MIDWEST CHP APPLICATION CENTER
In Partnership with the US DOE

UIC
University of Illinois at Chicago

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

U.S. DOE Industrial Technologies Program
Webcast Series
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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

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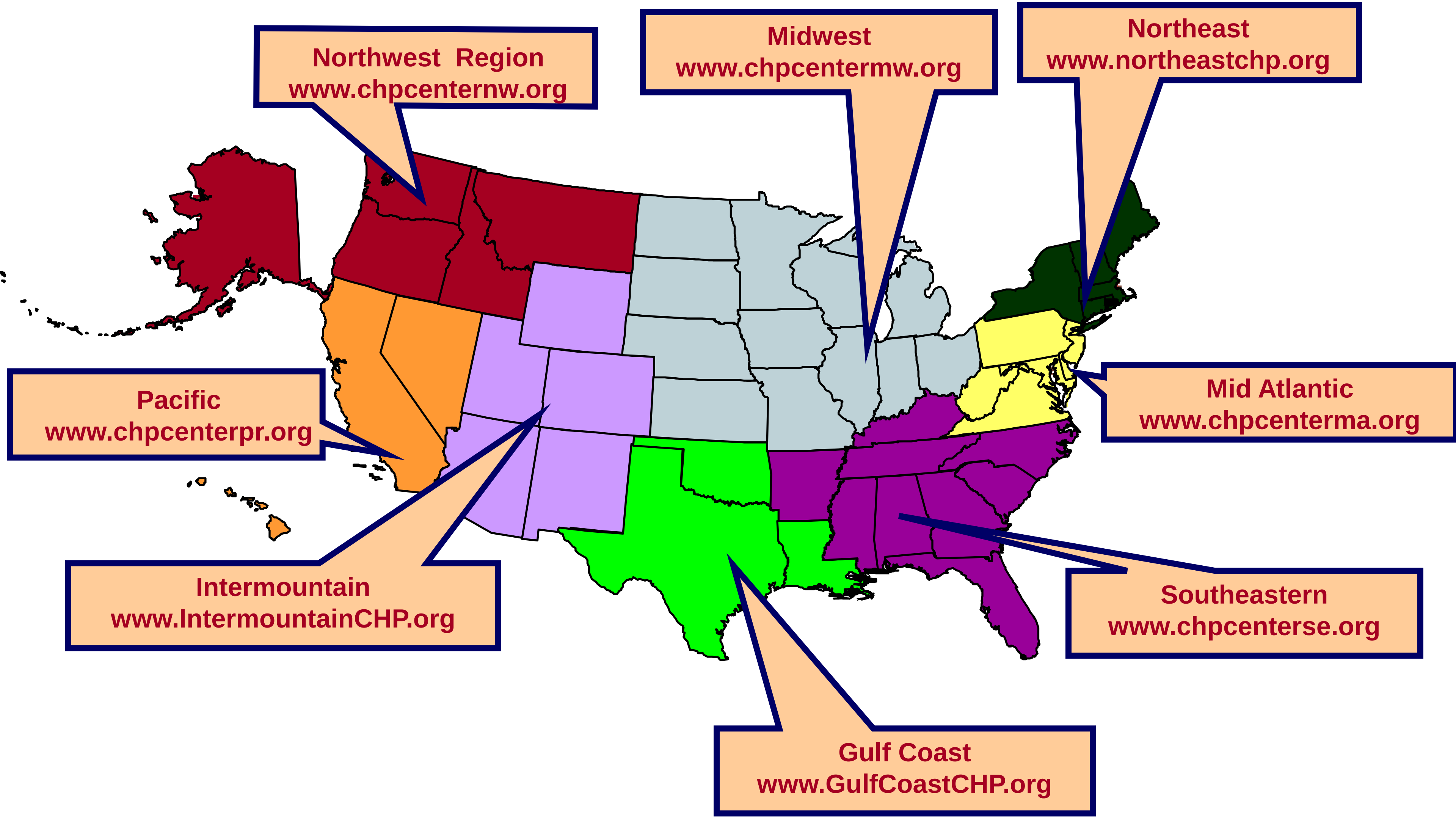

