CHP Principles – A Case Study

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Presentation Goals

- Share experiences with CHP feasibility in Massachusetts
- Provide brief review of CHP technology as it relates to feasibility of current projects
- Describe CHP incentives and associated requirements
- Discuss characteristics of good CHP candidates (technical and economic)
- Present two case studies in CHP feasibility

Good Candidates for CHP

- Facilities with long operating hours
- Facilities with consistent thermal loads
- Facilities where electric and thermal energy can be used locally
- Examples: hospitals, universities, hotels, prisons, natatoriums, airports, facilities with central heating plants, and industrial processes (such as paper mills, breweries, food processing)

Screening Potential Sites

- Quick screening – the first step
  - Monthly bills + operating hours
  - Basic central plant type
  - Determine average loads (“best case”)
  - Determine probable size range (kW)

Detailed Feasibility Studies

- Required for utility incentive
- Provided by utility-approved consultants
- Avoid conflict of interest with equipment vendors sizing CHP installations
- Investment-grade studies should include:
  - Hourly modeling of electric and thermal loads
  - Comparison of multiple unit sizes/ technologies
  - Sensitivity analysis w.r.t. utility costs

How long is this going to take and how much is it going to cost?

- Key factors:
  - Size of facility/potential CHP installation
  - Effort required to model thermal loads
    - What data is available (trend logs)?
    - What are you going to have to meter?
    - What are you going to have to model (software)?
  - Quantity and type of CHP systems to be analyzed
- $10 – 25+k, 1 – 6 months

Technologies

- Focusing on natural gas fired prime movers
  - Reciprocating engines
    - Turbo-charged or naturally aspirated
    - Rich burn or lean burn
  - Conventional gas turbines
  - Microturbines

Technologies by size

- Reciprocating engines
  - Smaller applications (under 1 MW)
- Conventional gas turbines
  - Larger applications (1 MW and up)
- Microturbines
  - Multi-module installations provide sizing flexibility (65 kW and 200 kW modules)

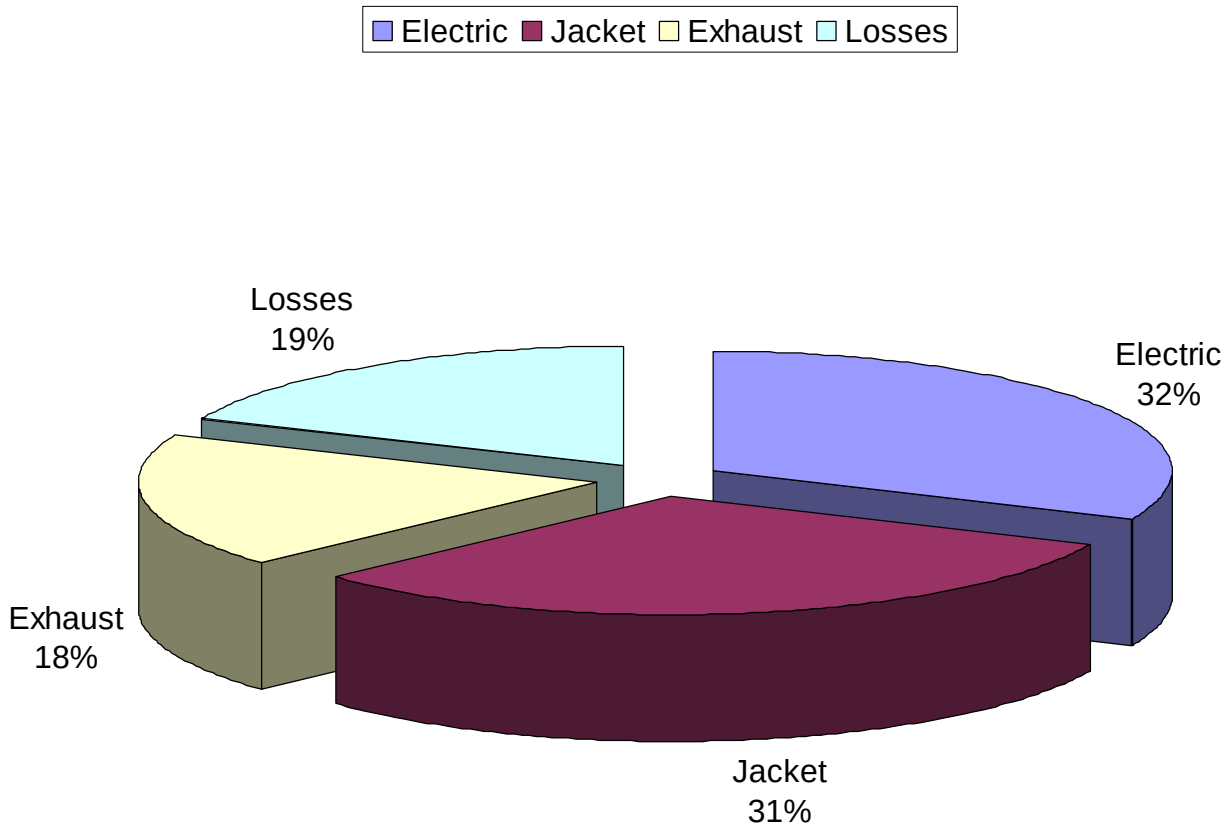
Mechanical Efficiencies (HHV-based)

- Reciprocating engines: upper 20%'s
  - Exhaust temp:
    - Rich burn: 900 – 1000°F
    - Lean burn: 800 – 900°F
- Microturbines: 30%
  - Exhaust temp: 540°F
- Conventional gas turbines: low 20%'s
  - Exhaust temp: 800 – 1000°F

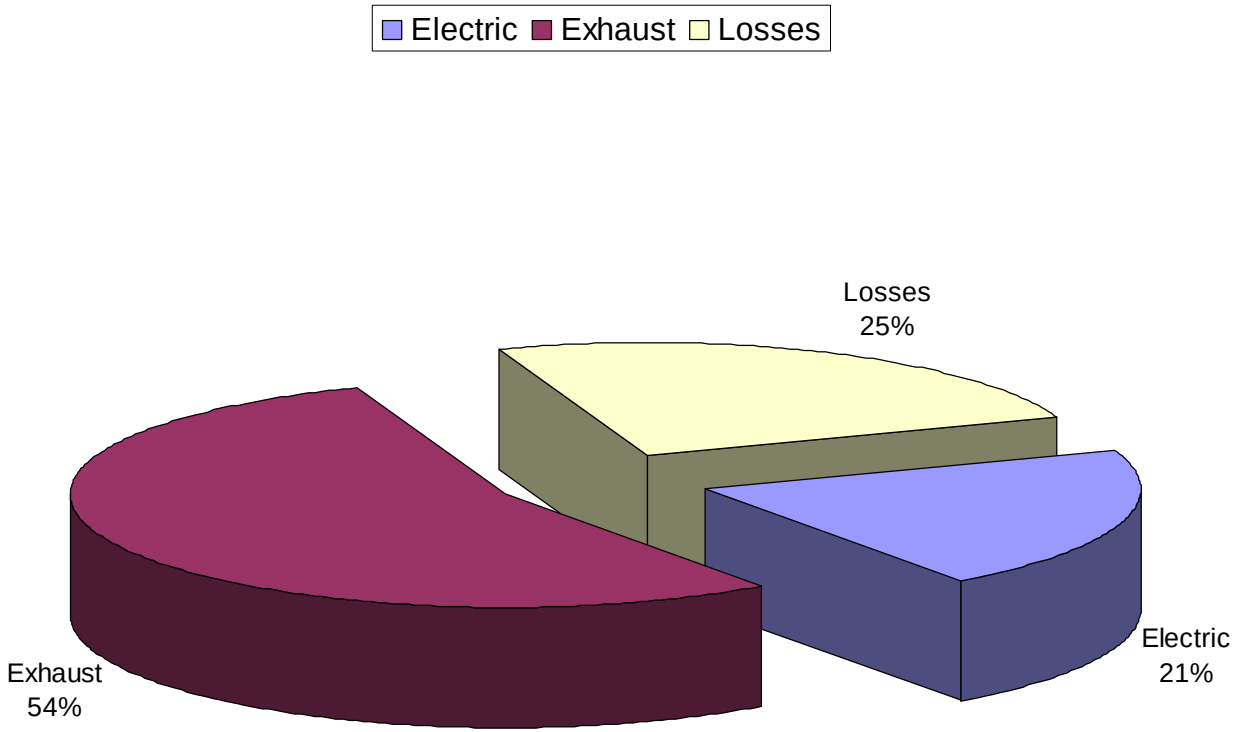
Steam vs. Hot Water

- Overall efficiency of CHP limited by lowest grade of displaceable heat
  - Low temp hot water is most efficient
  - High pressure steam is least efficient
- Exhaust gas – high temp (500 – 1000°F)
- Engine coolant – medium temp (180 – 240°F)
- Intercooler, oil cooler – low temp (<130°F)

