



# Combined Heat and Power for Commercial Buildings: Best Practices and Pitfalls

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# Acknowledgements

- Much of this material was developed while the presenter was employed with the US EPA's Combined Heat and Power Partnership ([www.epa.gov/chp](http://www.epa.gov/chp)) and in collaboration with our industry Partners, the US Department of Energy (DOE), the US Clean Heat and Power Association and other CHP stakeholders.
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# What We Will Cover

- Energy Supply and Distributed Generation
- CHP Basics: Applications and Technologies
- Benefits of CHP Efficiency
- The Project Development Process, Conceptual Design and Economics
- Theory into practice: CHP market penetration and the relevance of Cx for CHP



# Energy Supply: Characteristics of the Grid and Central Station Generation (eGrid 2007)

- By 2<sup>nd</sup> law of thermodynamics, over half of all energy input (fuel) to produce power is converted to waste heat.
  - Central Station Efficiency – barely changed in 100 years
    - 31.1% US Average
    - 30.5% CA average
    - 39.5% Combined cycle
- CO<sub>2</sub> emissions are the result of combustion of fossil fuels
  - Central Station CO<sub>2</sub> Emissions
    - 183 lb/ CO<sub>2</sub>/ MMbtu US average
    - 122 lb/ CO<sub>2</sub>/ MMbtu CA average (mostly natural gas, not coal)
    - 117 lb/ CO<sub>2</sub>/ Mmbtu Combined cycle
- Grid Characteristics – barely changed in 100 years
  - Line losses = 5 – 20 % of energy AFTER conversion losses depending on distance of transmission/ distribution. Rule of thumb for estimating line losses ~ 8% = CO<sub>2</sub>.



# The Role for Distributed Generation (DG) in the Clean Energy Economy

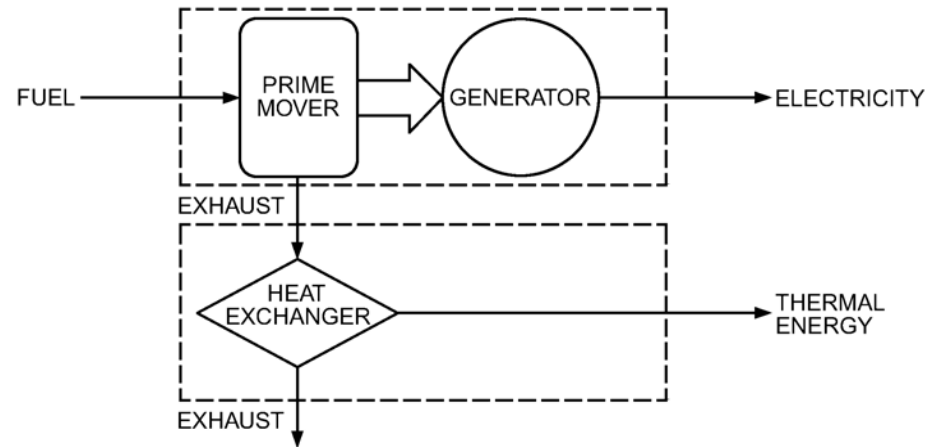
- Also called decentralized energy (DE) or distributed energy resources (DER)
- Benefits
  - Eliminate line losses by siting electricity generation close to load.
  - Avoid costly central station or transmission investments for smaller local load growth or grid congestion pockets.
  - Increases reliability and energy security through diversifying resources.
  - Ability to make use of renewable fuels where they are found tied to energy consuming buildings/ processes
  - An essential element of “zero energy buildings”
- Potential for CHP with combustion-based DG – dramatically increase efficiency of energy generation by recovering free waste heat!



# Combined Heat and Power Basics

CHP is a highly efficient energy system that:

- Is located at or near a building/facility
- Generates electrical and/or mechanical power
- Recovers waste heat for
  - heating
  - cooling
  - dehumidification
- Can utilize a variety of technologies and fuels
  - Fossil fuels
  - Biomass (wood, wood waste, ag. residue, crop plants)
  - Biogas

