Integrating CHP into An Existing District Energy System

A Cogeneration Case Study

R. Gordon Bloomquist, Ph.D.
Senior Scientist
Washington State University Energy Program

Fred S. Hazard, Jr.
Valu Tek

A prime target for achieving the goals of the US Department of Energy's Combined Heat and Power (CHP) Challenge is the approximately 6,000 large, institutional complexes with large, aggregated loads that are already served by thermal distribution.

One of these institutions, the Washington State University (WSU), recently undertook an evaluation of the benefits of CHP to meet future electrical as well as thermal requirements. Although initially driven by an emergency need to replace an obsolete power plant, the opportunities that CHP could provide relative to meeting the University's need well into the future, while shielding the University from anticipated rate increases resulting from utility deregulation, quickly became the driving force.

The preliminary design adapted a phased approach to implementation of CHP that best meets the University's present situation, staying within budgetary constraints, and yet providing the flexibility to quickly respond to changes in electrical or thermal demand, sudden rate increases, or other unforeseeable circumstances.

The deregulation and restructuring of the electrical utility industry, recent developments in gas turbine generation, and a move to distributed generation development have all helped put increasing emphasis on developments of combined heat and power (CHP) projects. In December 1998, this led to the announcement of the CHP Challenge Program by the United States Department of Energy. The goal of the CHP Challenge is to double the CHP capacity in the United States by 2010, and by so doing, reduce emissions of carbon dioxide, SO_x, NO_x, particulates, and ozono-depleting refrigerants.

In the U.S., 6,000 large institutional complexes have large aggregated loads that use nearly one quad of energy that are already served by thermal distribution systems, i.e., steam, hot water, and/or chilled water district energy systems, but have little or no self-generation capability at this time.

A large percentage have central boilers to meet site thermal requirements that frequently suffer from oversizing and insufficient maintenance leading routinely to inefficiencies of energy delivered to load of below 60 percent.

The production and distribution of chilled water for cooling is also of increasing concern to many of these facilities. The use of CFC refrigerants is already being phased out and even the use of HCFC refrigerants is slated to be phased out by 2020.

At the same time, the need for cooling is continuing to increase and in many parts of the country, peak summer electrical rates are skyrocketing. Concerns over escalating electricity prices, and security of supply have caused more and more energy managers to seriously consider self-generation in the form of CHP.

Of the approximately 6,000 district heating and/or cooling systems that serve large institutional complexes nationwide, over 2,000 are college and university campuses.

Washington State University (WSU), located in Pullman, Washington, is one of these campuses. The campus has a student population of 17,000 plus (1999-2000). The campus is presently served by a central steam boiler plant with steam distributed at both 60 and 200 pounds throughout the campus via over 7 miles of tunnels.

Chilled water is provided from a central plant, and several distributed chiller plants are connected to the central chilled-water distribution loop. A 2,000,000-gallon chilled-water storage tank provides for peak demand and helps balance the distribution system.

In 1990, WSU began looking at the potential for CHP, but due to extremely low electrical rates in the northwest, the University made a decision to not pursue CHP development at that time. However, by 1999, the University found itself in an emergency situation—no longer able to meet the campus requirements for heating, and with boilers that were increasingly dangerous to operate due to age and a lack of maintenance.

This article is an account of the work that led to the decision by the University to pursue CHP and what additional steps need to be taken to ensure that the system designed will provide maximum reliability and benefit to the University, ensure highest possible fuel use efficiency, and be designed so as to easily meet the University's long-term growth projections and/or react quickly to changes in utility rate structures and costs that are anticipated once Washington electrical utilities are deregulated.

This report can help other colleges and universities, as well as other institutional facilities, address opportunities for the development of CHP while at the same time avoiding some of the missteps that were made at WSU due to the emergency nature of the project.

BACKGROUND

In September of 1999, the University President declared an emergency and commissioned a power plant evaluation study. The cause: a series of uncontrolled steam valve openings described by a bystander as "shotgun concerts."

The study found that obsolescence (the plant was built in 1939) and deferred maintenance created serious threats to the safety of the plant and plant personnel, as well as severely compromising the reliability of critically important thermal energy supplies to campus facilities. Because the University supports significant bioscience research, reliable supplies of heating and cooling are vital if years, if not decades, of research are not to be jeopardized.

The existing power house, dating from 1937, contains six boilers, two of which are regularly used while a third operated 85 days last year. Two burn natural gas and one fires coal. A back pressure steam turbine (BPST) rated 2.5 MVA provides an average of about 2 MWe to the campus while reducing 600 psig steam down to 60 psig for campus heating and other uses. Annual average total campus loads are about 17,000 kWe and 90 MMBtu/hr of steam, which is supplied at both 60 psig and 200 psig.

What to Do?