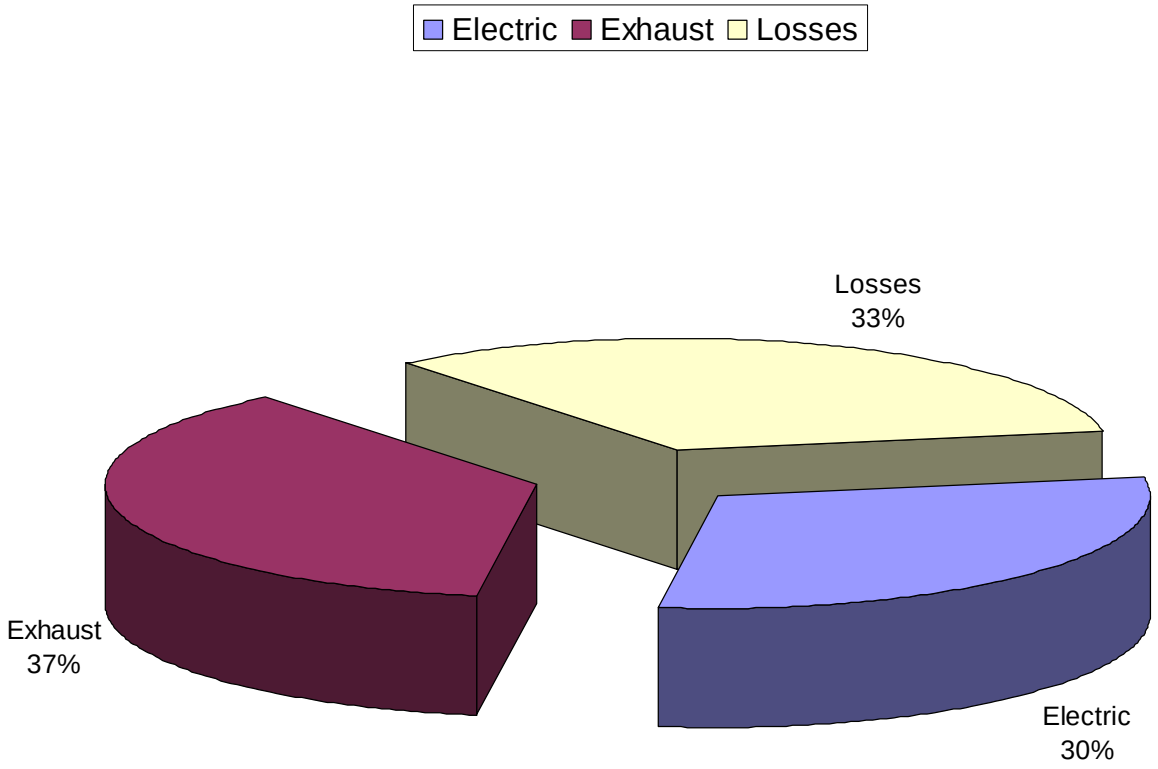
Typical Outputs for Recip Engine



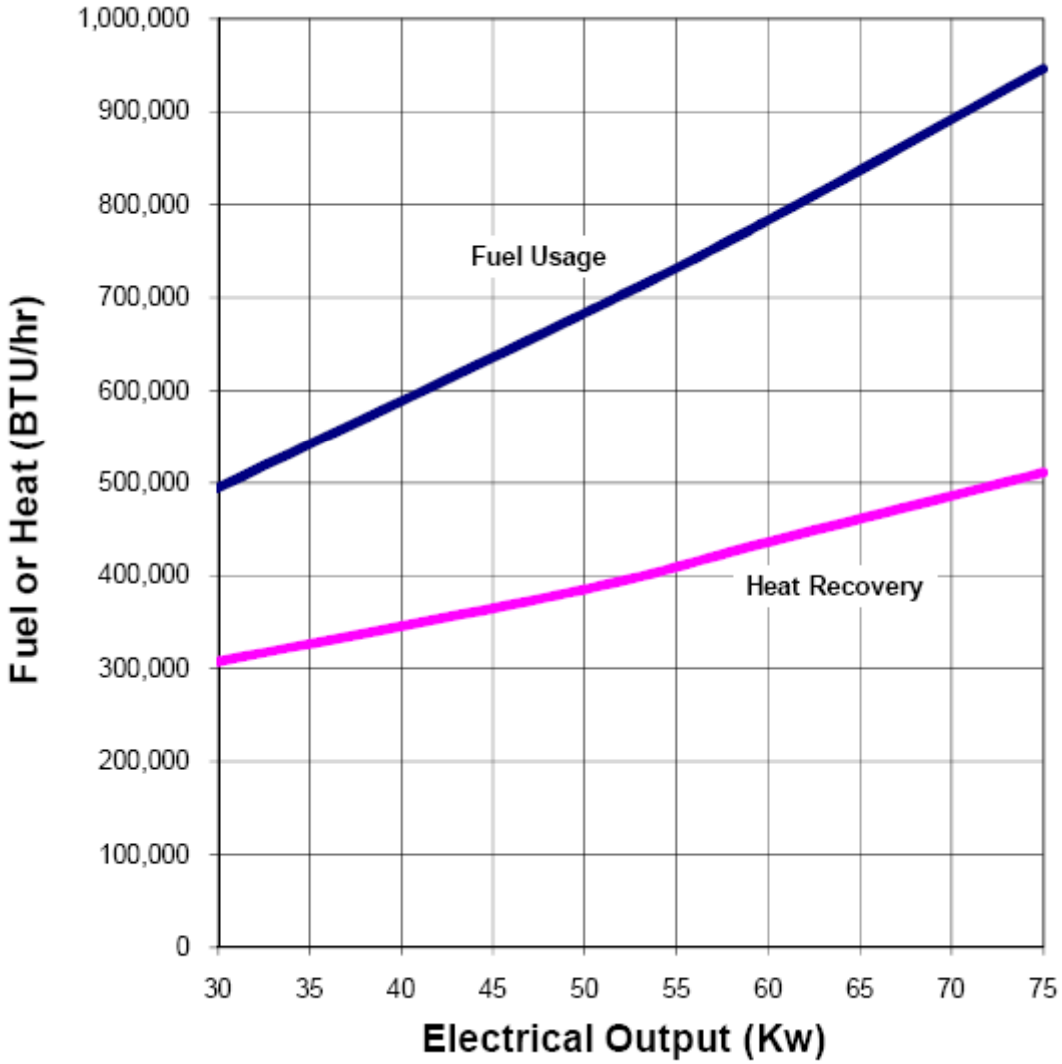
Typical Outputs for CTG



Typical Outputs for Microturbine



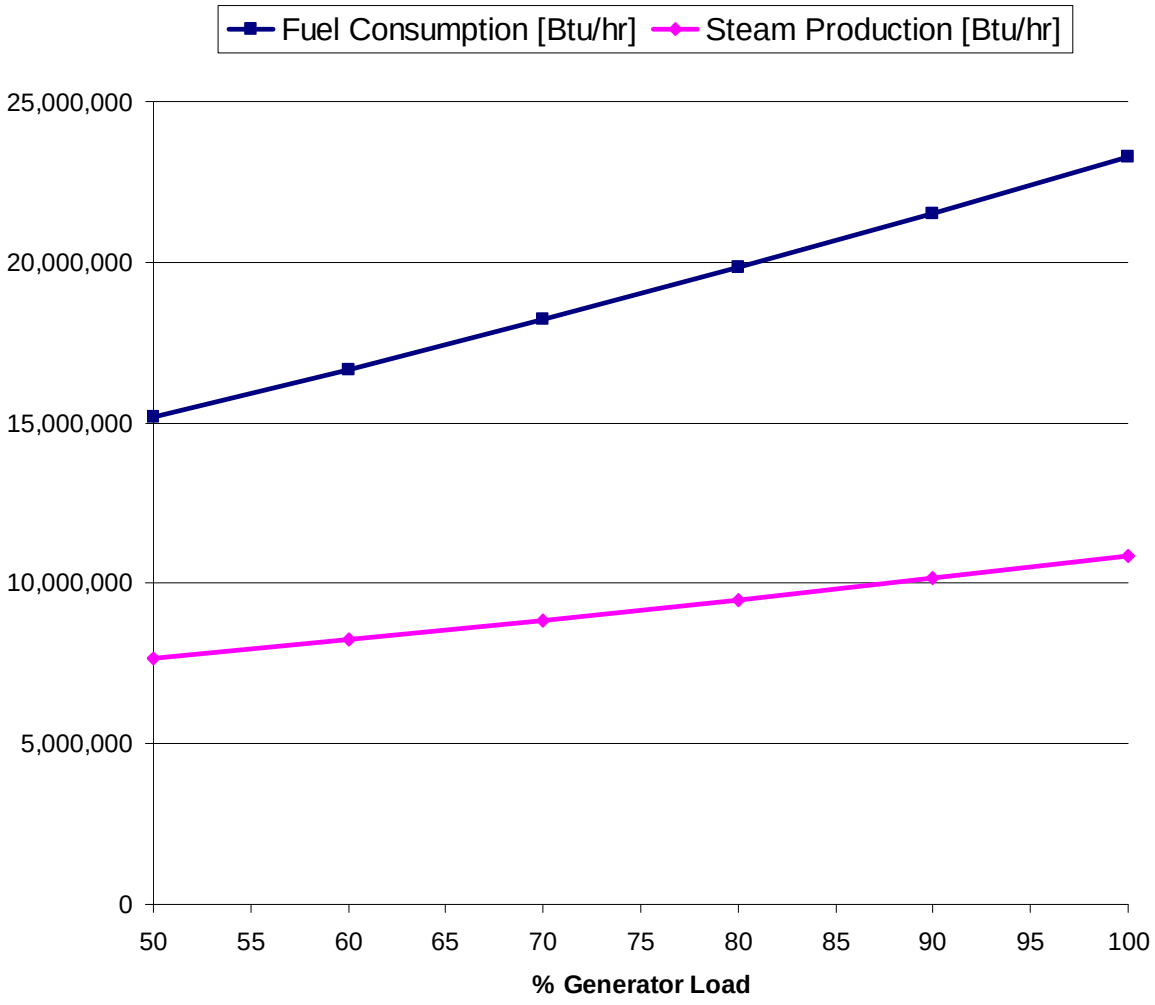
Part-Load Curve for Recip



Electrical Output (kW)	Fuel Usage (BTU/hr)	Heat Recovery (BTU/hr)
75	946,000	511,000
60	783,000	436,000
50	683,000	385,000
30	494,000	307,000

Electrical Output (kW)	Electrical Efficiency (%)	Overall Efficiency (%)
75	27.1	81.1
60	26.2	81.8
50	25.0	81.4
30	20.7	82.9