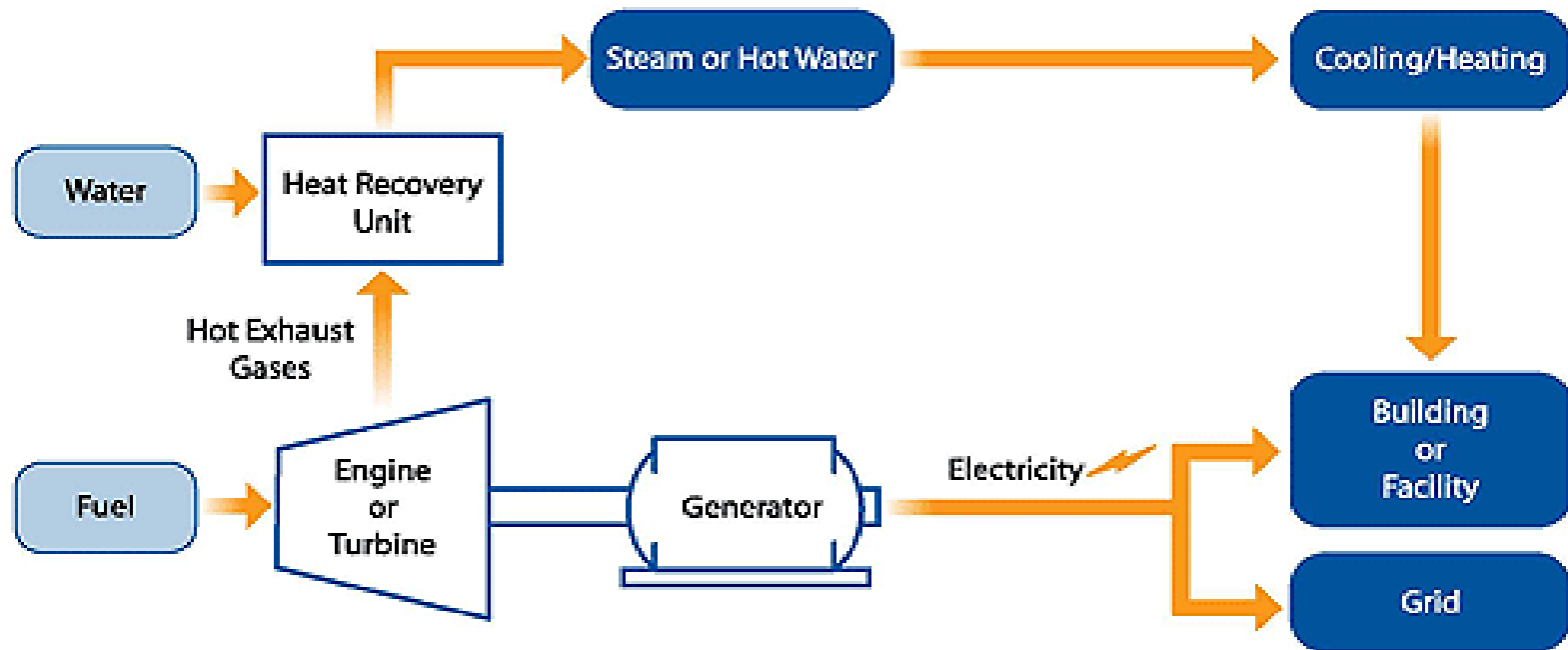


# What is CHP?

- Also called cogeneration, trigeneration, Combined Cooling, Heating and Power (CCHP), Building Cooling Heating and Power (BCHP), Recycled energy.
- It's all about thermal utilization – use heat as heat to avoid losses from throwing it away or converting it to higher quality energy (electricity).
- To utilize heat, must be located close to the heat load to avoid losses.
  - Used as HHW, DHW, Steam, CW
  - Offsets boilers, chillers
  - Thermal base loading as best practice design for high efficiency.
- Types
  - Merchant plants, utility scale (IPPs)
  - District energy systems (campuses, cities)
  - **Customer-sited, within-the-fence and wheeling**
  - Renewably fueled (biomass and biogas)
  - Waste heat driven systems, bottoming cycle (industrial)