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CHP Decision Making Process

Presented by

Ted Bronson

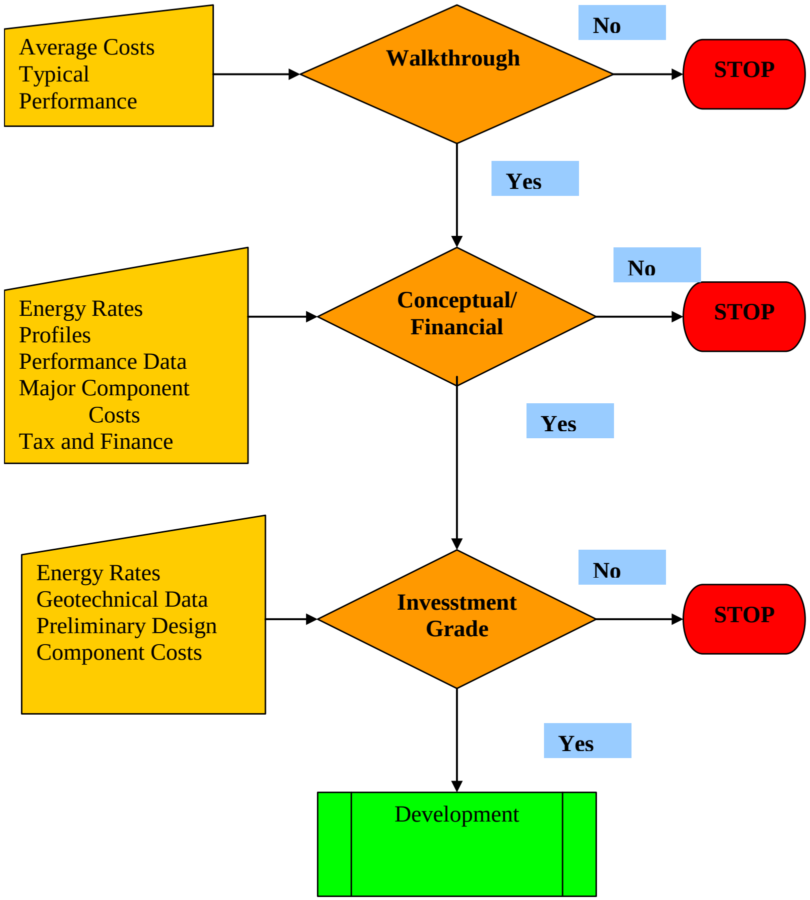
&

Joe Orlando

Webcast Series

January 8, 2009

CHP Regional Application Centers



Levels of CHP Site Assessments

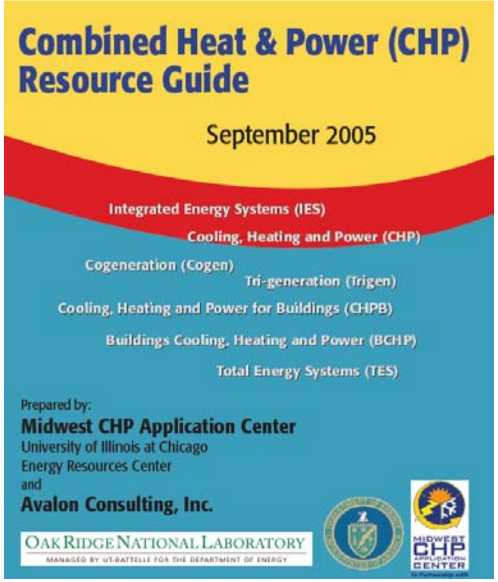
- Questionnaire: (overly simplistic)
- Level 1: Screening Analysis
  - 1 to 2 day effort by a Regional Application Center
  - Computer model and/or spread sheet analysis
  - 30% to 50% accurate
- Level 2: Conceptual/Financial Analysis
  - 1 to 3 week effort (depending on size/complexity)
  - Computer 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



Combined Heat & Power (CHP) Resource Guide

September 2005

Integrated Energy Systems (IES)
Cooling, Heating and Power (CHP)
Cogeneration (Cogen)
Tri-generation (Trigen)
Cooling, Heating and Power for Buildings (CHPB)
Buildings Cooling, Heating and Power (BCHP)
Total Energy Systems (TES)

Prepared by:
Midwest CHP Application Center
University of Illinois at Chicago
Energy Resources Center
and
Avalon Consulting, Inc.