Universities exist to educate students and support research, so an infrastructure renovation potentially costing tens of millions of dollars loomed as a problem, not an opportunity. First thoughts turned to patching what could be fixed and replacing elements that were beyond repair.

However, many factors converged to show that a very wide range of options needed to be evaluated; among many others the most important were:

- How many years will the grandfathered coal-fired boiler operate under today's federal EPA rules, without incurring unacceptable emissions control expenditures?

- The University offers a classic opportunity for very efficient CHP generation, but the present plant seizes only a small fraction of the opportunity.

- Washington State has gone slowly on power market deregulation, but market forces throughout the West make it almost certain that Washington's very low electric rates will soon be a memory.

- The University has been incurring significant Operating and Maintenance (O&M) budget overruns.

ORGANIZING THE PROJECT

For decades projects have been conceived, designed and built by "project" organizations specialized in just those fields. Those organizations were measured by minimizing construction cost and duration. The plants they built were then "turned over" to "operating" groups who had to take what they were given and get the best results they could. In past years, "maintenance" groups commonly were separate organizations with different objectives.

The authors used a current organizational model to maximize results over the life of the project (Figure 1). We assembled a team of University people representing not just those who would plan or oversee the construction of a new facility, but more importantly, also those who will have to live with the results.

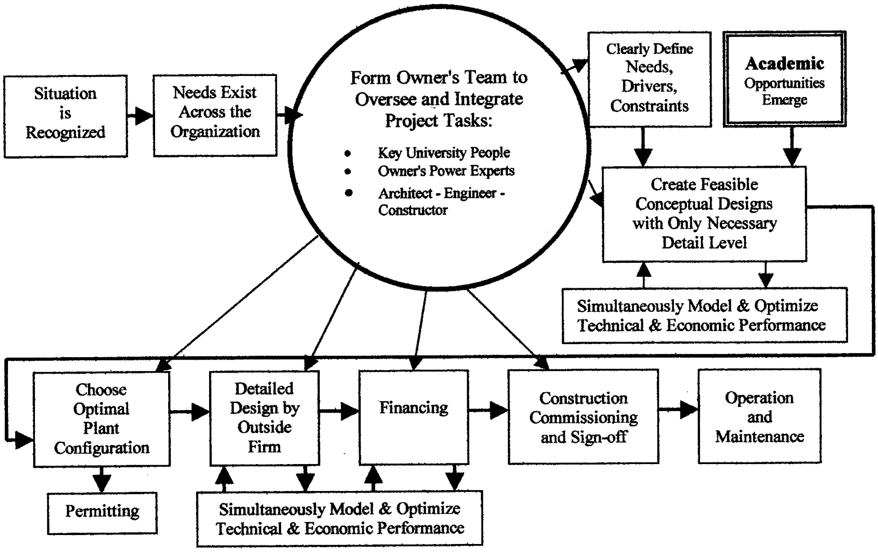


Figure 1. Today's Optimizing Approach to Power Projects

In order to determine how the University's energy needs could best be met well into the future, several alternatives were evaluated. These included:

- **Do Nothing** (emergency remediation is mandatory).
- **Make Only Steam**. Buy power.
- **Build a coal-fired ~10 to ~30 MW steam plant with a Back Pressure Steam Turbine**.
- **Build an ~10 MW plant "Minimum Electric Needs and Maximum Steam Demand."**
- **Build an ~30 MW plant "Peak Electric Needs and Maximum Steam Demand."**

Although these were the primary alternatives variations of each were also evaluated as were various alternatives to phasing the project. Figure 2 represents the pro-design schematic.