# Typical CHP System for Commercial or Institutional Applications

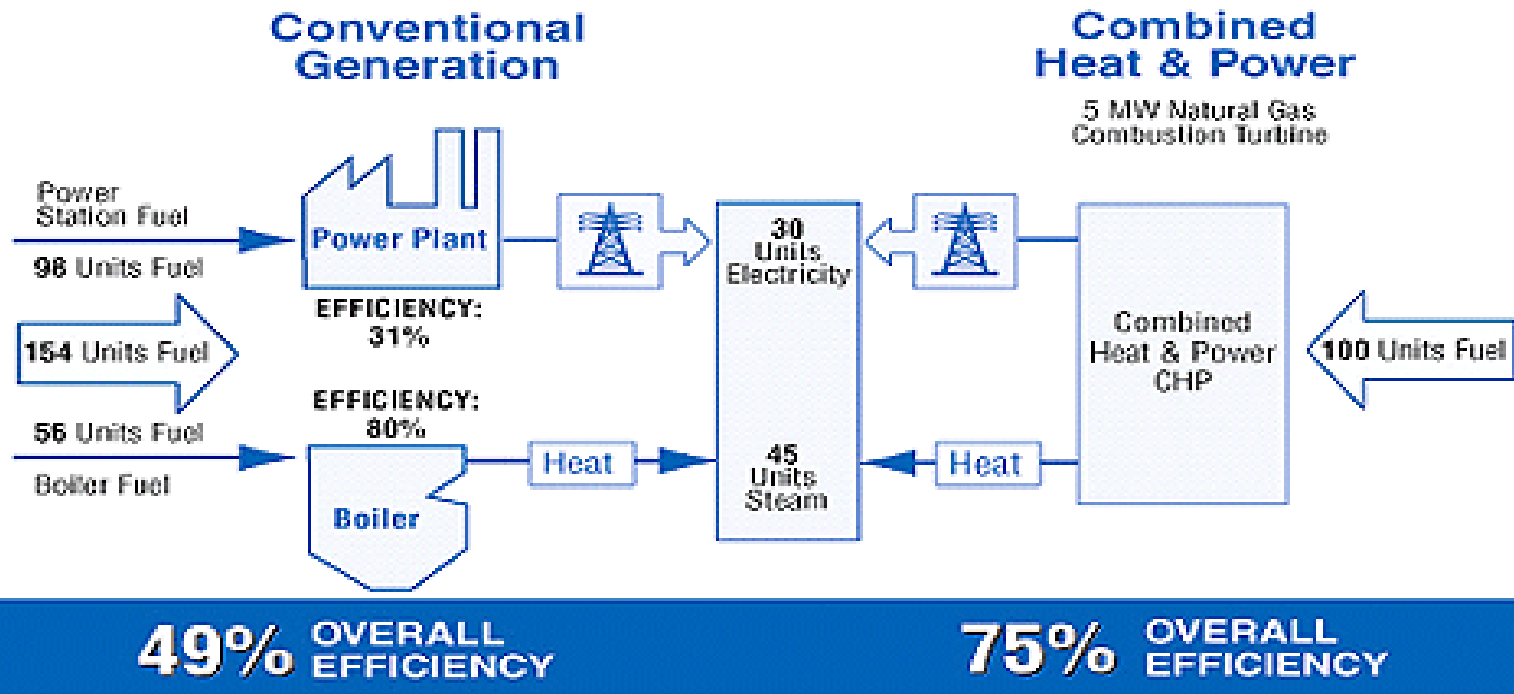


# CHP Technologies – Ready for Primetime?

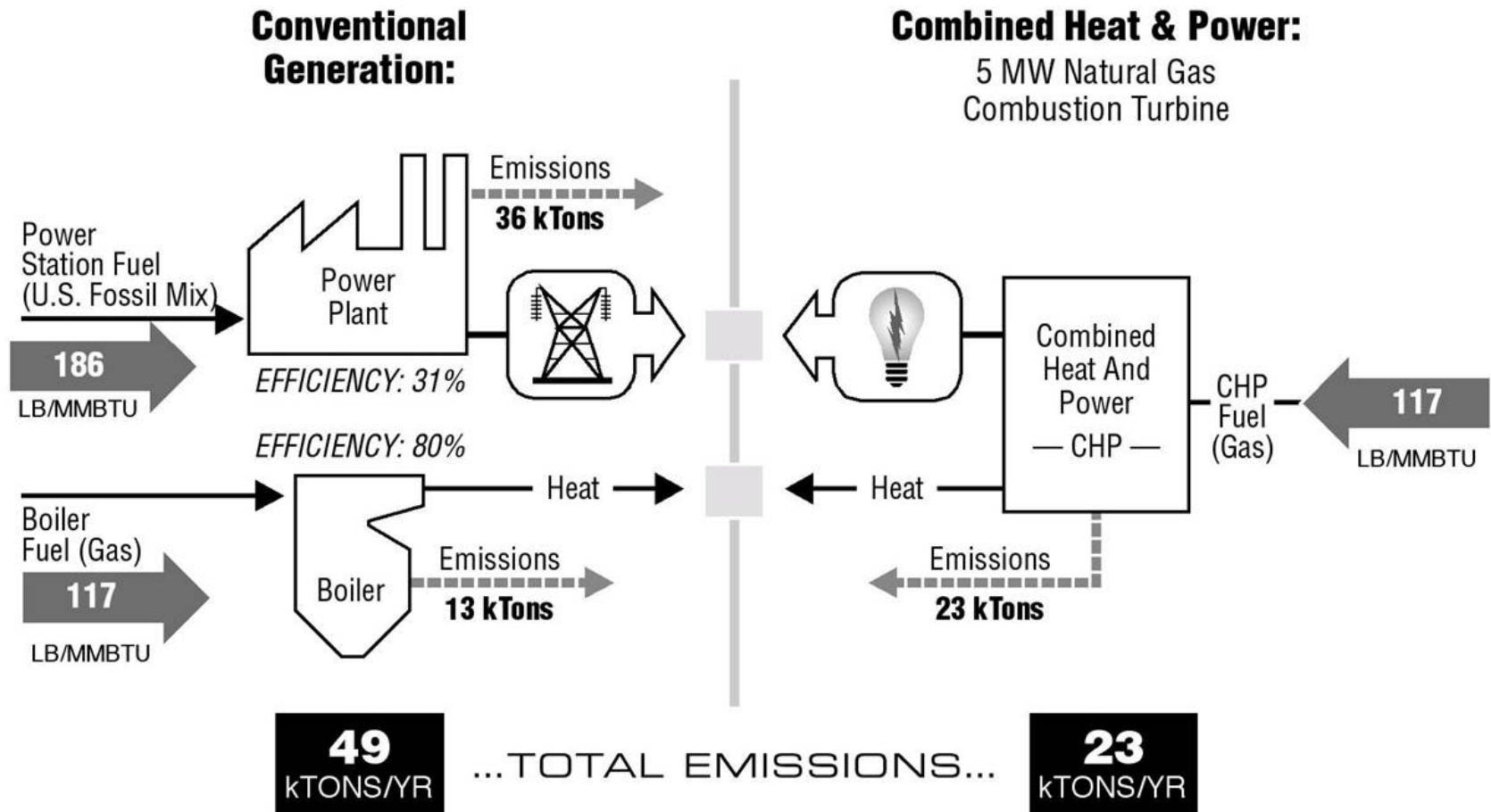
- Turbines, micro-turbines, engines, boilers are fully commercial/proven with > 95% availability. All available from multiple manufacturers.
- Fuel cells and gasifiers are becoming commercialized now. Some products available.
- Heat recovery/ thermal technologies are commercial ie, HRSGs, heat exchangers, absorption/adsorption chillers, thermally-activated dessicants.
- Controls & switchgear are fully commercial and enable remote operation, safety and flexibility in grid connection or island operation.
- Pumps, fans, heat dump radiators, cooling towers, gas compressors all standard equipment.



