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Backpressure Steam Turbine Optimization

Presented at the:

Texas Technology Showcase

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Bremerton Naval Complex (BNC)

---Naval Station Bremerton

---Fleet Industrial Supply Center

---Puget Sound Naval Shipyard & Intermediate Maintenance Facility (PSNS & IMF)

Includes drydocks, controlled industrial area: ships undergoing overhaul, maintenance, repair

---Homeported Ships (piers plus moorings)

300 Buildings, 100 served by the steam plant

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The Steam Plant

---Contains 3 identical Riley Stoker boilers

--- Each can deliver 140,000 lbs/hour of steam

---Capable of firing natural gas or #2 fuel oil

---Rated at 700 psig/750 °F

---Operating at 240 psig/430 °F

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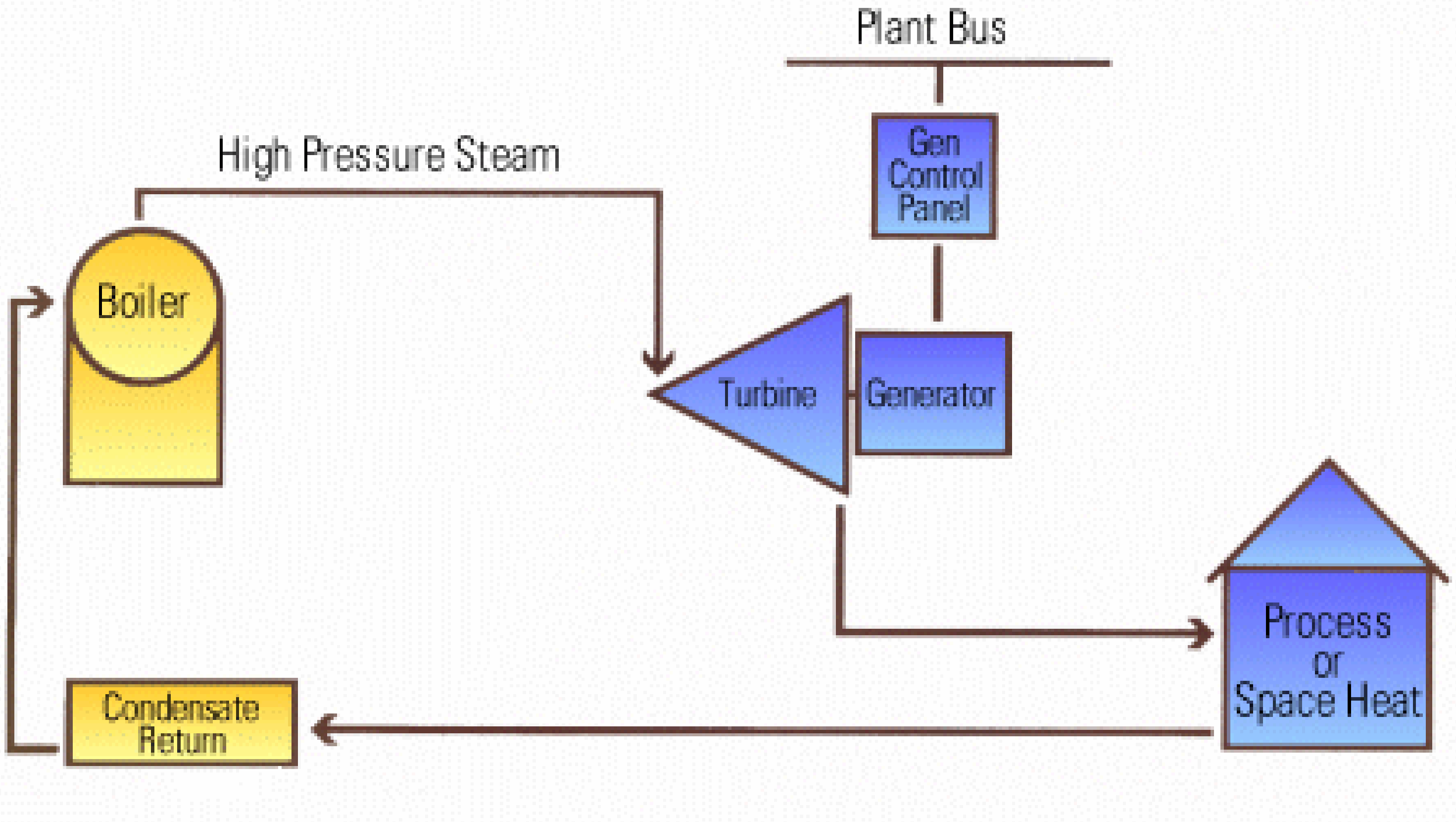
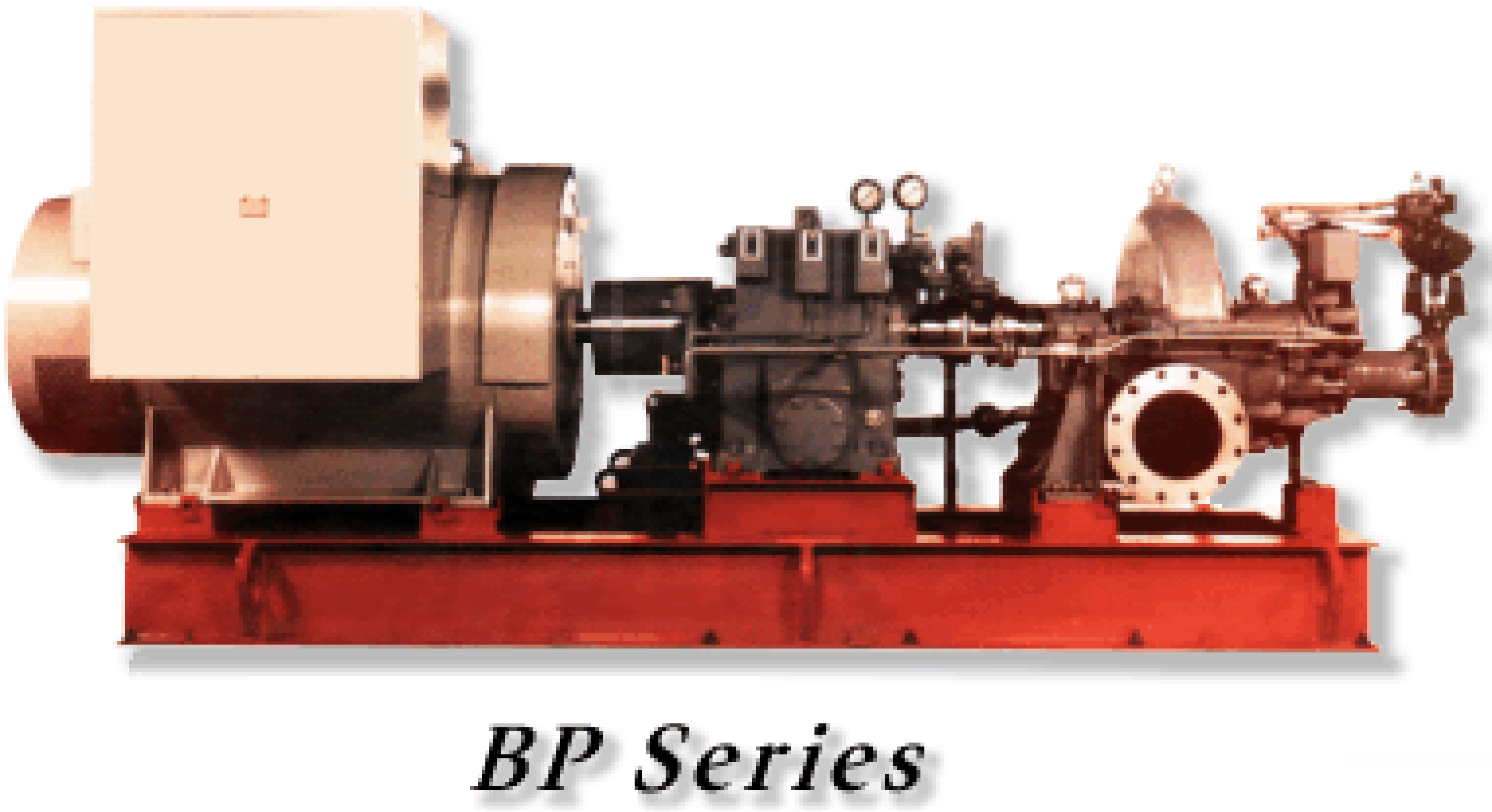
What is a Backpressure Turbine?



