 year payback

- What would be the next step?
Summary: When Looking at your Facility

- Is there a use for the CHP waste/recycled heat?
- Is there a major rehab or thermal equipment change planned?
- Is there sufficient “spark spread”?
- Identify size and type prime mover to meet thermal requirements (high efficiency).
- Will the selected configuration provide adequate waste heat levels for heating and/or cooling?
- Are there potential installation issues – estimate installation costs?
- What do basic economics look like?
- Is the application worth pursuing with a formal analysis?
- Make use of the CHP Resource Guide Book

- Get more info at [www.chpcentermw.org](www.chpcentermw.org)

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Questions / Discussion