# CHP System Efficiency Compared to Separate Heat and Power



# Environmental Benefits of CHP: CO<sub>2</sub> Emissions Reductions



# CHP Industry Practices: The Project Development Process

- Where the rubber hits the road – the opportunity to put theory into practice through fallible human intelligence and market channels.
- For CHP projects, it takes a village
  - multiple owner/operator reps, financier, engineers, architects, contractors, multiple permitting authorities, gas and electric utilities, nimby neighbors.
  - Some required participants may not be friendly.
- Cx and RCx approaches and practices have a role could help reduce risk and downtime substantially.



# Qualifying: Basic Economics of CHP

- Spark spread – cost of fuel vs power
- Assuming 100% thermal utilization and anecdotal thermal load info only

<b>Gas Turbine CHP</b>	
Net CHP Power, MW	10
Unfired HRSG Steam Output, lb/hr	57,000
Total Thermal Output to Process, Btu/kWh	5,700
<b>CHP Cost to Generate Power Estimator</b>	
Operating Assumptions	
CHP Electric Efficiency, %	28.0%
CHP Fuel, Btu/kWh	12,186
Thermal Output, Btu/kWh	5,700
CHP Power to Heat Ratio (no duct burner)	0.60
Displaced Thermal Efficiency	80.0%
Thermal Utilization, %	100.0%
Incremental CHP O&M Costs, \$/kWh	\$0.0100
CHP Fuel Cost, \$/MMBtu	\$8.00
Displaced Thermal Fuel Cost, \$/MMBtu	\$8.00
Operating Cost to Generate	
CHP Fuel Costs, \$/kWh	\$0.0975
Thermal Credit, \$/kWh	(\$0.0570)
Incremental O&M, \$/kWh	\$0.0100
<i>Operating Costs to Generate Power, \$/kWh</i>	<i>\$0.0505</i>