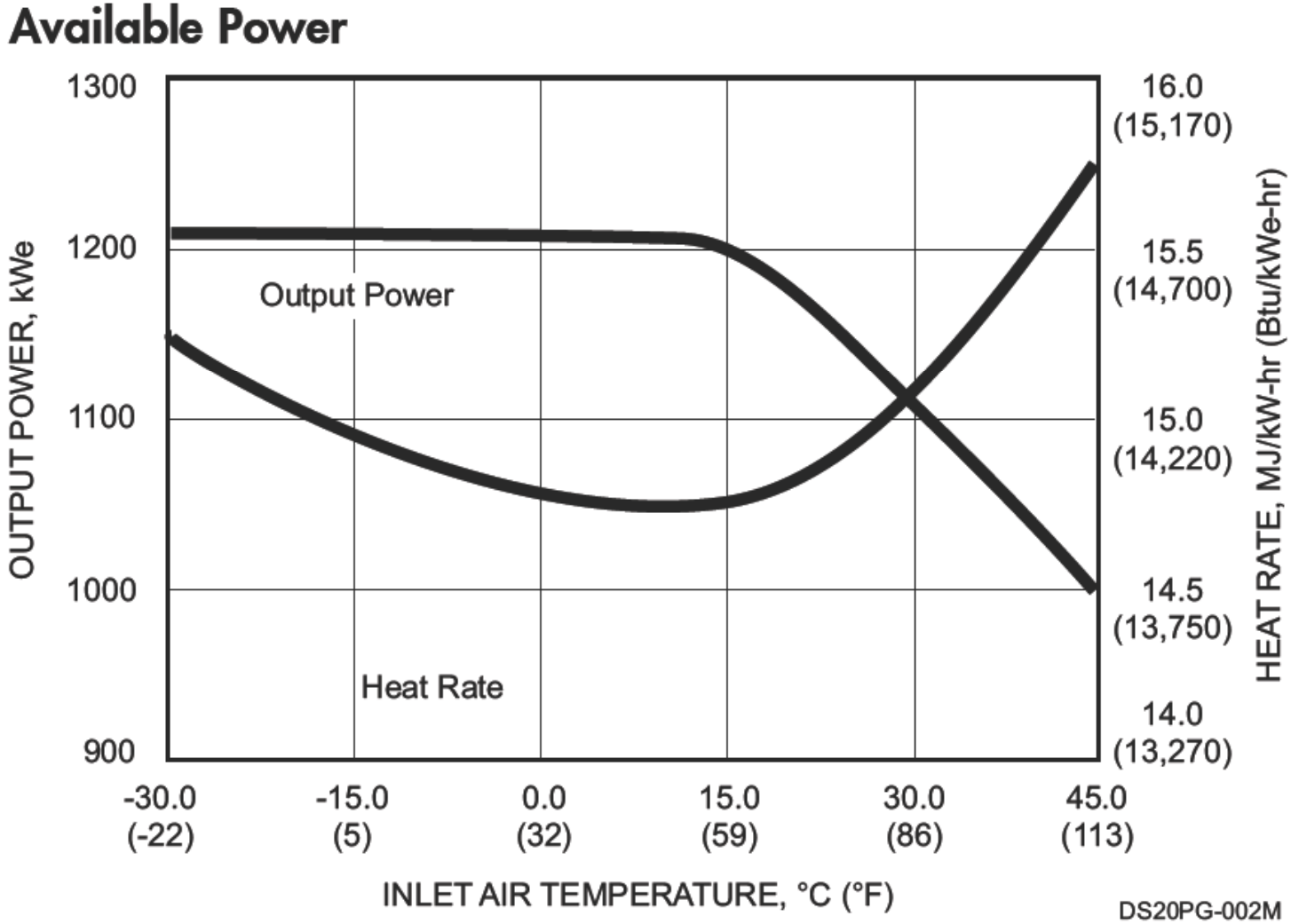
Part-Load Curve for CTG



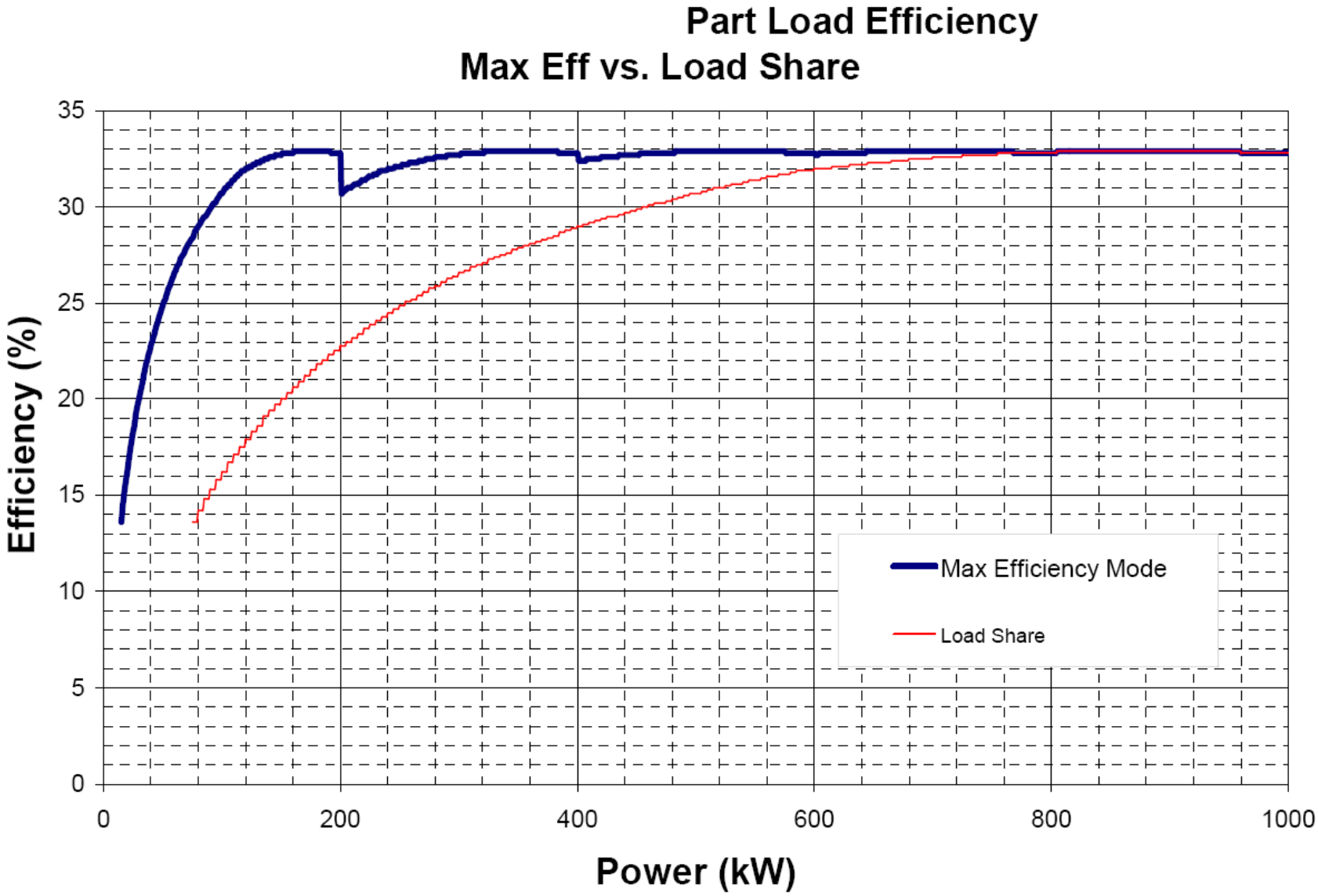
Electrical Output (kW)	Fuel Usage (Btu/hr)	Heat Recovery (Btu/hr)
1,448	23,272,856	10,860,000
1,303	21,536,088	10,147,915
1,158	19,853,684	9,466,364
1,013	18,230,039	8,832,591
868	16,669,244	8,233,653
724	15,182,247	7,675,062

Electrical Output (kW)	Electrical Efficiency (%)	Overall Efficiency (%)
1,448	21.23%	67.89%
1,303	20.65%	67.77%
1,158	19.91%	67.59%
1,013	18.97%	67.42%
868	17.78%	67.18%
724	16.27%	66.82%

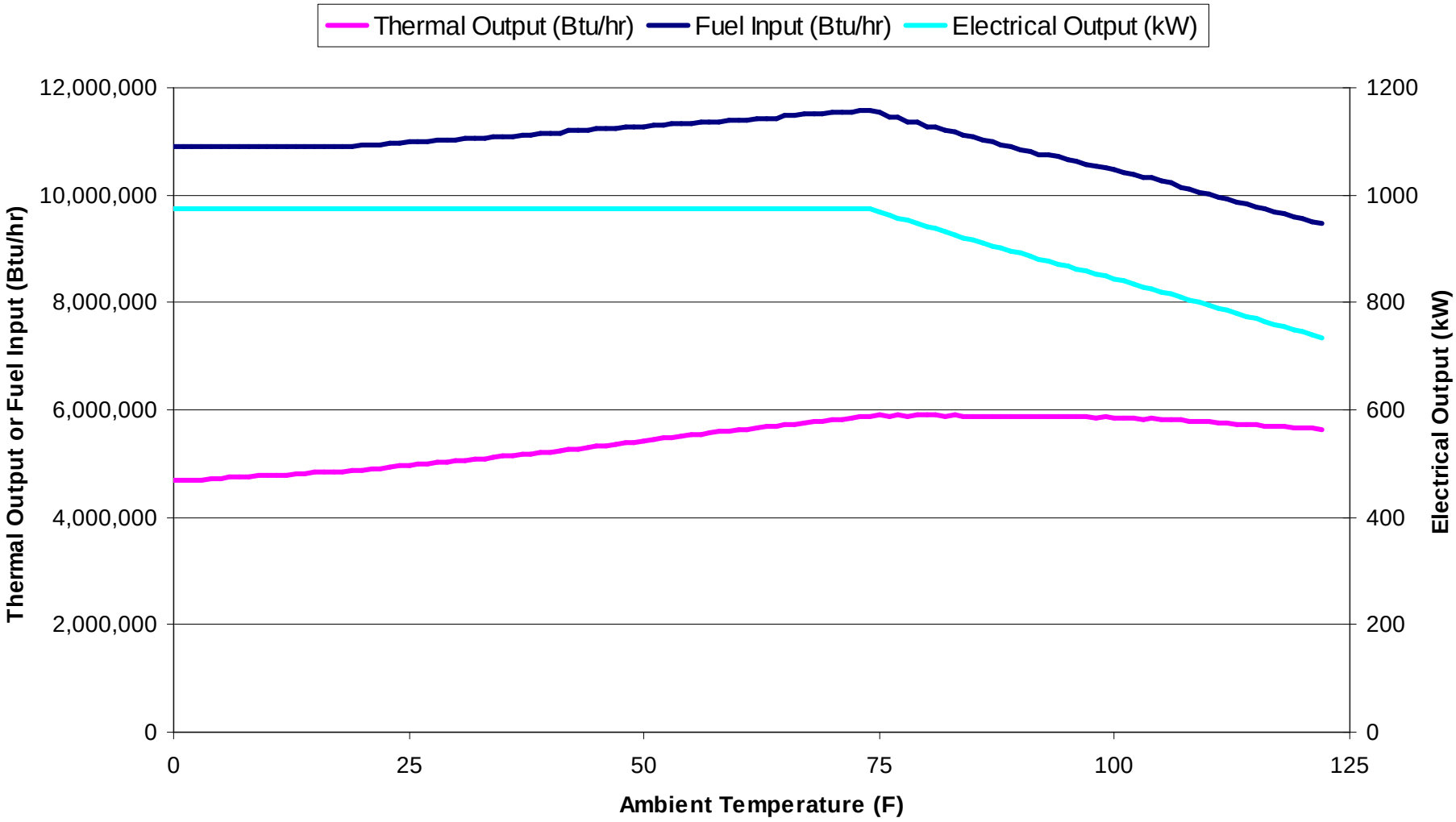
Ambient Temp Effects on CTG



Part-Load Curve for Microturbine



Ambient Temp Effects on Microturbine



Economics

- Key factors
  - CHP technology
  - Consistency of electrical and thermal loads
  - Quality of available thermal loads
  - Local gas and electric tariffs, demand savings
- Metrics
  - Total run-hours vs. equivalent full-load hours
  - Efficiency (full-load, part-load, annual)
  - Savings per hour of operation
  - Installation cost per kWe of CHP system

CHP Incentives

- Electric utility incentive
  - Up to $750/kW
  - Requires detailed study
  - Must pass utility benefit/cost screening
- MA Alternative Portfolio Standard
  - Issuing $20/MWh for “Alternative Energy Certificates”
  - Requires revenue-grade metering and periodic reporting of system production

Utility Benefit/Cost Screening

What matters?