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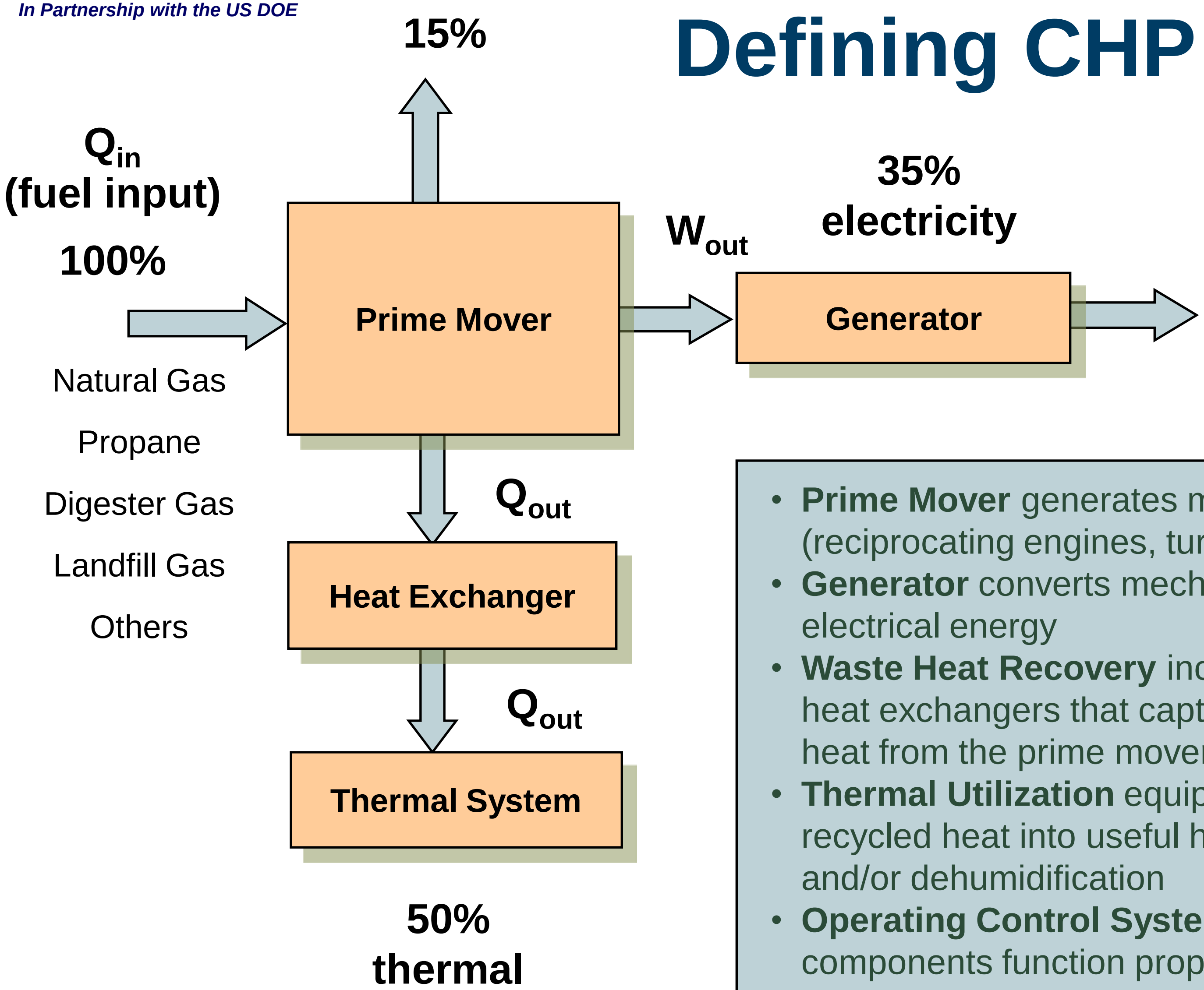
Resource Guide Available for download at