Avg. retail cost of power to C&I consumers in CA

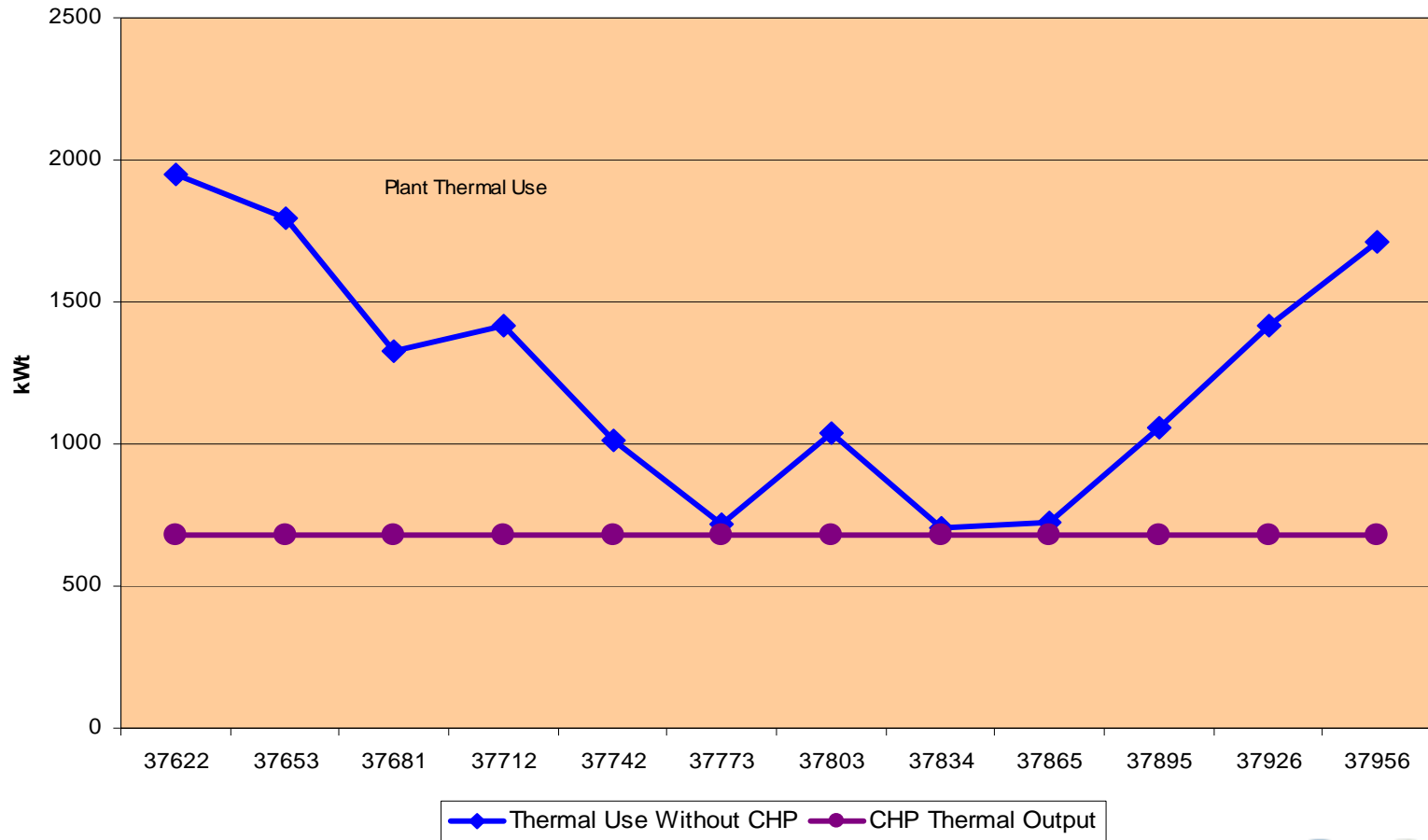
~ \$.125

Taking credit for use of free heat and offset boiler fuel, CHP cost to generate power in this example ~ \$.05