1. Total cost of CHP installation (including equipment, labor, engineering, commissioning, PM, etc.)
2. Annual maintenance cost
3. kWh produced, equivalent gas/oil offset, fuel input
4. Average kW reduction during “super-peak” hours (Jun, Jul, Aug, M – F, 1pm – 5pm)

Lessons Learned in 2010

- Typical project timeline
- What to expect for simple paybacks
- Electric/gas rate trends
- Relationship of CHP plant efficiency to thermal load type
  - Challenges with steam
    - Temperature of waste heat available from CHP
  - Challenges with hot water utilization in smaller facilities
    - Thermal storage
- Should we consider absorption chillers?
  - Typically not economical, single-effect chillers cost 4 – 5 times as much as electric centrifugal chillers to operate
  - Steam/HW is better used directly for heating

Customer Type	CHP System Type	Estimated Cost	Annual Savings	Run-Hours; Efficiency	Simple Payback
Food/ Beverage	250 kW recip HW	$766,686*	$169,986	5,300 hrs 79%	3.4 yrs
Hospital (Inpatient)	600 kW recip LP stm	$1,929,477	$396,570	8,500 hrs 73%	3.7 yrs
Food/ Beverage	1.5 MW CTG HP stm	$5,790,000	$700,711	7,800 hrs 68%	6.7 yrs
Manufacturing	250 kW recip HW	$976,015*	$165,494	8,500 hrs 78%	4.8 yrs
Hospital (Inpatient)	1.5 MW CTG HP stm	$4,994,882	$512,896	8,500 hrs 66%	6.9 yrs
Gym w. pool and dorms	100 kW recip HW	$350,000	$59,068	7,900 hrs 84%	4.9 yrs
Hospital (Inpatient)	1 MW microT HP stm & HW	$3,100,000*	$586,398	8,100 hrs 64%	4.0 yrs
Hospital (Outpatient)	250 kW recip HW	$1,000,000	$269,627	8,500 hrs 77%	3.1 yrs
Hospital (Inpatient)	250 kW recip HW	$1,000,000	$258,300	8,500 hrs 79%	3.2 yrs

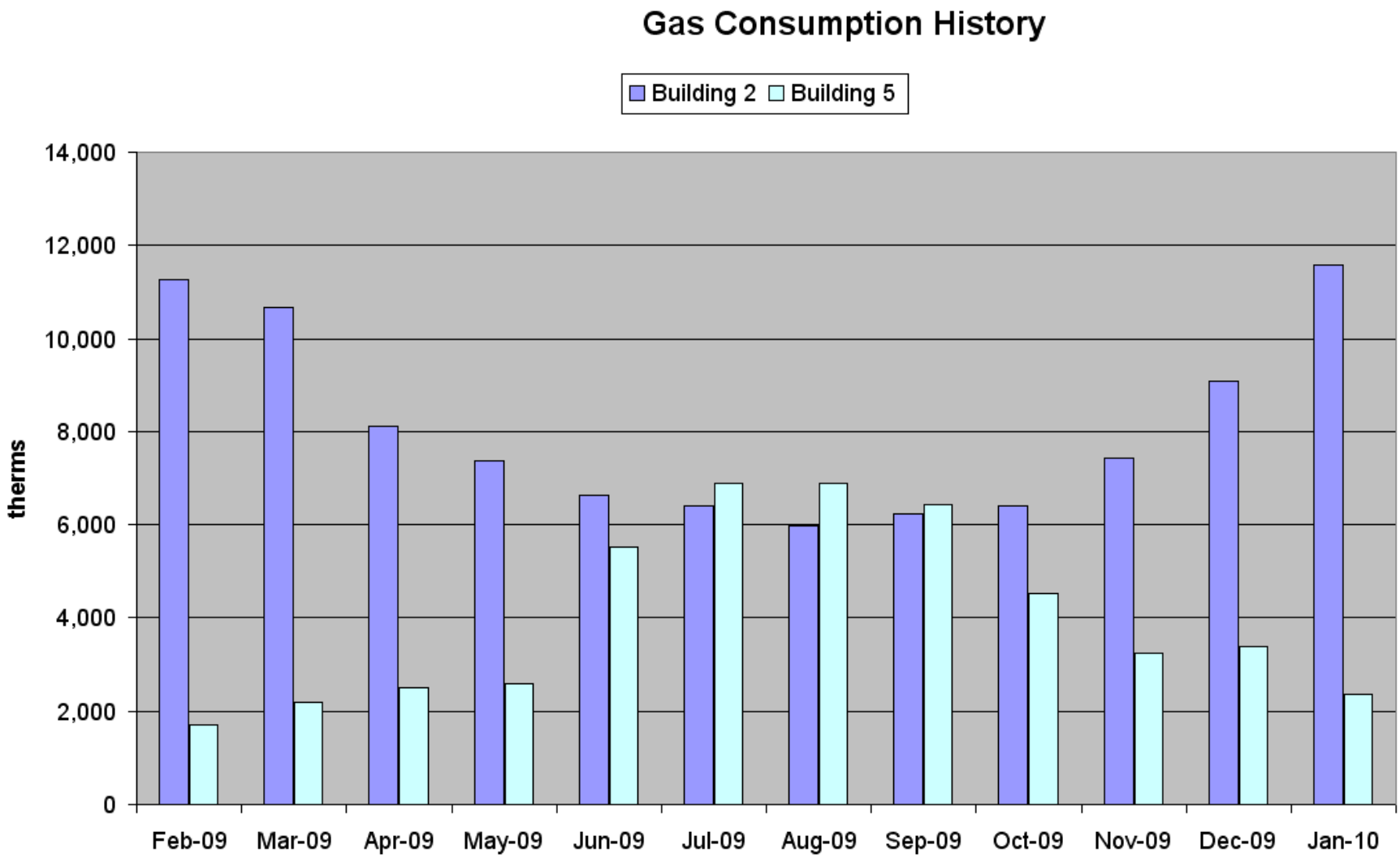
Case Study #1
(Simple HW System)

- Manufacturing facility in MA
- Hydronic heating – CHP to provide HW to three of five buildings at the site
- Significant summer reheat loads due to low %RH requirements
- 250 kW reciprocating engine
- Expected installation cost of ~$1.0M
- Expected simple payback of ~5 years

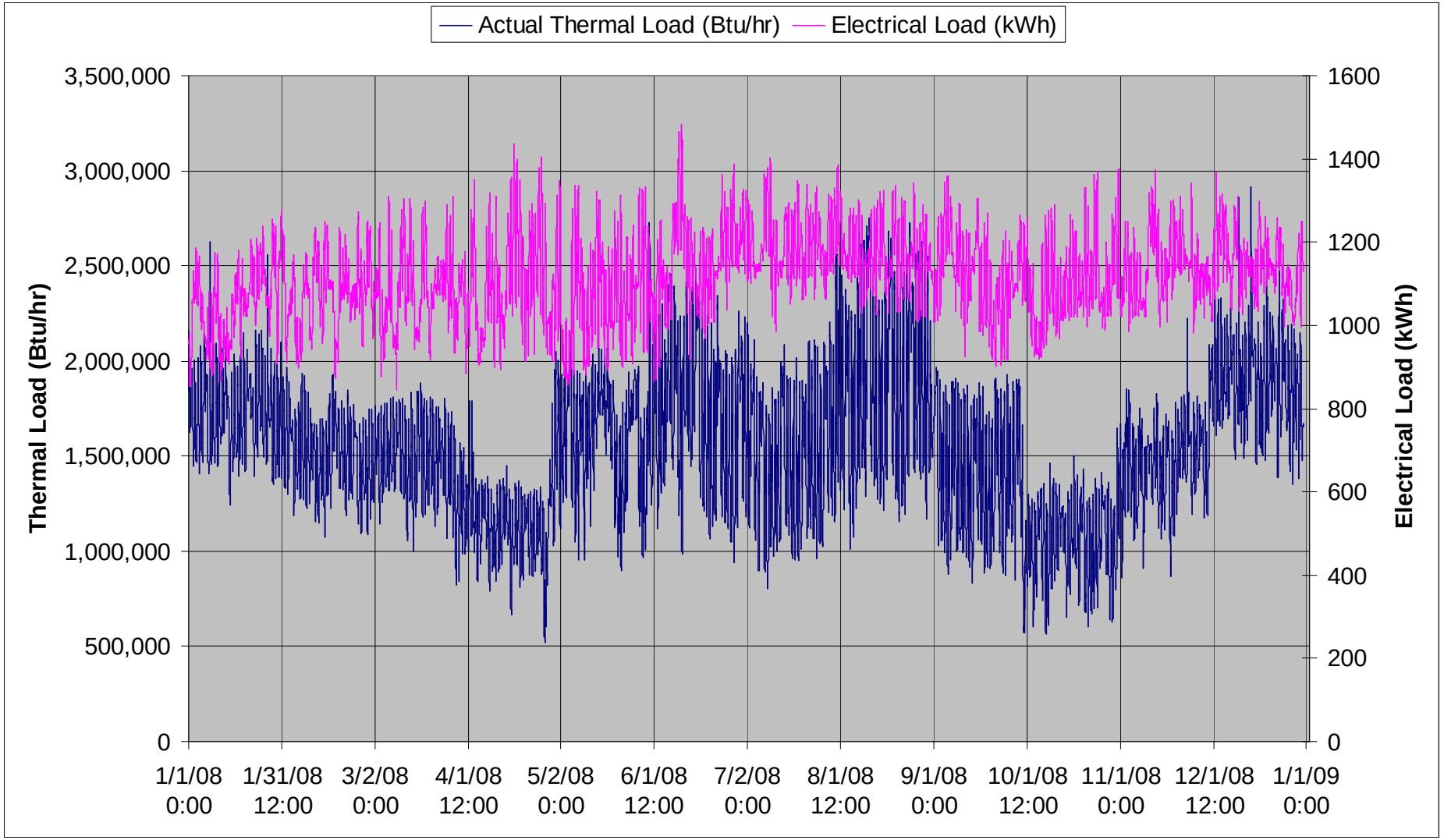
Case Study #1

- Thermal load modeling took place in eQUEST
- Utility bills were used to calibrate model
- Analyzed the cost-effectiveness of interconnecting various buildings
- Reheat loads in summer made CHP feasible at this site