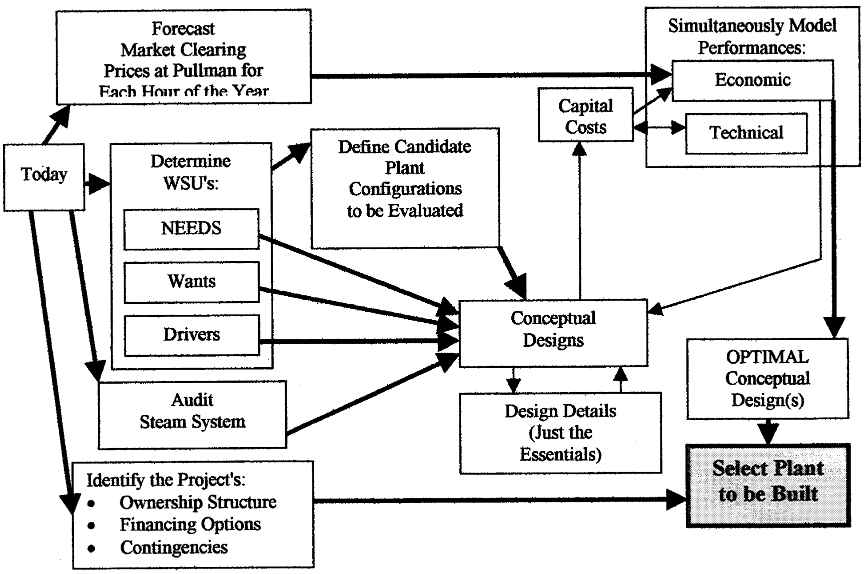


Figure 2. Going Forward: Pre-design Phase

Unfortunately for everyone involved with the project, its emergency nature resulted in an initial decision to limit the scope of the study to the power plant itself without any consideration being given to the steam and chilled water distribution systems or to opportunities for reducing electrical as well as thermal loads, Because of this, a number of very conservative assumptions had to be made that (at least through the pre-design study) did not allow for a true optimization of the design.

For example, bemuse of a lack of knowledge relative to steam distribution required to meet all projected loads, a decision to distribute steam at 200 lbs. was recommended.

Wants/Needs, and Constraints

Needs and constraints must be satisfied by the Optimal Solution, while **wants** receive significant consideration in the evaluation (each ones weight depending on its importance), but wants do not absolutely have to be met.

In order to best structure the design process, a list of University wants and needs was developed.

WSU Wants Included.

- **Build an innovative plant** that will inspire the entire University community with excellence (quality, reduced costs).
- **Reduce environmental impacts** as much as feasible, consistent with meeting all the University's needs for this plant.
- **Stay out of the power business**.
- **Hold the capitol budget under $25 million** if possible to remain within the Legislature's current expectations.
- **Identify important issues** in the University's energy delivery system to avoid future surprises, while clearly differentiating required power house renovations for actions needed beyond it.
- **Offer the ability to burn alternative fuels** that may become available from pilot plants.
- **Establish the fastest schedule** for the power plant renovation project that can be met and which does not compromise the quality of the outcome.
- **Fully remedy the current power house emergency** with this project, also accommodating forecast load growth for the intermediate term, while providing for future growth via modular additions and other foreseeable improvements.

WSU's Needs for the Power and Steam Plant Included:

- Maintain a record of personnel and equipment safety equal to the norm of the safest comparable cogeneration plants.
- Provide all steam demanded by the campus with reliability and availability comparable to other Best Performing thermal plants.
- Supply all electric power demanded by the campus as reliably as comparable "Best Performing" facilities.
- Optimize design, operation, and maintenance for lowest Total Life Cycle Costs (TLC) while meeting all other needs.
- Identify upfront the important Life Cycle Needs (O&M, etc.).

- Create very high operating flexibility for widely varying thermal and electric needs, T/E ratio.
- Provide for expandability, given many uncertainties in the future environment using modularity where possible.
- Because a serious emergency clearly exists **now, this is the time to fully rectify the situation without compromise** (a "ruthless assessment" is required, with a solution that uses no "half measures").
- Meet all current permitting requirements, including federal and state EPA.
- Black start capability.

Constraints Included.

- Maximum demands: 27 MWe and 416 MMBtu/hr of steam.
- Minimum Demands: 13 MWe and 48 MMBtu/hr.
- Range of Thermal/Electric (T/E) Ratios: 0.52 to 6.04
- Three Potentially Practical Sites: At or near current power house, at steam tunnel near campus center, or east campus.
- Existing steam distribution system is in poor condition and will require an uncertain pressure between 60 to 200 psig.
- Old, inadequate, and uncalibrated instrumentation creates ~20 percent uncertainty in steam demand data.

A paradigm commonly used by today's progressive owners **minimizes the Total Life Cycle Costs (TLCC)** of facilities. This calls for an objective function including long-term O&M costs as well as the facility's initial Capital Cost. **The optimal solution minimizes the Net Present Value (NPV) of all life cycle costs** using appropriate assumptions of capital cost and expected inflation rates.

We strongly prefer a more sophisticated objective function that **includes all revenues the plant is expected to produce, net of the costs required. The optimal solution maximizes the NPV of all <u>Net</u> Revenues**, quantifying the effect that incremental capital costs will have on plant flexibility and its ability to produce more output when the product is uncommonly valuable.

An example combined-cycle/CHP plant might include an "over-sized" heat recovery steam generator (URSG) and uncommonly heavy supplemental firing **capability**, to be used during periods when de-regulated power markets create prices rising to hundreds of dollars per MW-hr.

Both of the methods cited above, and most optimizations, assume that financial performance is essentially the only consideration in the objective function. **This case is different because the University deems criteria other than financial performance to be critically important.**

We had to "work through" many differing, often conflicting "wants," concerns, and "views of the future" held by important members of the University community. We used regular Team meetings and a modified brainstorming format to develop a full Situation Analysis, first separating **true Needs and Constraints** from Wants.