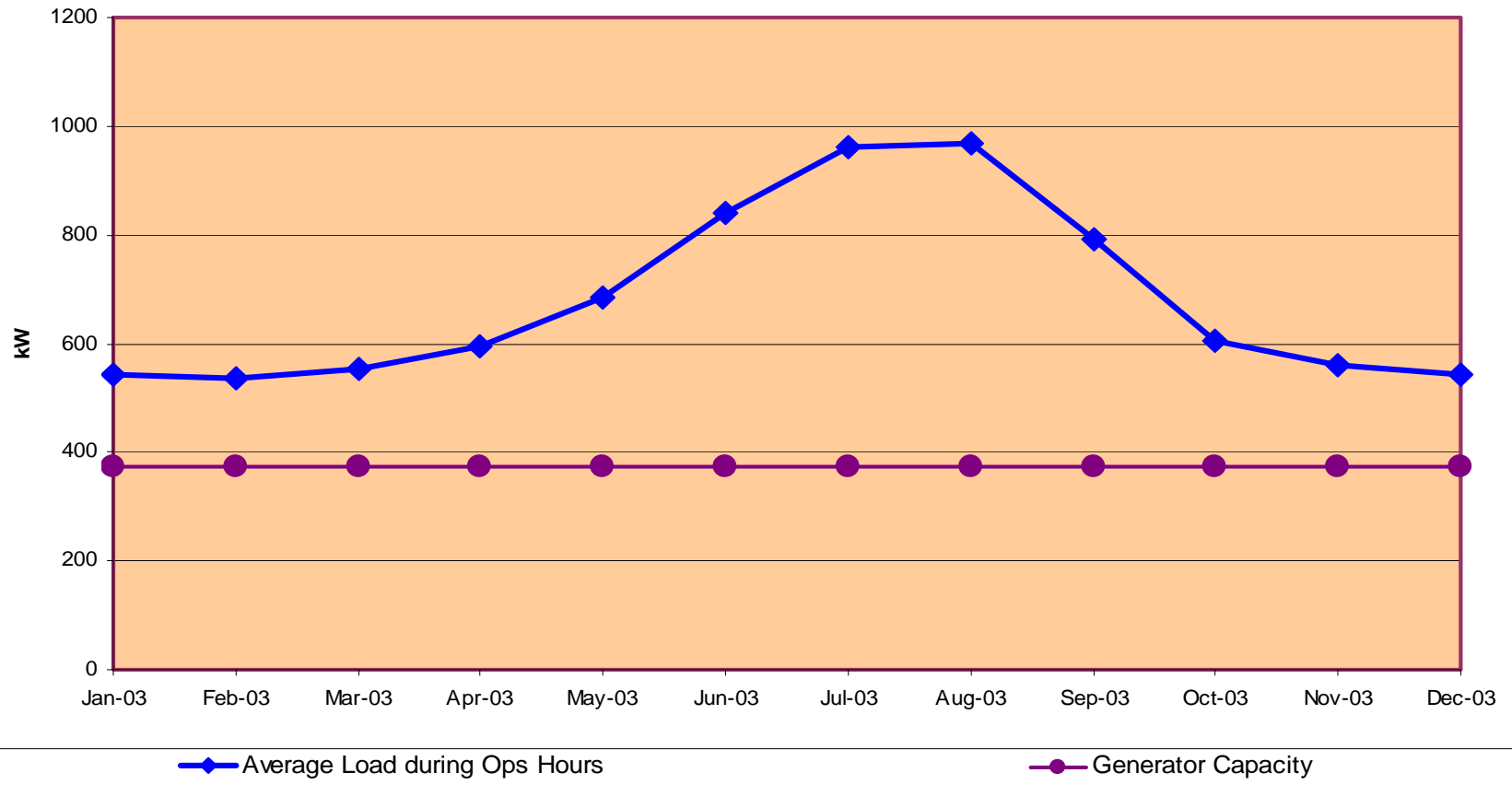
# Efficient CHP: Thermal Base-loading

## CHP Thermal Output vs. Thermal Demand



# Efficient CHP: Electrical Base-loading

## Average Electric Load



# Conceptual Design and Analysis

- Prime mover type and size (kW) based on power to heat ratio of prime mover matched to load profiles
- Operating hours at full or part loads – optimize with rate analysis
- Thermal application(s) and equipment, peripherals.
- Configured for reliability/ island operation?
- Location of system, tie-ins, changes to facility if any
- Operation and maintenance costs
- Turnkey system capital costs and cost of money



# Costs and Benefits are Site Specific

- Realistic turnkey pricing ranges:
  - Under 2 MW: \$1,600 – \$3,000/ kW
  - 2-10 MW: \$1,100 – \$2,500/ kW
  - Over 10 MW: \$ 700 - \$1,500 / kW
- A small, economically feasible 120 kW CHP system in a mid-size hotel could cost between \$180,000 - \$360,000 and provide \$50,000 - \$125,000/ yr in energy savings if operated 24/7.