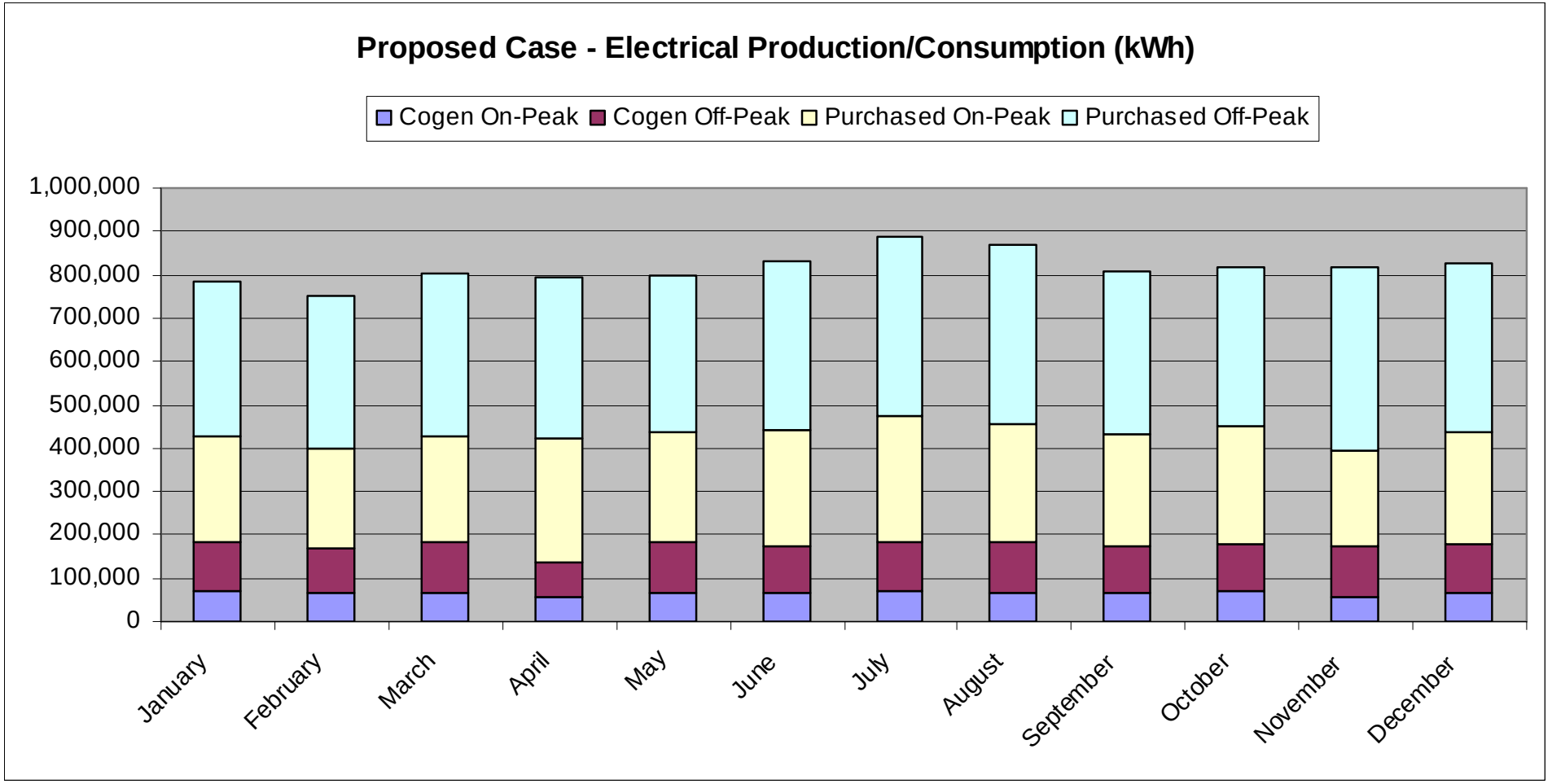
Monthly Gas Use



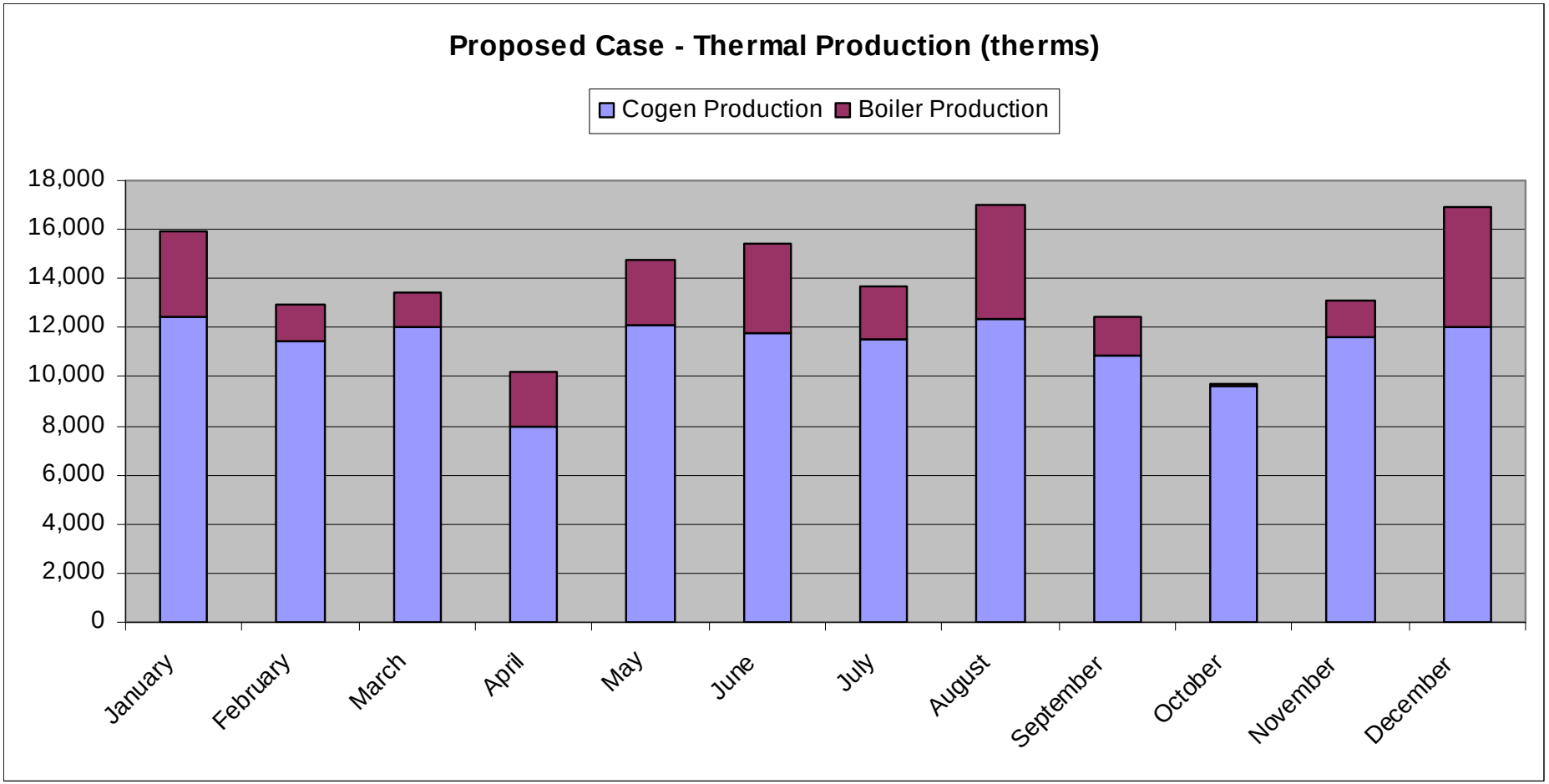
Hourly Loads



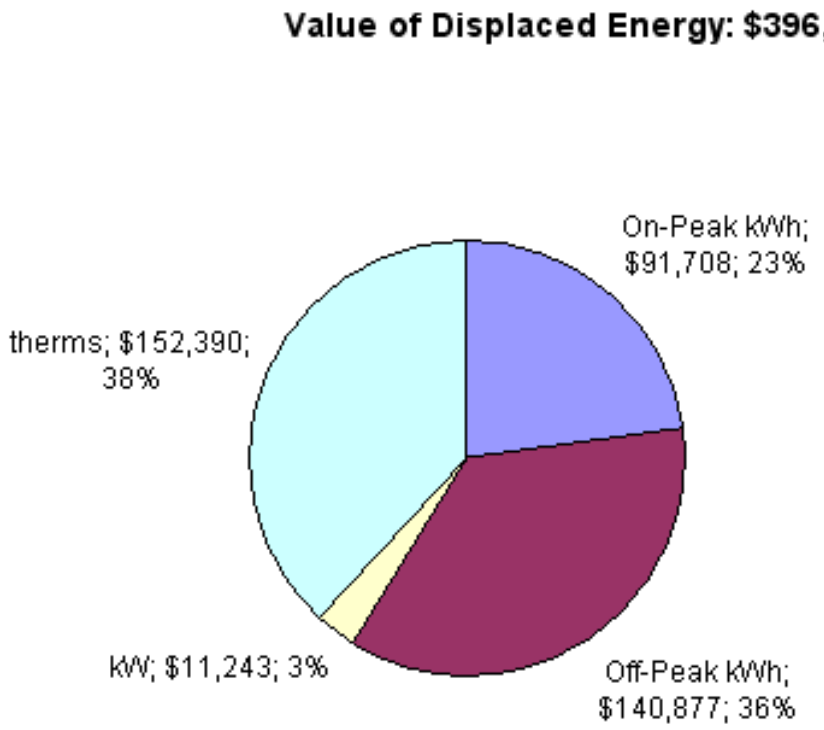
Post-CHP Electric Consumption

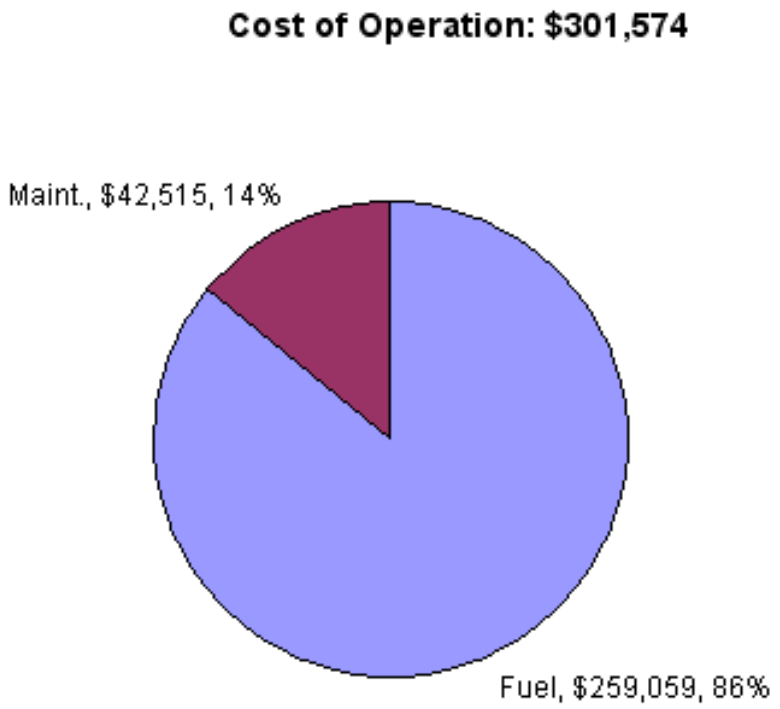


Post-CHP Gas Consumption



Expected Costs/Savings





System Design

- CHP package located outdoors
- 35% PG mix to prevent freezing
- Glycol HW distributed to two mechanical rooms
- Piping system designed for 20°F ΔT
  - 900’ of 3” S&R piping (100 GPM)
  - 1400’ of 4” S&R piping (140 GPM)
- (2) 5hp glycol pumps for distribution to local plate & frame heat exchangers (parasitic loads)