BP Series in a simple pressure reducing application
Power production is proportionate to process steam demand

What does the Equipment Look Like?
(BP Series is rated at 50 to 150 kW)



Fuel Cost Comparison

BNC Energy Use and Cost, CY 2003

Natural Gas	Electricity
998,800 MMBtu	246.1 million kWh
(Steam plant only)	(839,940 MMBtu)
~ $5.86 million	$8.46 million
$5.87/MMBtu	$0.0344/kWh (10.08/MMBtu)

Steam Production: 835,255 klbs/year

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Fuel Cost of Producing Electricity with a Backpressure Turbine

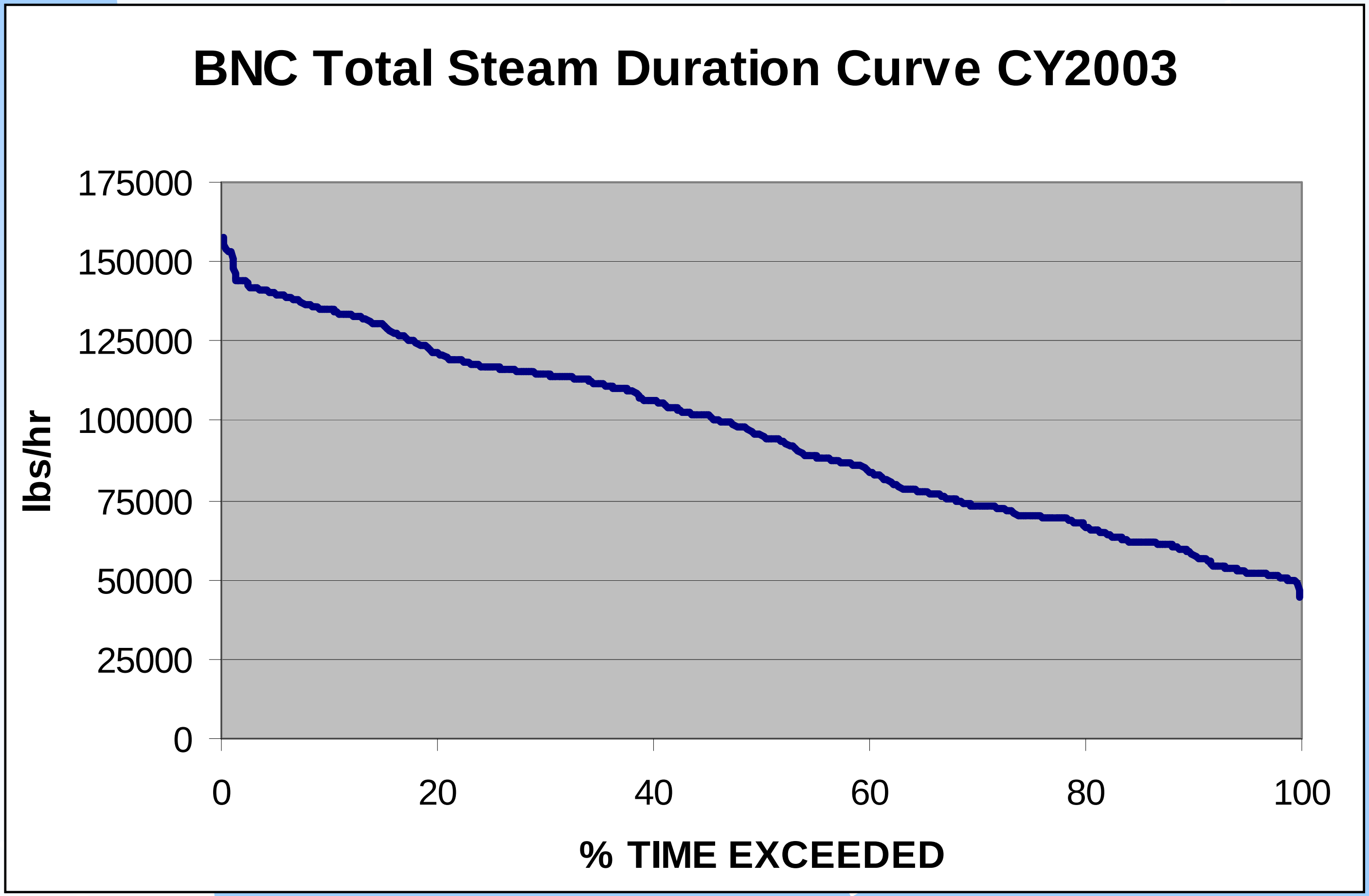
The fuel-related cost of producing electricity with a backpressure turbine is the fuel cost (in \$/MMBtu) divided by both boiler efficiency (about 84.2%) and electrical generator efficiency (typically 95%). The generating costs are:

Fuel Cost/kWh

= \$5.87/MMBtu x 3413 Btu/kWh x (1 /0.95 x 0.842)

= \$0.025/kWh or 2.5 ¢/kWh

BNC Annual Steam Flow Duration Curve



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Initial Analysis of 1,548 kW BP Turbine on Main Steam Header

Pressure Drop: 700-psig/750°F to 240 psig

Installed Generating Capacity: 1,548 kW

Annual Electrical Output: 11.26 million kWh

Increase in Natural Gas Use: 48,050 MMBtu

Equipment Costs: $400,000 (Source: Turbosteam)

Installation and Startup Costs: $415,000

Total Installed Cost : $1.07 million

Simple Payback, years: 10.8 (at 3.44 ¢/kWh)

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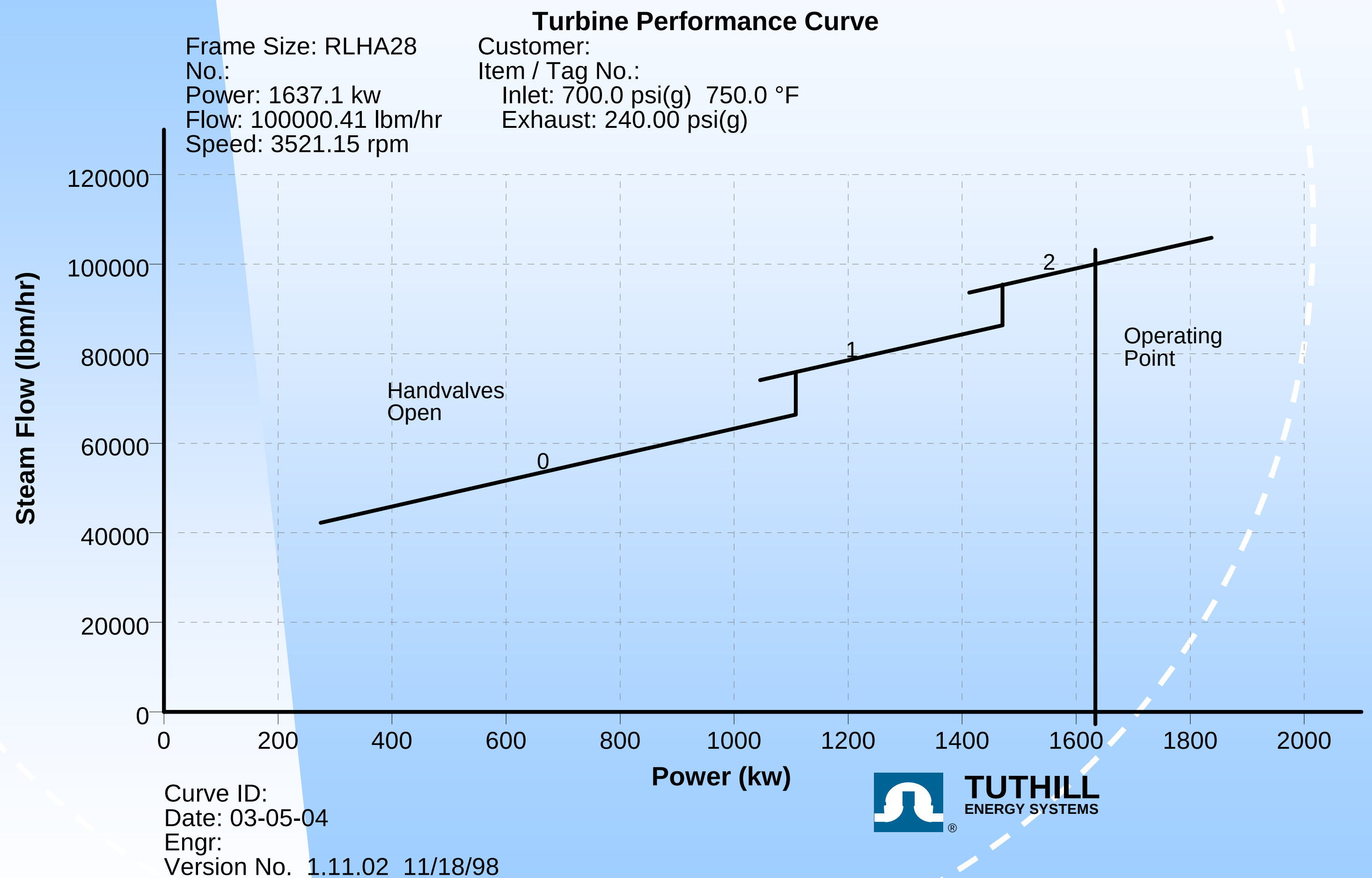
Backpressure Turbine Performance