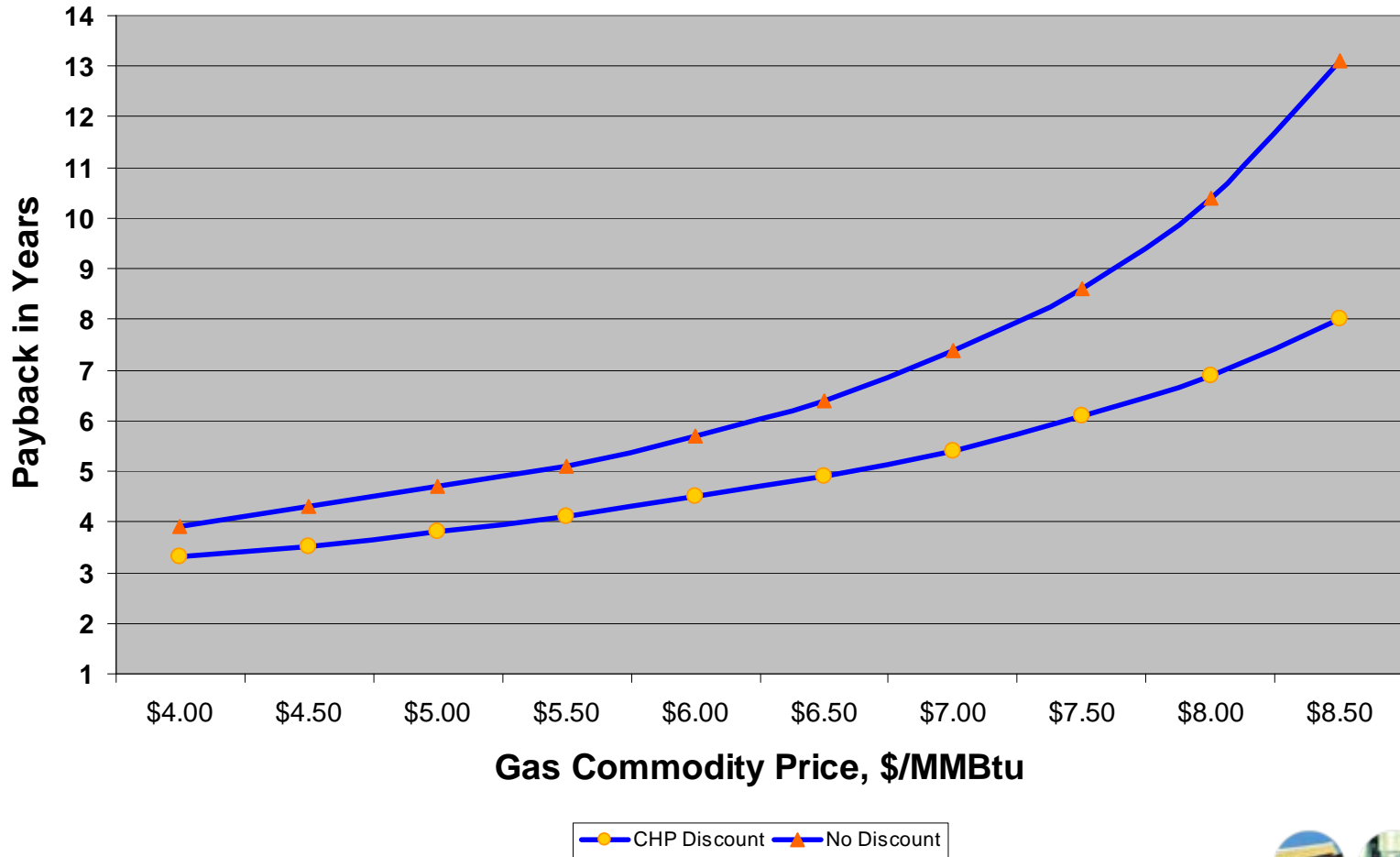
# Economic Effect of Externalities

## Grant Me the Serenity.....

- Barriers – uncontrollable negative externalities
  - Corporate power purchase agreements which require 100% subscription
  - Utility or regulatory policies which prevent or hamper on-site power
  - If externalities prevent CHP, halt efforts until these change.
  - If externalities hamper CHP, budget costs of overcoming them into Level 1 analysis
- Rate and Incentive Sensitivity Analysis
  - Offset electricity rates and fuel costs (spark spread) largest impact on economics.
  - Both existing and projected post-CHP electric & gas rates should be researched and documented.
  - Include sensitivities for disincentives (exit fees, standby rates, etc) and incentives (favorable gas rates, environmental revenue streams, grants etc)