www.chpcentermw.org/pdfs/Resouce_Guide_10312005_Final_Rev5.pdf

Defining CHP Concept

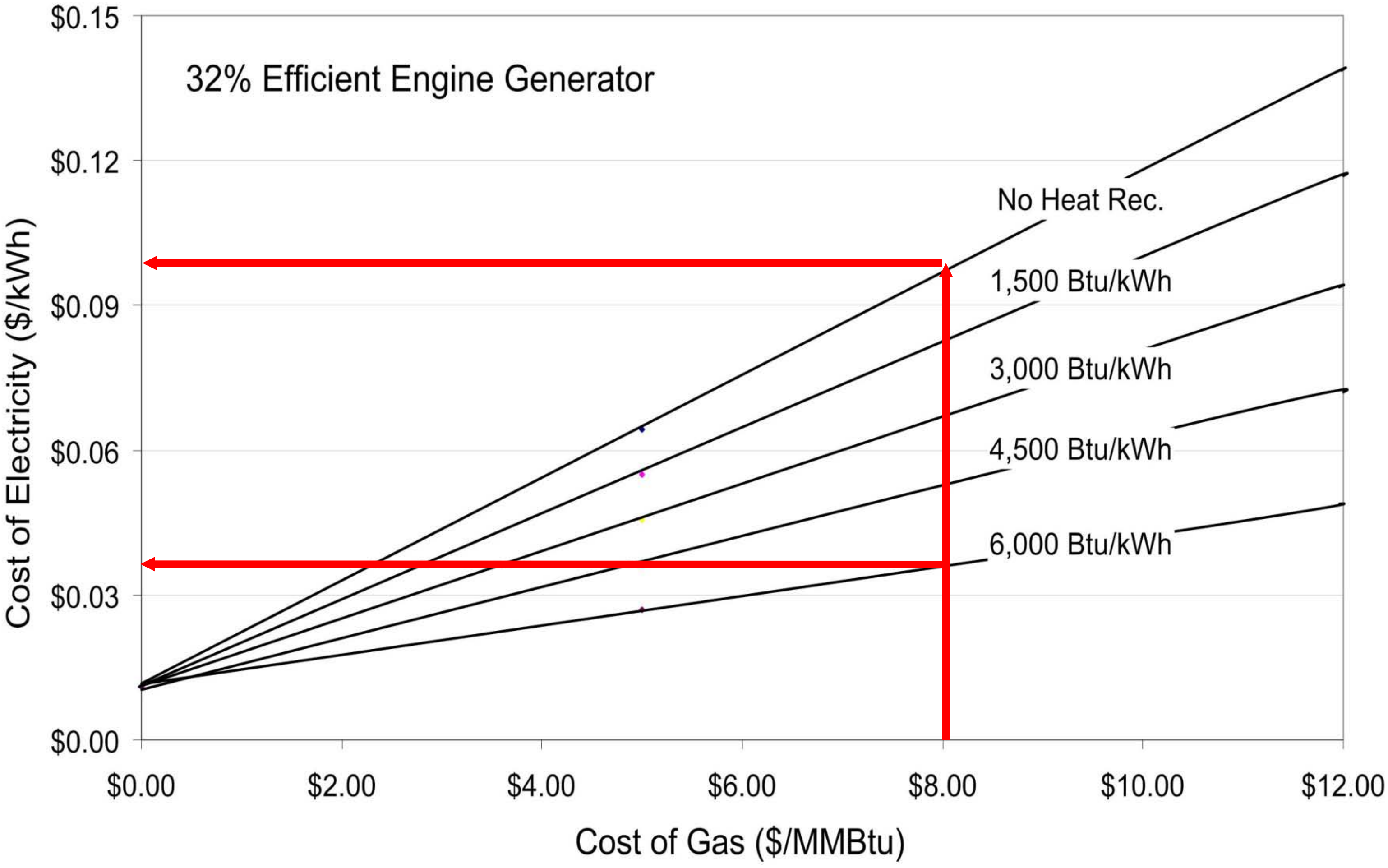


- **Prime Mover** generates mechanical energy (reciprocating engines, turbines, fuel cells)
- **Generator** converts mechanical energy into electrical energy
- **Waste Heat Recovery** includes one or more heat exchangers that capture and recycle the heat from the prime mover
- **Thermal Utilization** 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



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

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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.	a. **Sum** the total cost for gas from the last 12 months of bills: **Total Cost**	$	700,000	
b.	b. **Sum** the number of Therms utilized over the last 12 months of bills: **Total Therms**		1,000,000	Therms
c.	c. **Divide** the Total Cost by the Total Therms: **Average Annual Gas Cost**	$	0.70	/Therm
d.	d. **Multiply** the **Average Annual Gas Cost** ($/Therms) 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
	Spark Spread	$	16.44	
4.	**Is the "Spark Spread" >$12/MMBtu? Yes / No**		**Yes** No	

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

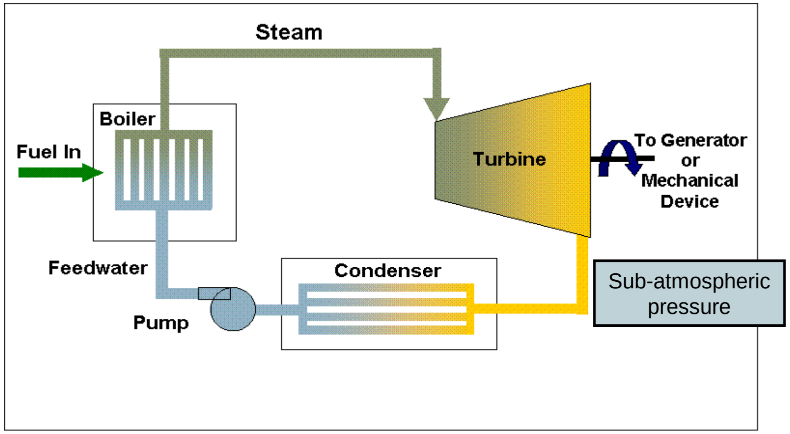
- **Reciprocating Internal Combustion Engines:**
  - Most common for CHP <5 MW
  - Good for hot water/low pressure steam applications