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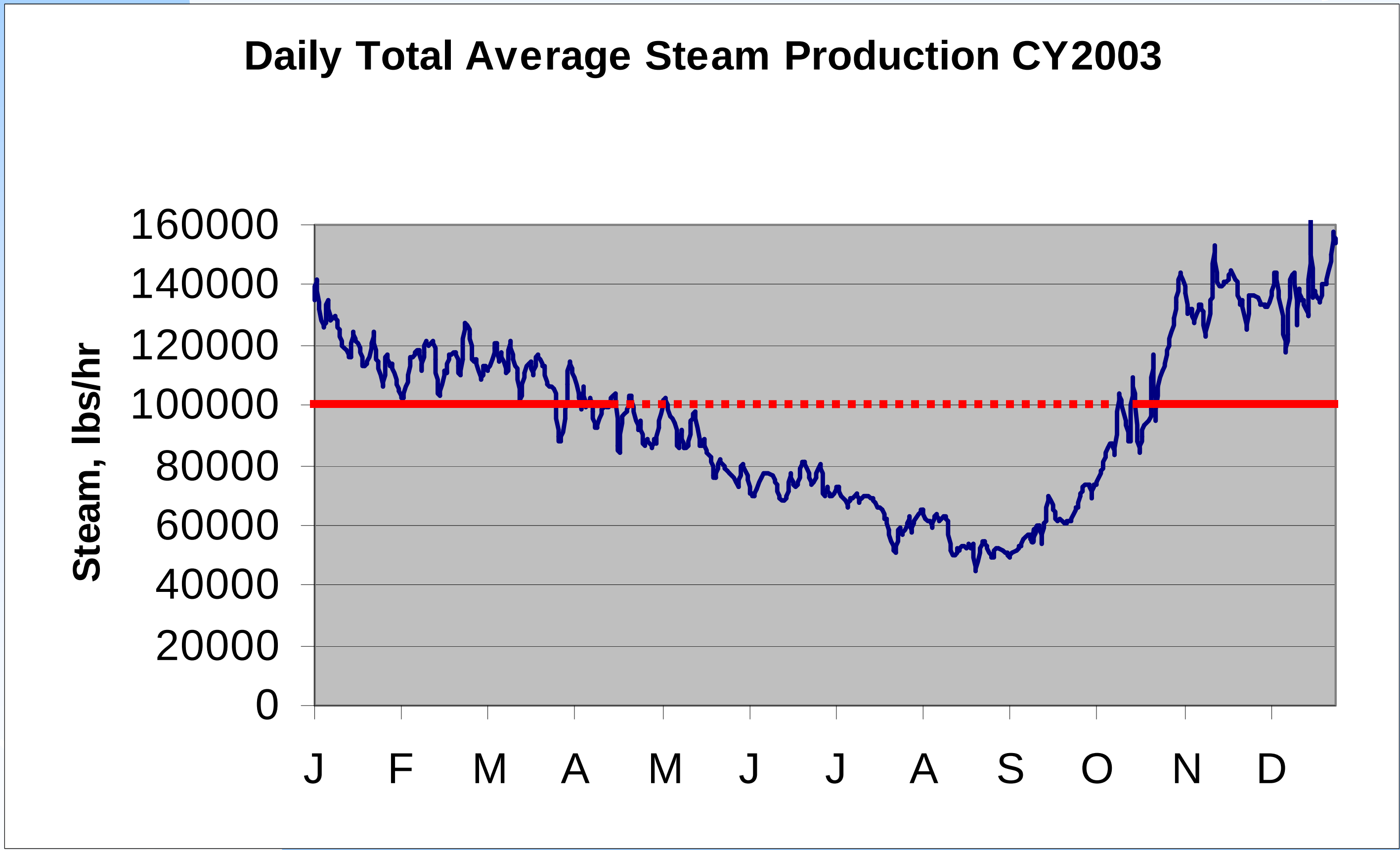
Main Steam Header BP Steam Turbine Design Flow (100,000 lbs/hour)



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Initial Analysis of 366 kW BP Turbine on Deaerator Steam Supply Line

Pressure Drop: 240 to 20-psig

Installed Generating Capacity: 366 kW

Annual Electrical Output: 3.2 million kWh

Increase in Fuel Use: 13,680 MMBtu/year

Equipment Costs: $180,000 (Source: Turbosteam)