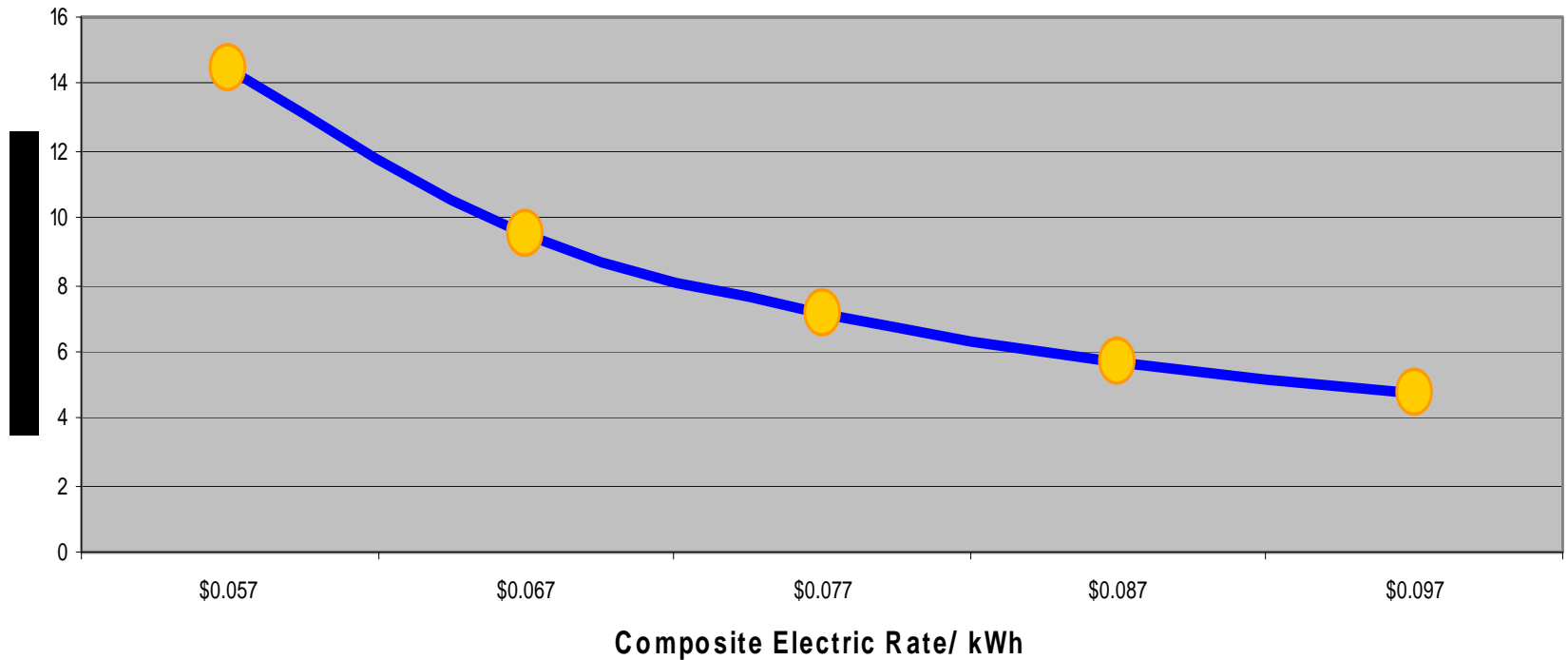


# Sensitivity of Payback to Gas Price and Gas Incentives – PG&E



# Electric Rate Cost Sensitivity Analysis

## Electric Rate Sensitivity



# Level 2 (Investment Grade) Analysis: the Solution

- Goal is to replace all assumptions in Level 1 analysis with verified data.
- All project/ owner goals should be identified prior to this stage.
- All information for investment decision should be provided by this analysis.
- Level of effort should go to ~ 30% design to ensure system pricing is accurate.



# Procurement

- Construction
  - Design/ bid/ build
  - Turnkey
- Financing – risk/ reward balance
  - Owner capitalization
  - Leasing
  - 3<sup>rd</sup> Party Build/ Own/ Operate
- Contract negotiation may include
  - Permitting responsibility
  - Application for grants and incentives
  - Ownership of environmental benefits/ RECs
  - Power purchase agreements
  - Commissioning
  - Monitoring & control
  - Service & maintenance
  - Fuel purchase
  - Schedule and cost



# CHP Installed in the U.S.

- 85,184 MW at 3,364 sites
- 23,115 MW at 955 sites new since 2000.
- Average capacity is 25.3 MW
- Median capacity is 1.5 MW
- Represents about 9% of total U.S. generating capacity
- Saves over 3 quads of fuel each year!
- Eliminates over 400 million tons of CO<sub>2</sub> emissions each year!



# CHP Applications by Commercial Sector in CA

Application	Number of Sites	Capacity, MW	Avg Size, kW	Technologies
Schools	110	8.6	78	Recip Engines, Microturbines
Laundries	64	1.1	17	Recip Engines
Hotels	63	28.9	459	Recip Engines, Microturbines, Fuel Cells
Health Clubs	46	6.2	135	Recip Engines, Microturbines
Colleges	45	269	5,978	Gas Turbines, Recip Engines
Hospitals	42	170.1	4,050	Gas Turbines, Recip Engines, Boiler/Steam
Office Buildings	41	34.1	832	Recip Engines, Microturbines, Fuel Cells
Waste Water Treatment	30	108.7	3,623	Recip Engines, Gas Turbines, Microturbines
Apartments/Condos	24	1.6	67	Recip Engines, Microturbines
Nursing Homes	16	4.9	306	Recip Engines

Source: EEA



# CHP Theory Put Into Practice: Relevance of Cx for CHP

- Many in the CHP industry are experts in products or systems, not integration, operation or building performance.
- CHP developers may not use best practices in diagnosis of baseline HVAC operations, resulting in oversized or misapplied CHP systems, loss of efficiency, reduced or non-existent economic and environmental benefits.
- Errors in designing or executing well-integrated system with existing HVAC, controls or electrical systems.
- Challenges in coordinating multiple disciplines, complex project teams, potentially adversarial external stakeholders.
- Lack of protocols for commissioning of CHP systems
- All will be seen in our next presentation of CHP Cx case studies.



# Thank You for Your Interest

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