Cost Estimate

OPINION OF PROBABLE COST

Cogen Install

CLIENT:
CUSTOMER:
LOCATION:

REVISION DATE: 3/3/2011
ESTIMATED BY: MM
CHECKED BY: PB

CONTACT:

Description

Item #	Source	Description	Unit	Unit Cost	Qty	Material Cost	Labor Rate	Hours	Labor Cost	Equipment Cost	Item Cost
1	quote	250 KW CHP package	ea	$442,965	1	$442,965			$0		$442,965
2	incl above	Engine/Generator Controls	incl above			$0			$0		$0
3	incl above	Sound Attenuating Enclosure	incl above			$0			$0		$0
4	incl above	Exhaust Flue	incl above			$0			$0		$0
5	incl above	Waste Heat "Dump" Radiator & Radiator Fans	incl above			$0			$0		$0
6	incl above	Piping to/from dump radiator	incl above			$0			$0		$0
7	incl above	Additional emissions reduction system (if req'd)	incl above			$0			$0		$0
8	eng	Fuel Piping & Fittings from source to unit	lf	$75	100	$7,500			$0		$7,500
9	eng	Pad for CHP package	allow	$3,500	1	$3,500			$0		$3,500
10	eng	Rigging	allow	$5,000	1	$5,000			$0		$5,000
11	quote	Secondary pumps	ea	$2,000	4	$8,000	$75.00	40	$3,000		$11,000
12	quote	New heat exchangers; fittings	ea	$5,000	2	$10,000	$75.00	16	$1,200		$11,200
13	quote	pump vfd	ea	$3,000	2	$6,000	$75.00	32	$2,400		$8,400
14	Means	Glycol	gal	$10	250	$2,500	$50.00	8	$400		$2,900
15	quote	Primary Pumps	ea	$2,500	2	$5,000	$75.00	20	$1,500		$6,500
16	eng	Pipe steel welded, insulated	lf	$57	1200	$68,400			$0		$68,400
17	eng	Valves, Fittings, trim	allow	$25,000	1	$25,000	$75.00	250	$18,750		$43,750
18	combination	Electrical: See attached	ea	$110,000	1	$110,000			$0		$110,000
19	eng	Add for BAS controls and	allow	$35,000	1	$35,000			$0		$35,000
20	eng	TAB	allow	$1,500	1	$1,500					
21	eng	Start-up and Contractor Commissioning	allow	$3,500	1	$3,500			$0		$3,500
22	eng	General Construction	allow	$10,000	1	$10,000			$0		$10,000
23	eng	DEP Permitting	allow	$5,000	1	$5,000			$0		$5,000
24	eng	Town Permitting	allow	$1,500	1	$1,500					

Sources:
1) Means
2) Vendor Quote
3) Engineering Est

NOTE: State Sales Tax not included.

DISCLAIMER: B2Q does not expressly warrant or represent the accuracy of the above cost estimates due to unforseeable factors in the construction industry, including price volatility of labor and materials

Sub-Total		**$774,615**
Contingency	5%	$38,731
Overhead & Profit	10%	$81,335
Engineering	5%	$40,667
Eng Commissioning	2.5%	$20,334
Construction Management	2.5%	$20,334
Total Cost with Mark-up		**$976,015**

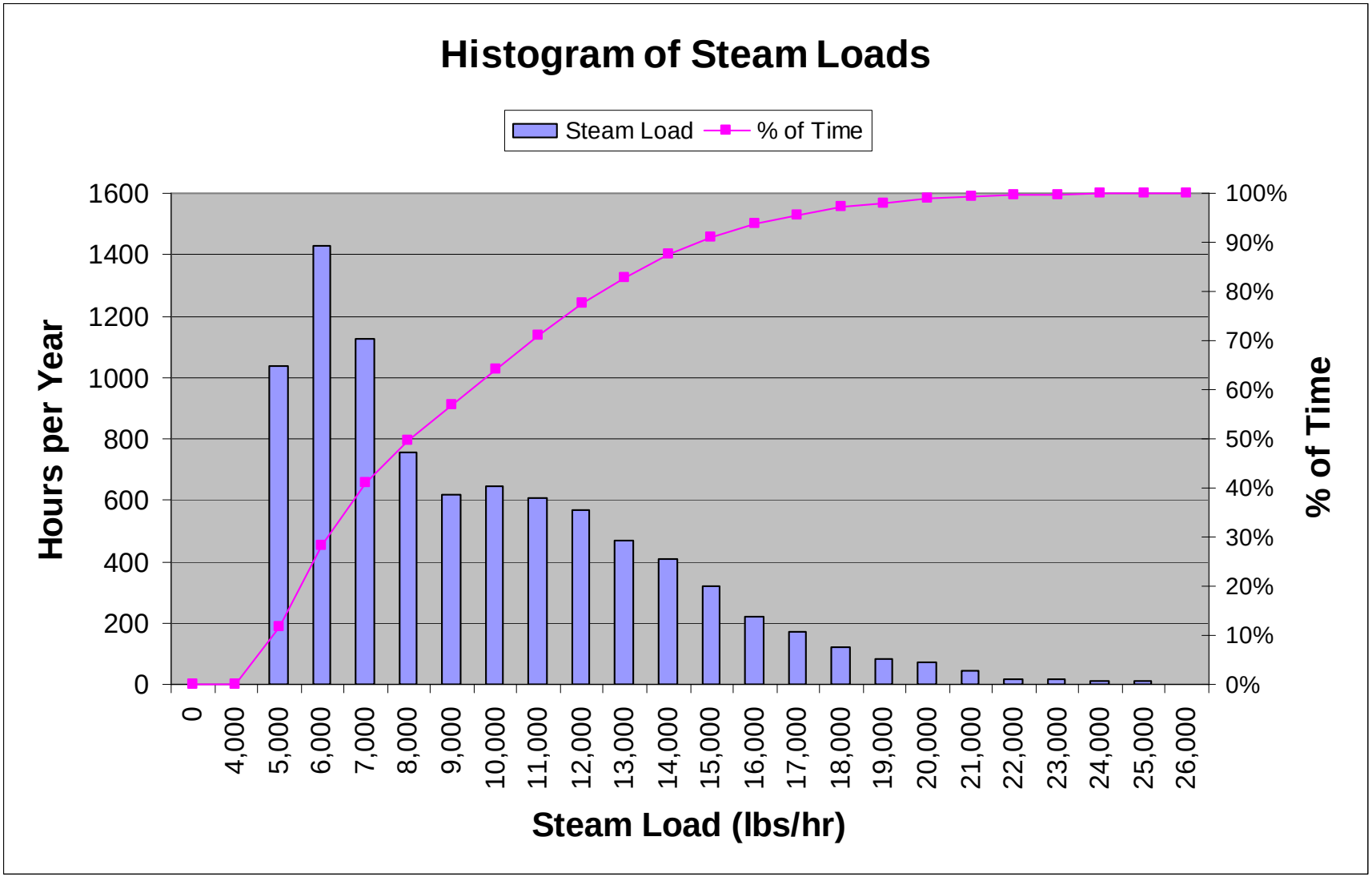
Project Timeline

- Study began March 2010
- Study completed April 2010
- Utility pre-approves incentive, design begins, major equipment ordered in May 2010
- Design completed end of June 2010
- Installation begins July 2010
- Proposed CHP location moves, design redone in November 2010
- Installation completed December 2010
- Startup scheduled for March 2011

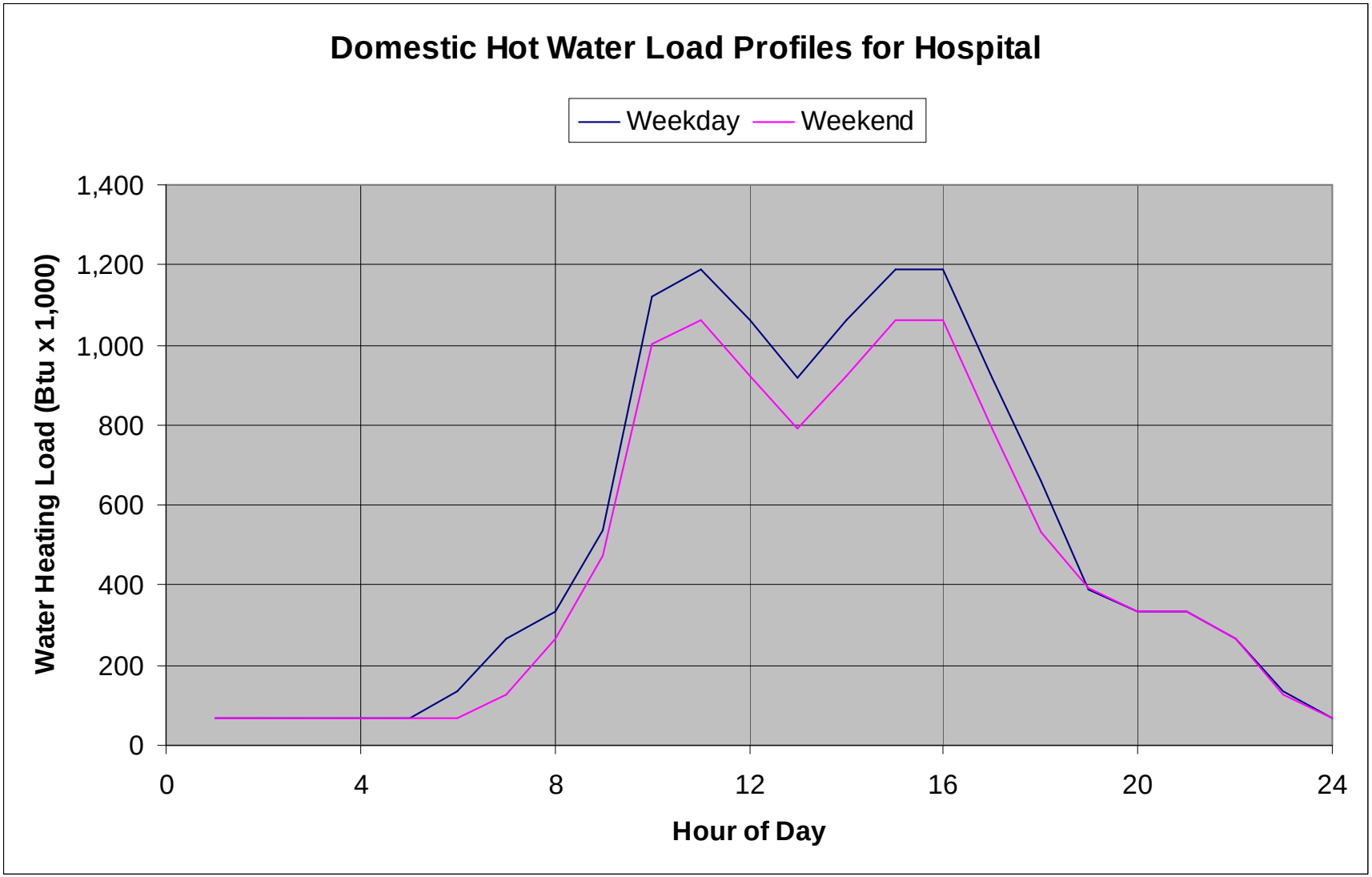
Case Study #2
(Steam & HW System)