Installation and Startup Costs: $170,000

Total Installed Cost : $476,735

Simple Payback, years: 17.8 years (at 3.44 ¢/kWh)

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PRV Station	Steam Pressure Reduction (psig)	Estimated Steam Flow, lbs/hour
1.	240-145	435
2.	240-145	5,830
3.	240-160	42,746
4.	240-110	7,318
5.	240-110	3,708
6.	240-110	6,809
7.	240-110	15,154
8.	240-90	6,616
9.	240-110	4,688
10.	240-110	30,683
11.	240-110	5,155
12.	240-110	2,858
13.	240-120	10,432
14.	240-110	36,782
15.	240-150	NA
16.	240-90	NA

Estimates of Backpressure Turbine Generation at PRV Stations

PRV #	Steam Flow lbs/hour (design)	Capacity kW	Output kWh
4	4,480	45	198,000
6	4,145	40	176,000
8	4,030	40	176,000
10	12,835	125	550,000
13	3,270	35	154,000
14	21,335	144	804,800

Backpressure Steam Turbine at PRV #14

Pressure Drop: 240 to 110 psig

Installed Generating Capacity: 144 kW

Annual Electrical Output: 804,800 kWh

Increase in Natural Gas Use: 3,430 MMBtu/year

Equipment Cost: $135,000 **(Source: Turbosteam)**

Installation and Startup Costs: $155,000

Total Installed Cost : $395,505

Simple Payback, years: 52.4 **(at 3.44 ¢/kWh)**

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Backpressure Turbine Economies of Scale

Main Steam Header BP Turbine:
$1,072,720/ 1,548 kW = $693/kW

Deaerator BP Turbine:
$476,735/ 366 kW = $1,302/kW

PRV #14 BP Turbine:
$395,010/ 144 kW = $2,743/kW

Utility Impacts of Two Turbine Project

1,914 kW, Cost is $1.55 million

Expected Electrical Generation:

14.5 million kWh per year (use down 5.9%)

Savings of $498,800 annually

Expected Increase in Natural Gas Use:

61,730 MMBtu per year (use up 6.2%)

Cost increase $362,355 annually

Utility Cost Savings: $136,445 per year

Simple Payback: 12.3 years

(assumes 3.44 ¢/kWh and $5.87/MMBtu)

Available Utility Incentives?

BPA Conservation Augmentation Program

Standard Offer Program Design Features:

The Bonneville payment is set at $0.12 per first year kWh for projects with a 10-year measure life, or 60 percent of actual project costs, whichever is less.

A key principle is that BPA funds must produce incremental conservation that would otherwise not be delivered.

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After Site Visit

---Site visit made by Turbosteam engineers

---Single superheater section constrains the system to providing 700 psig/525 °F steam

---Design steam flow rate increased to 112,920 lbs/hr

---Cost estimate includes piping, PRV station, and feedwater pump replacement with pumps rated for higher pressure

--- Electrical output adjusted to reflect increased feedwater pump use

---Turbine located in steam plant parking lot, requiring a small enclosure

The "Baseline" Project

- A 1,371 kW backpressure turbine exhausting steam into the main supply header at 240-psig
- Annual electrical generation is 9.3 million kWh
- Annual increase in fuel use of 39,528 MMBtu
- Net annual cost savings is $129,900
- Total Investment is $1,258,730
- Simple Payback is 9.7 years (at 3.8 ¢/kWh)

Can we do better?

Backpressure Turbine Optimization

Three Questions exist:

1. **Can we increase the power output by increasing the pressure drop across the turbine (by reducing the steam pressure in the main supply system)?**
2. **How would project performance and cost-effectiveness change if steam could be delivered at 150-psig?**
3. **What is the minimum supply steam operating pressure? Identify constraints.**