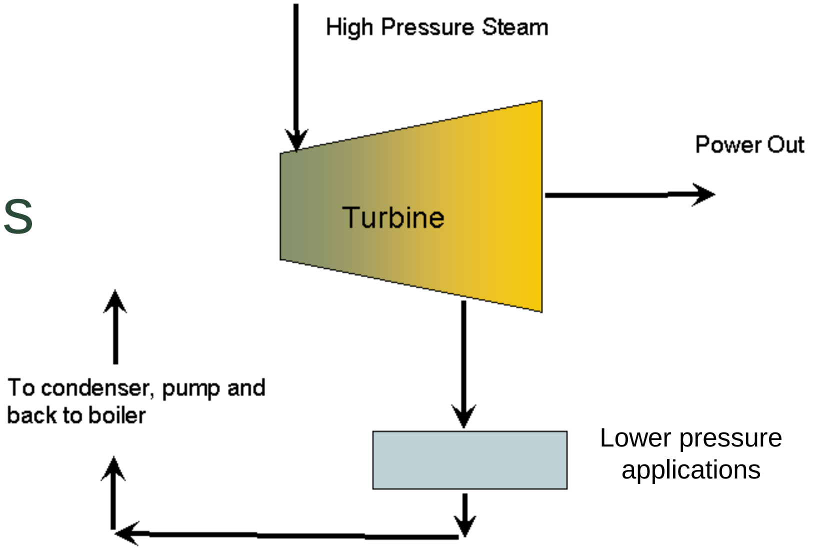
- **Gas Turbines (Combustion Turbines)**
  - Generally used for larger applications (>4MW) where a lot of high pressure steam is required per unit of electric power

- **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	Therms
b.	**Multiply** the **Total Therms** by 100,000 to get Thermal Btu: **Total Thermal Energy Purchased**	$100 * 10^9$	Btu
c.	**Multiply** the **Total Thermal Energy Purchased** by Boiler/Equipment Efficiency (typically 0.8) **Total Thermal Energy Delivered/Used**	$80 * 10^9$	Btu
2. Determine Electrical Use			
a.	**Sum** the number of **kWh** utilized over the *last 12 months* of bills: **Total kWh**	16,000,000	kWh
b.	**Multiply** the **Total kWh** by 3413 to get Btu **Total Electric**	$55 * 10^9$	Btu
3. Determine T/P Ratio			
	Divide Total Thermal *(Btu)* by **Total Electric** *(Btu):* **T/P Ratio**	1.46	

If **T/P =**	
0.5 to 1.5	Consider ***engines***
1 to10	Consider ***gas turbines***
3 to 20	Consider ***steam turbines***

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).

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Prime Mover Recoverable Useful Heat

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

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?

ABORPTION CHILLERS (LiBr-H_2O)

Capacity Range *(kW)*	Single-Effect	Double-Effect
COP	0.6-0.67	0.9-1.2
Heat Source		
Minimum Temperature, °F	180	350
Hot Water Flow Rate, lbs/h per RT	1,000	400
Steam Flow Rate, lbs/h per RT	18	10-11
Steam Pressure, psig	15	115-125
Integration w/ Waste Heat from:		
Reciprocating engines, RT/kW	0.22 - 0.28	0.3-0.4
Combustion turbines, RT/kW	0.28 - 0.33	0.4-0.5
Microturbines, RT/kW	0.33 - 0.45	NA
Average Electric Power Offset	0.6kW/RT	0.6kW/RT
Installed Cost *($/RT)*		
100 RT	1000	1200
500 RT	700	900
1,000 RT	650	850
2,000 RT	500	700
O&M Costs *($/RT/yr)*		
100 RT	30	30
500 RT- 2,000 RT	16-28	17-25

Step 4: Approximating System Costs

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

	Installed Costs	O&M Costs
Reciprocating Engines	$1,000 to $1,800 per kW	$0.010 to $0.015 per kWh
Gas Turbines	$800 to $1,500 per kW	$0.005 to $0.008 per kWh
Microturbines	$1,000 to $2,000 per kW	$0.010 to $0.015 per kWh

- 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

  www.chpcentermw.org/pdfs/Resouce_Guide_10312005_Final_Rev5.pdf

- Get more info at www.chpcentermw.org

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Questions / Discussion