- Hospital
- Steam and HW loads
- Thermal loads are condensate heating, DHW, and hydronic heat/reheat loops
- 1 MW microturbine
- Expected installation cost of $3.1M
- Expected simple payback of 4 years

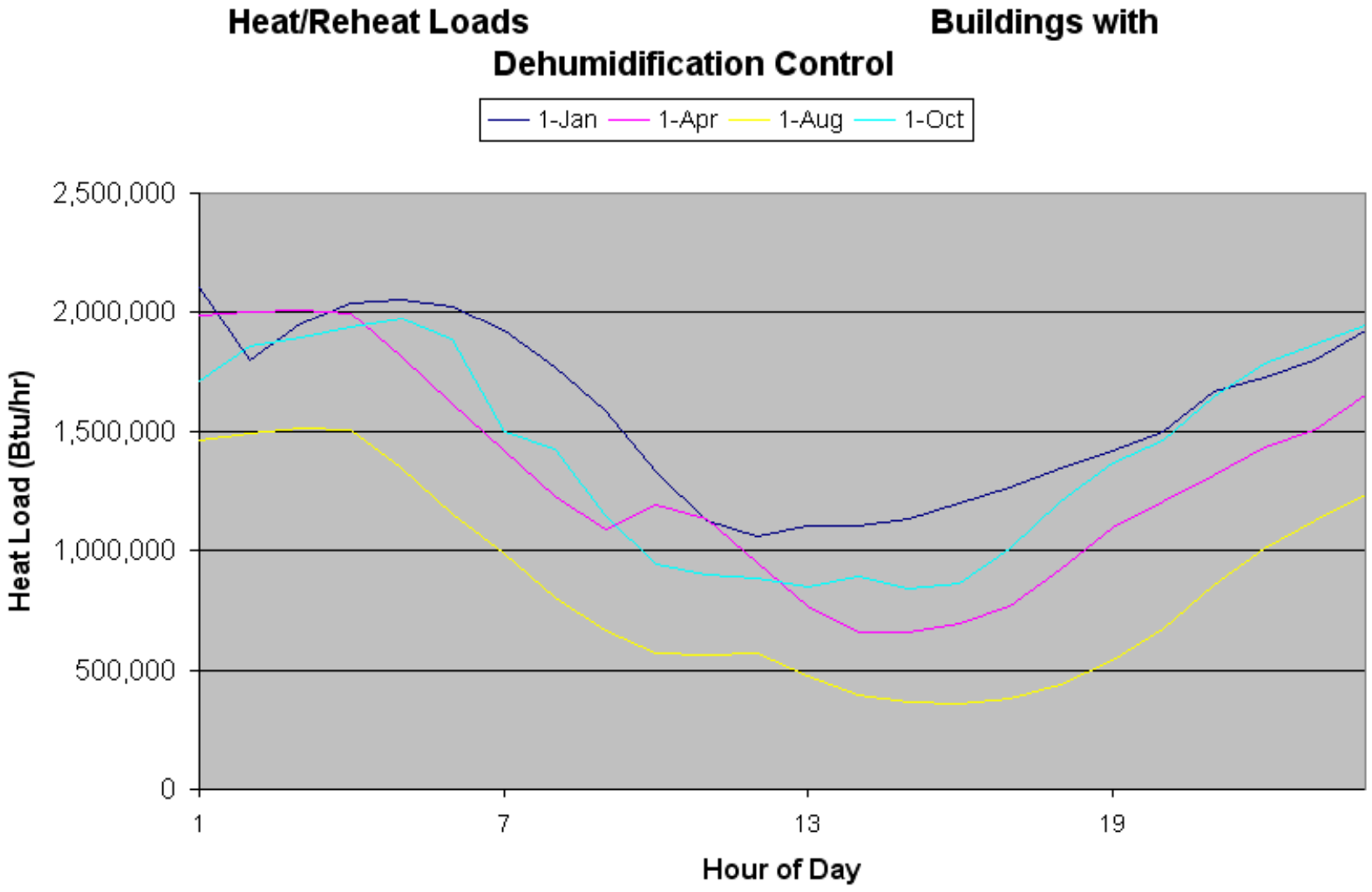
Steam/FDW Loads



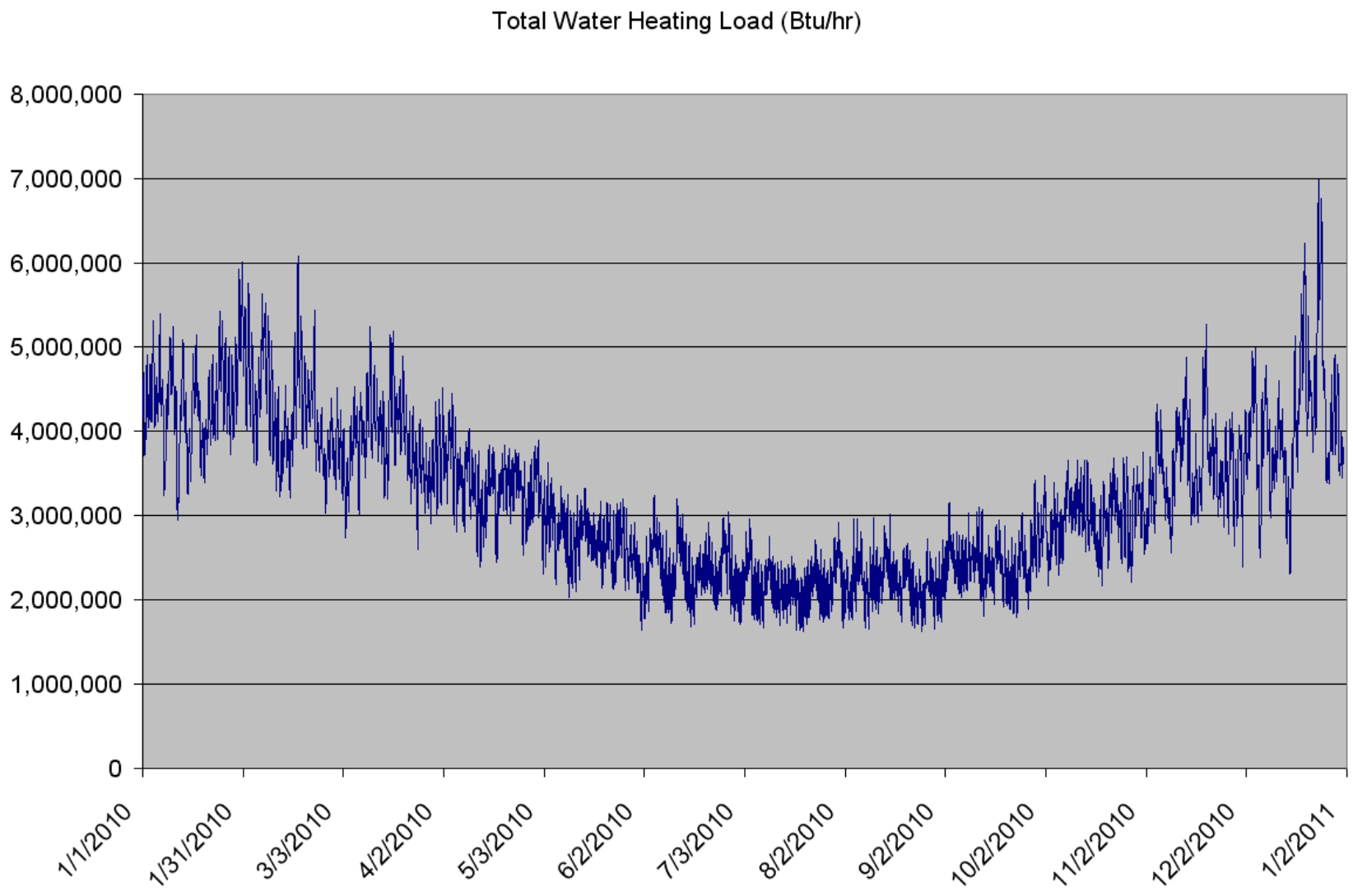
DHW Loads


Domestic Hot Water Load Profiles for Hospital
Weekday
Weekend
Water Heating Load (Btu x 1,000)
1,400
1,200
1,000
800
600
400
200
0
0
4
8
12
16
20
24
Hour of Day