The *Heatmap* software tool was used to help answer these questions

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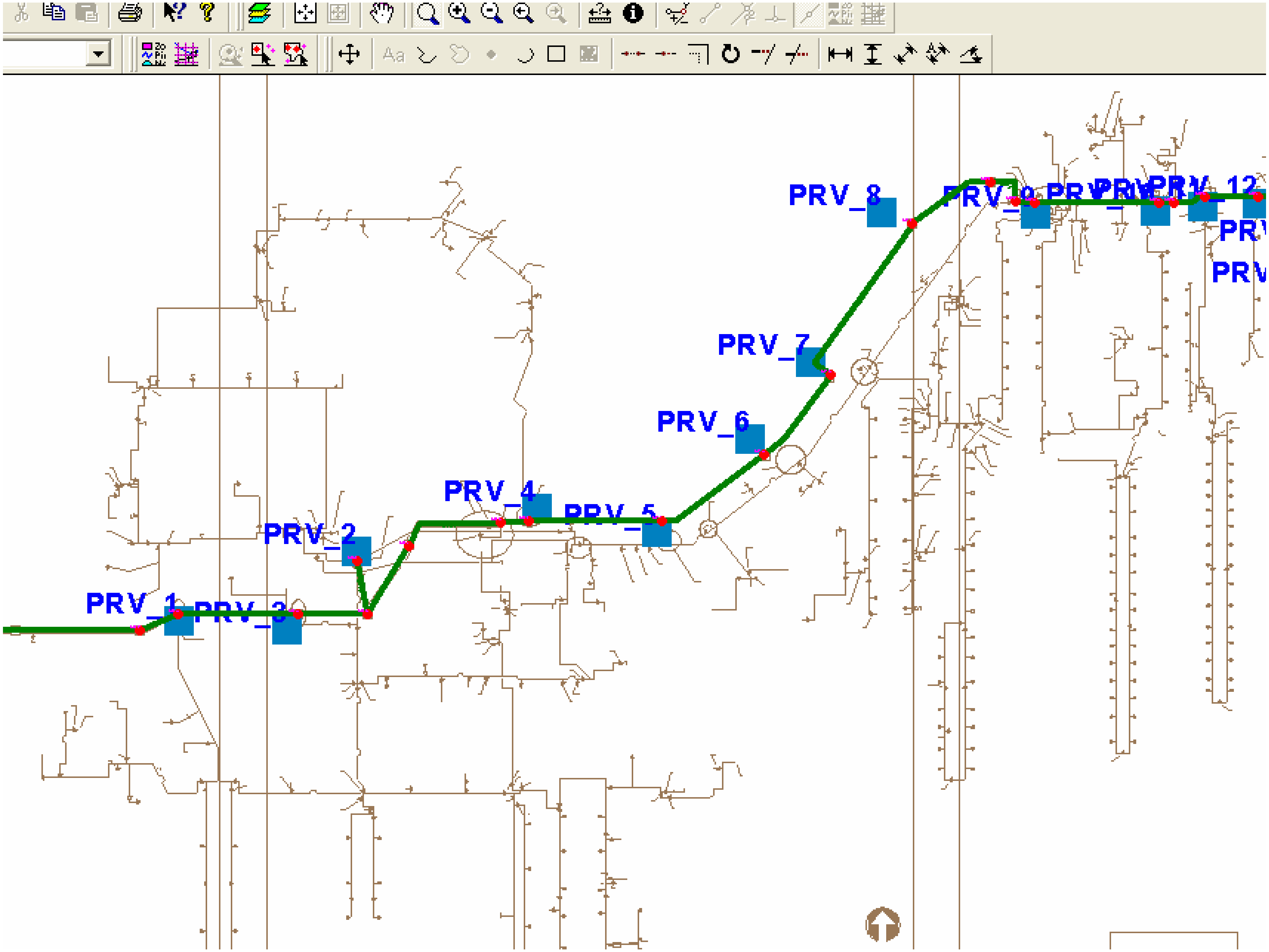
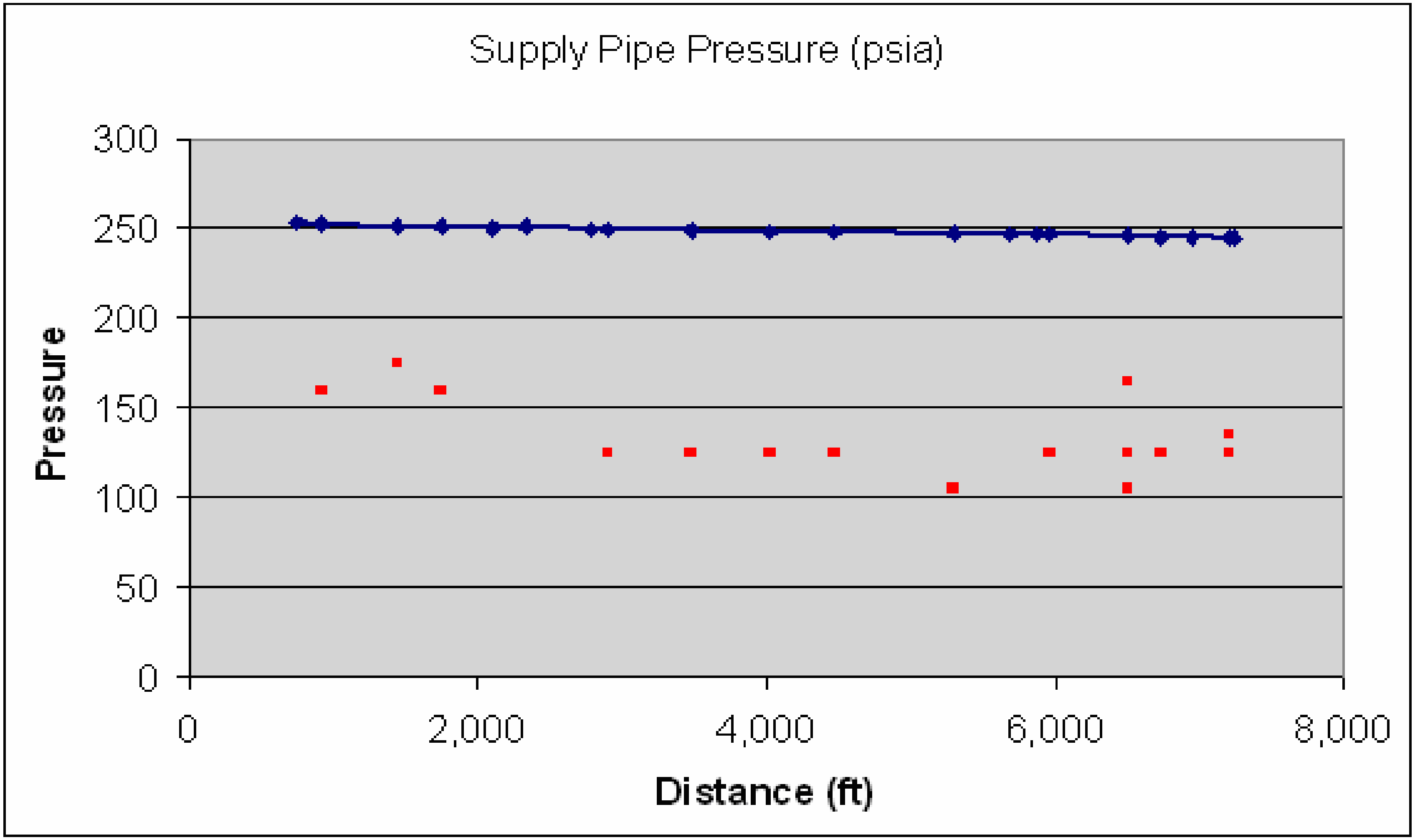
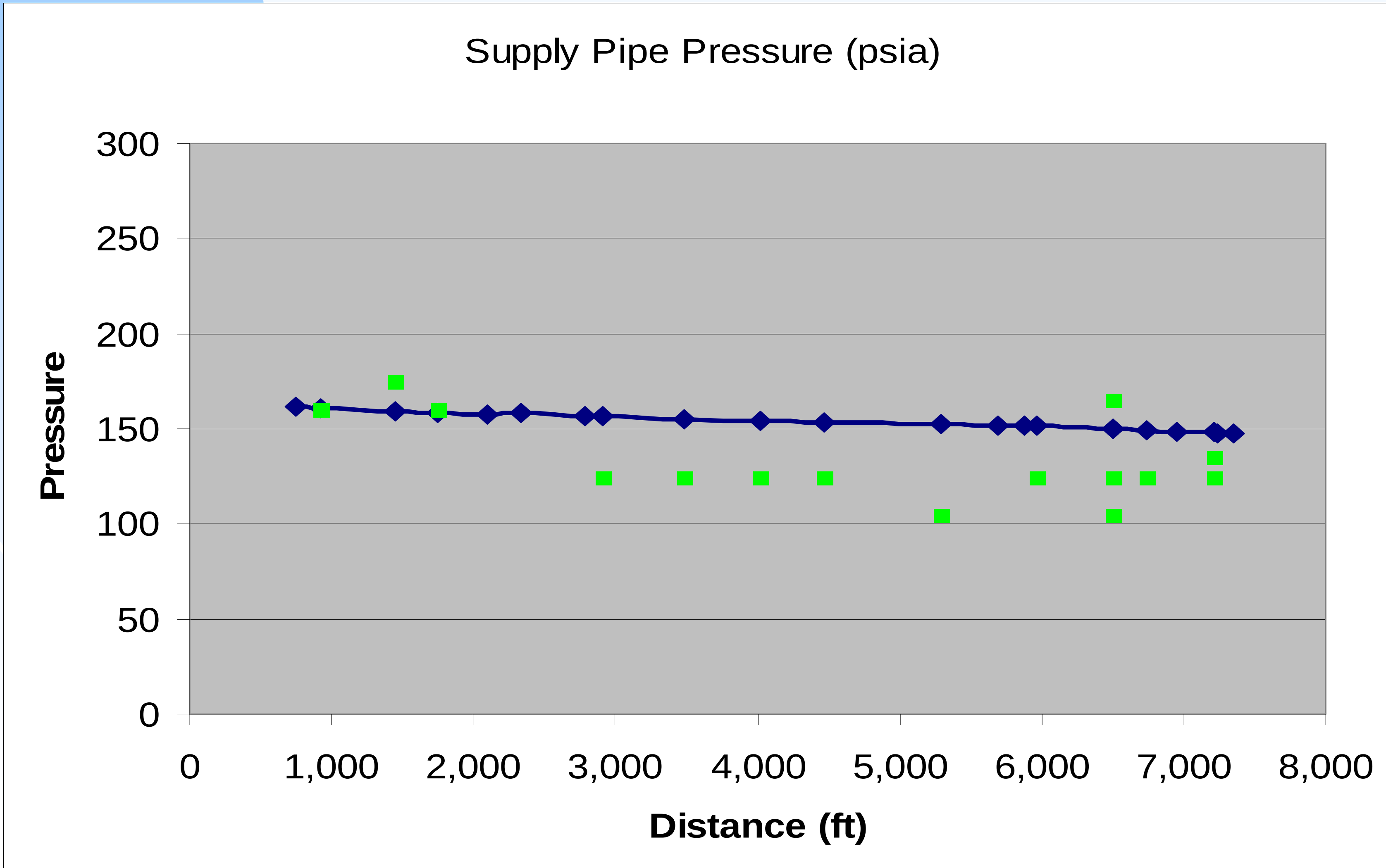

PRV_8
PRV_7
PRV_6
PRV_4
PRV_5
PRV_2
PRV_1
PRV_3
PRV_12

HeatMap Output: 16-inch Header Operating with 150-psig Saturated Steam

Pressure Drop at 240-psig
(total drop is 10.2 psi given a "worst case" steam load of 179,500 lbs/hour)



Pressure Drops at 150-psig Supply Pressure (total drop over length of line is 16.7 psig)



Detailed Look at Pressure Requirements

PRV #3 "Needs" 160-psig. Actual PRV setting is 112-psig. (Might reset to 140 to 150-psig if a carrier is tied up at pier). Provides 101-psig steam to drydock area. Laundries on vessels impose the highest pressure requirement of 100-psig.

PRV #15 "Needs" 150-psig. Actual PRV setting is 118-psig. Serves rubber (gasket) shop. Shop workers indicate that 125-psig is ideal. Steam pressure is regulated to 103-psig when silicone gaskets are being produced---to 75-psig for regular work.

PRV #10 Steam drop forge. Reduce to 90-psig.

Heat Loss Benefits/Costs

The heat loss through 16-inch diameter steam supply header insulation is reduced from 2.29 to 1.94 MMBtu/hour when the pressure is reduced from 240-psig to 150-psig.

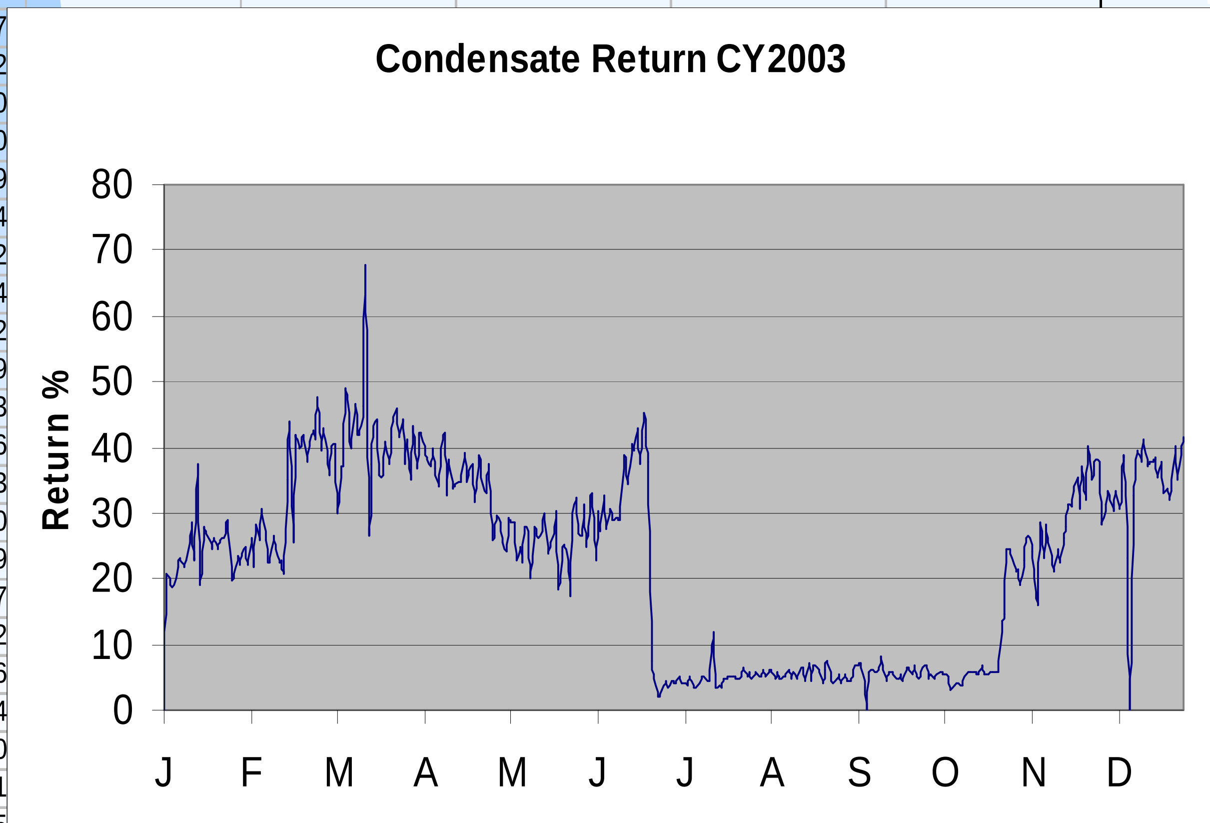
This loss reduction would save 3,650 MMBtu of natural gas annually at a savings of $21,425 per year.

Heat loss coefficients derived with 3E Plus 3.2

Condensate formation increases from 297 to 2,241 lbs/hour (loss of 3,370 MMBtu/yr if 50% return). More steam traps needed?

Deaerator Interaction/Full Condensing Economizer Considered

2914	243708	80	601950	23	267	834355
297						9945
292						1802
290						3082
280						0000
279						8373
274						1160
272						6668
284						4314
282						2343
279						2207
273						1537
276						6921
283						0609
290						3943
299						5819
287						1724
282						6849
296						0526
284						1729
280						8100
281						2997
285						0806



Comparative Economic Assessment

	240-PSIG EXHAUST 1,371 kW	150-PSIG EXHAUST 1,986 kW
Annual Generation, kWh/year	9,342,349	13,965,000
Value of electrical energy produced	$355,009 per year	$530,670
Less: Increase in natural gas usage	$209,107 per year	$312,580
Less: estimated annual O&M cost	$16,000 per year	$16,000 per year
= Net annual benefits	$129,902 per year	$202,090 per year
Base equipment costs	$521,690	$568,000
Total Installed Cost	$1,258,700	$1,380,790

Note: Within this Table, electrical energy is valued at $0.038/kWh. Natural gas is priced at $5.29/MMBtu.

Optimization Results

Total Installed Cost:

----1,371 kW Project (\$1,258,700 \$918/kW)

----1,986 kW Option (\$1,380,790 \$695/kW)

While the electrical output increases by 49.4%, the total installed costs increase by only 9.7%.

Simple Payback goes from 9.7 to 6.8 years

(3.8 ¢/kWh and \$5.29/MMBtu)

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Reasons for Economies of Scale

---Identical backpressure turbine frame

---Rated for virtually identical steam flow

---Identical piping modifications

---Same feedwater pump modifications

---Identical foundation and enclosure requirements

---Same controls and switchgear

---Same pressure reduction and isolation valve requirements

Slightly larger generator is required.

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What Happened?

Natural Gas Price Runup/Electric Rates Stable

Oct 2004	$5.56/1000 CF
May 2205	$7.39/1000 CF
Nov 2005	$10.12/1000 CF
May 2006	$8.01/1000 CF

No utility incentive. The project was categorized as a generation project rather than a conservation or efficiency improvement project. Diminished "Non-Wires" Program interest.

Source: EIA City Gate Prices

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