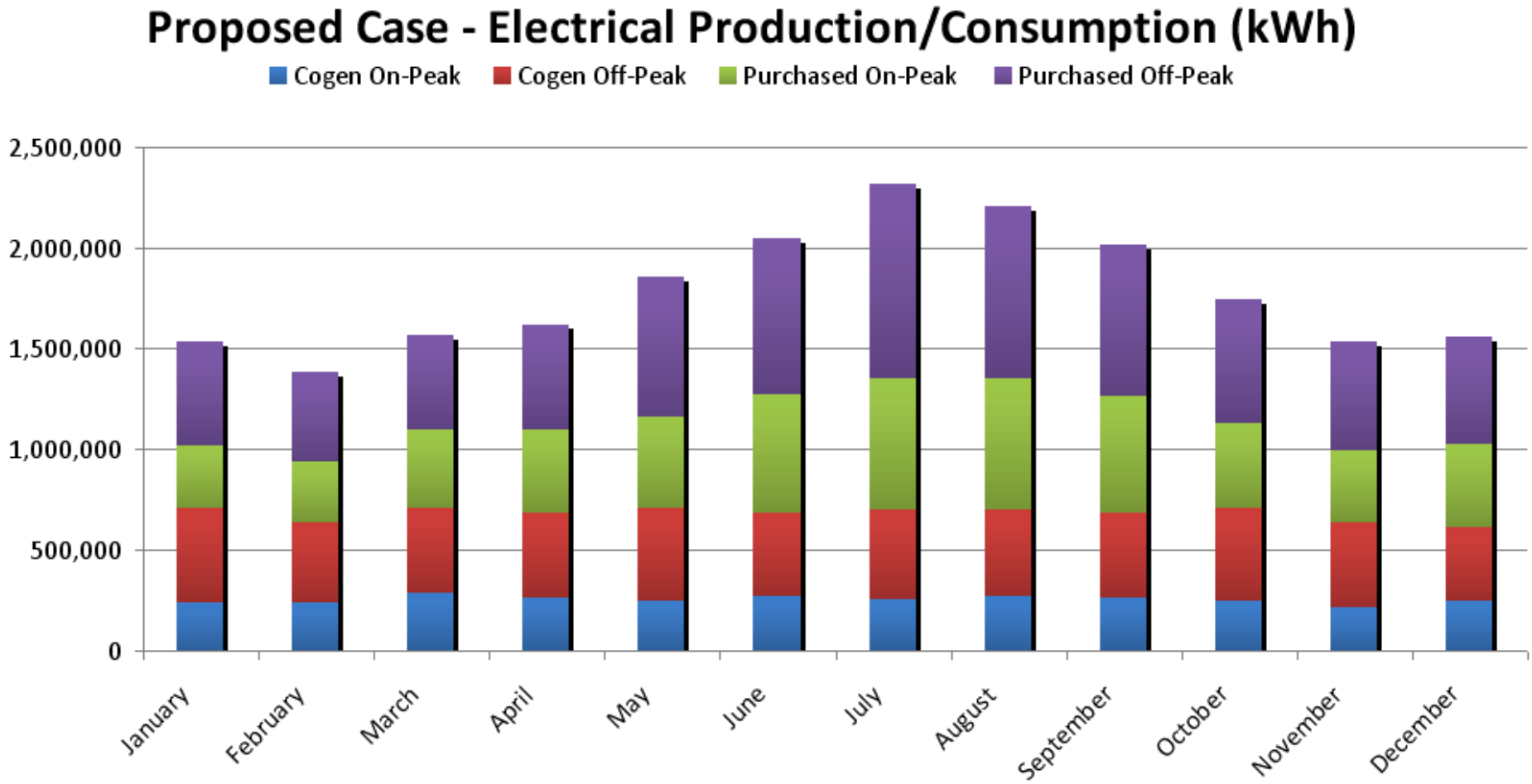
Heat/Reheat Loads



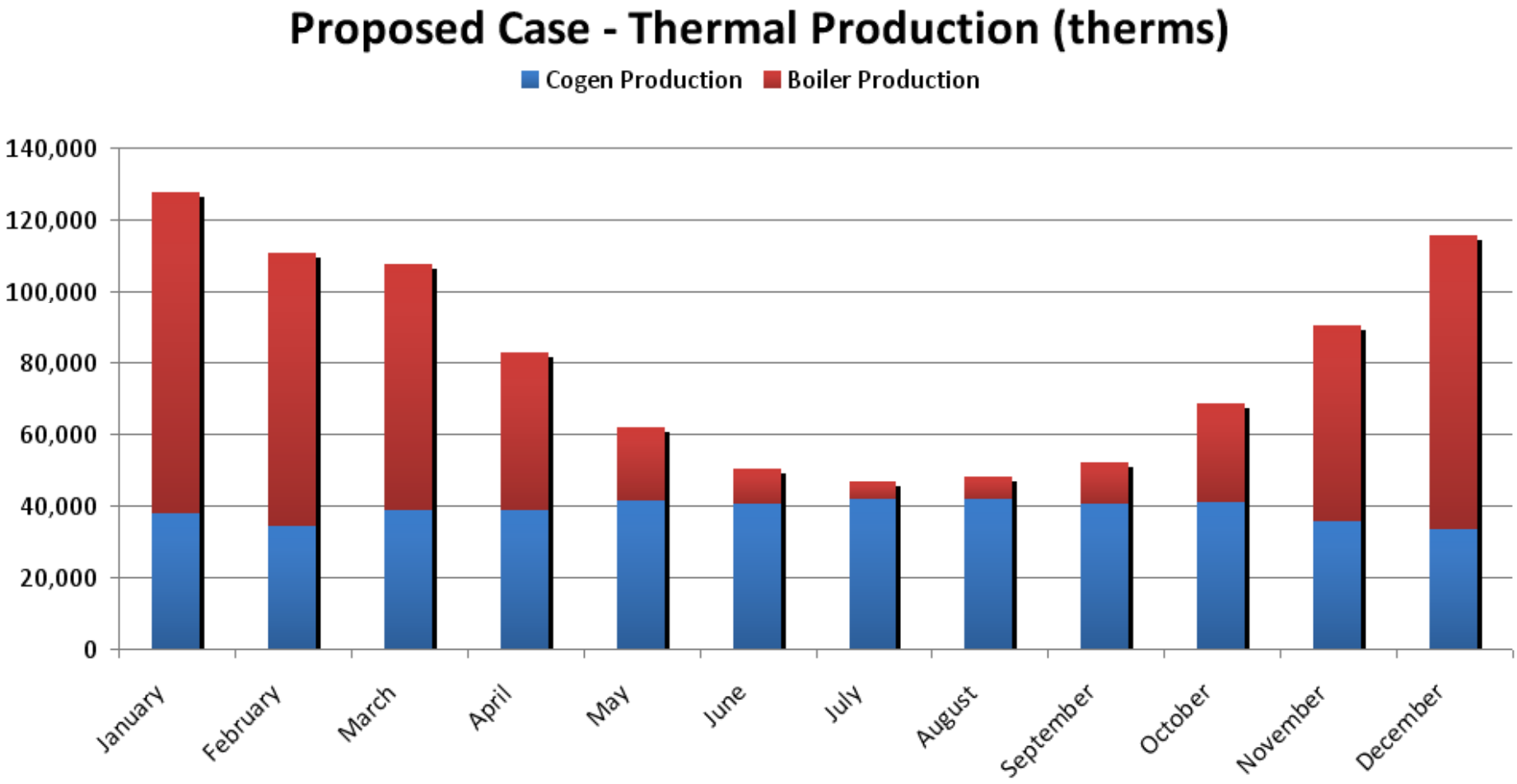
Combined HW Loads



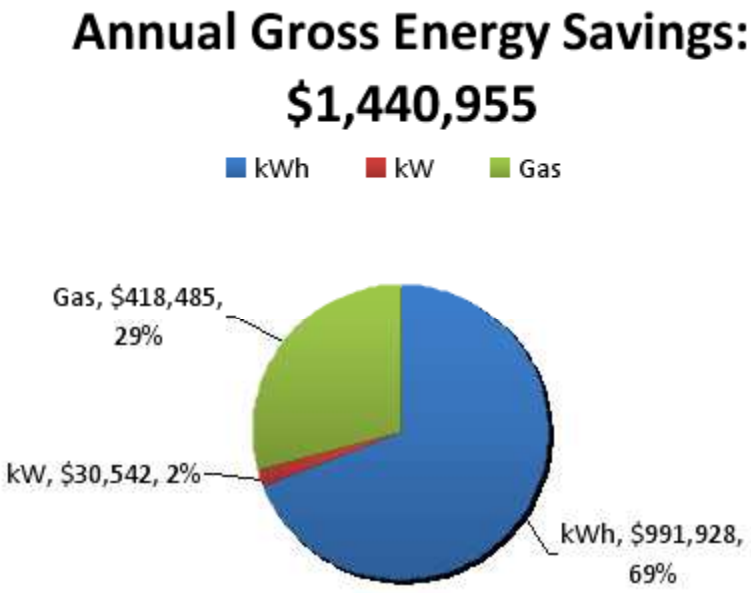
Post-CHP Electric Consumption



Post-CHP Gas Consumption



Expected Costs/Savings



Case Study #2

- System design
  - 1 MW microturbine to consist of (5) 200 kW modules which are staged in series to maximize part-load efficiency
  - HRSG to provide 2,200 lbs of 75 psig steam
  - Stack economizer to provide 1,835 MBH of water heating up to 310°F

Cost Estimate

OPINION OF PROBABLE COST

Cogen Install

CLIENT:
CUSTOMER:
LOCATION:

REVISION DATE: 3/3/2011
ESTIMATED BY:
CHECKED BY: MS

CONTACT:

Item #	Source	Description	Unit	Unit Cost	Qty	Material Cost	Labor Rate	Hours	Labor Cost	Equipment Cost	Item Cost
1	quote	1000 KW CHP package	ea	$0	1	$0			$0	$1,340,000	$1,340,000
2	incl above	Exhaust Flue	incl above	$0		$0	$98.00	160	$15,680		$15,680
3	ea	Heat Exchangers	ea	$0		$0			$0	$216,000	$216,000
4	ea	Piping to/from HX (cond & DOM HW)	ea	$0	0	$26,000	$98.00	340	$33,320		$59,320
5	incl above	Piping to/from HX (reheats)	ea	$0		$33,000	$98.00	800	$78,400		$111,400
6	eng	Fuel Piping & Fittings from source to unit	ea	$0	0	$4,600	$98.00	160	$15,680		$20,280
7	eng	Pad, retaining wall & fence for CHP	ea	$0	1	$42,000			$0		$42,000
8	eng	Steel, roofing, rigging, door	ea	$0	1	$148,000			$0		$148,000
9	quote	Electrical	ea	$0	1	$397,000			$0		$397,000
10	eng	Add for BAS controls and metering	allow	$0	1	$18,000			$0		$18,000
11	eng	Start-up and Contractor	allow	$0	1	$0	$98.00	120	$11,760		$11,760
12	eng	General Construction	allow	$0	1	$3,000	$98.00	40	$3,920		$6,920
13	eng	Interconnect Allowance	allow	$0	1	$35,000			$0		$35,000
14	eng	Town Permitting	allow	$0	1	$10,000					$10,000

Sources:
1) Means
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3) Engineering Est

NOTE: State Sales Tax not included.

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Sub-Total		**$2,431,360**
Contingency	2%	$48,627
Overhead & Profit	14%	$347,198
Engineering	6%	$148,799
Eng Commissioning	2.5%	$62,000
Construction Management	2.5%	$62,000
Total Cost with Mark-up		**$3,099,984**

Summary

- Screen projects carefully
- Best projects have long operating hours and majority of hours at full load
- Be especially careful with assumptions about thermal loads and utility rates
- Consider a range of sizes and technologies – be aware of the pros/cons
- Involve the electric utility early on

Questions?

Thank You!

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