OTHER DESIGN CONSIDERATIONS

The Situation Analysis helped us identify a number of design considerations and strategies in addition to those stated above. The most important of these are listed below.

Design Strategies and Considerations

1. Eliminate single points of failure.
2. Identify and minimize single events that can impact redundant elements.
3. Employ 3 × 50 percent elements.
4. Identify and prepare strategies against single failures that become critical if they occur during maintenance procedures.
5. Maximize modularity to improve capacity reliability and expandability.
6. Incorporate fuel flexibility.
7. Consider extremely heavy supplemental firing for emergencies.
8. Develop maintenance strategies to maximize reliability and utilization.

As members of the technical team, we developed customized emulations of each Finalist Candidate Plant using a Multi-Purpose Technical-Economic Performance Model.

Based on model outputs from the pre-design study, the optimal plant designed to meet preset as well as future anticipated load growth, i.e., 20-year horizon, turned out to employ 3 × 10 MW-class combustion turbine (CTs) and 1 × 10 MW back pressure steam turbine (BPST).

THE OPTIMAL PLANT

After identifying the approximate configuration of the Optimal Plant we performed extensive "what if" studies using the Technical-Economic Performance Model. This resulted in several design approaches seldom used in plants of this size and type.

One example is an HRSG with two pressure levels and more surface area than is normally used with machines this size. Two pressures were used, and the surface was increased until the incremental future operating savings created by increased heat recovery approached the cost of the surface area added to recover it.

Important Plant Attributes Include:

- The basic design philosophy of this plant is to follow electrical demand by varying the number of CTs on line and their firing level. Steam demand is met simultaneously by adjusting duct firing as needed. While the plant must be able to supply steam demanded down to –40°F ambient with any major element failed, **economic considerations drive how it accomplishes this**. In well designed CHP plants additional supplemental firing produces incremental steam extremely efficiently, This plant operates in this mode most of the time.

  However there is a limit to the flexibility that can be designed into any HRSG without incurring excessive capital cost, seriously reduced efficiency under some conditions or both. For this reason this plant uses conventional package boilers to supplement the HRSGs under the very coldest conditions, about to 5% of the time.

- The plant can supply maximum design case (–40°F ambient) steam with any one major element (CT, ST, package boiler, etc.) failed. **This drives steam capability.**

- It can make full summer peak power at a dry bulb ambient of 102°F with only 0.6% probability of demanding peak power from the standby tie, assuming competent maintenance. **This prepares for high spot electric rates after deregulation.**

- It can supply **all the University's planned needs for steam and power for the next two decades**, insulating WSU against electrical power price increases likely as power markets deregulate.

  Total self-sufficiency and cost escalation insulation have been given significant weight, because WSU has experienced difficulties in obtaining capital budget monies to quickly address unexpected uncontrollable operating cost increases.

- One unit (CT and/or HRSG) can undergo maintenance in shoulder season with almost no risk of purchasing power. An emergency weekend outage during summer or winter could replace a CT or perform significant HRSG repairs with very low exposure to significant power purchase costs.

- An average of 14 MW of power over WSU's needs is available (varying widely over the year), created by the necessary redundancies stated above. We agree with the choice to not become a proactive power marketer.

  However, buying and reselling energy from WSU on request may well be attractive to the standby power provider, creating an **unquantified** upside.

- The design includes a provision to let down BP steam around the BPST to supply the Campus, primarily for use during maintenance and in emergencies. Pending a parallel study, we don't know with certainty the pressure vs. flow characteristics of the steam distribution system.

  University experience shows that 60 psig will move the steam needed ~90 to 95% of the time, so we chose this level for economic reasons. The pressure reduction and de-superheating system that parallels the BPST will move higher quantities.

If the Final Distribution Study shows that a pressure significantly lower than 60 psig will suffice for more than 90-95% of the time, that pressure should be carefully considered for economic improvement.

- The University has experienced significant power quality issues, including fractional-second outages due to recloser operation,[1] longer outages, voltage sags and surges. **Improved power quality and reliability will be additional benefits, which we have not quantified.**

A summary of characteristics of the operating system is shown below.

An overview diagram of the optimal plant follows, including technical performance parameters for operation during several common operating periods and modes.

Following that are technical performances averaged over each operating period (see Summary Characteristics of Operating Periods, Optimal Plant Conceptual Design [Scenario III], and 3 × 10 MW × 1 × BPST: Operating Summary).

PHASING THE PROJECT

As the project neared completion, questions arose about financing any capitol cost—significantly over $25,000,000. The team was asked to develop an Optimal Design for a revised Objects Function: Consider capitol cost = $25,000,000 a **Constraint**, not a **Want**.

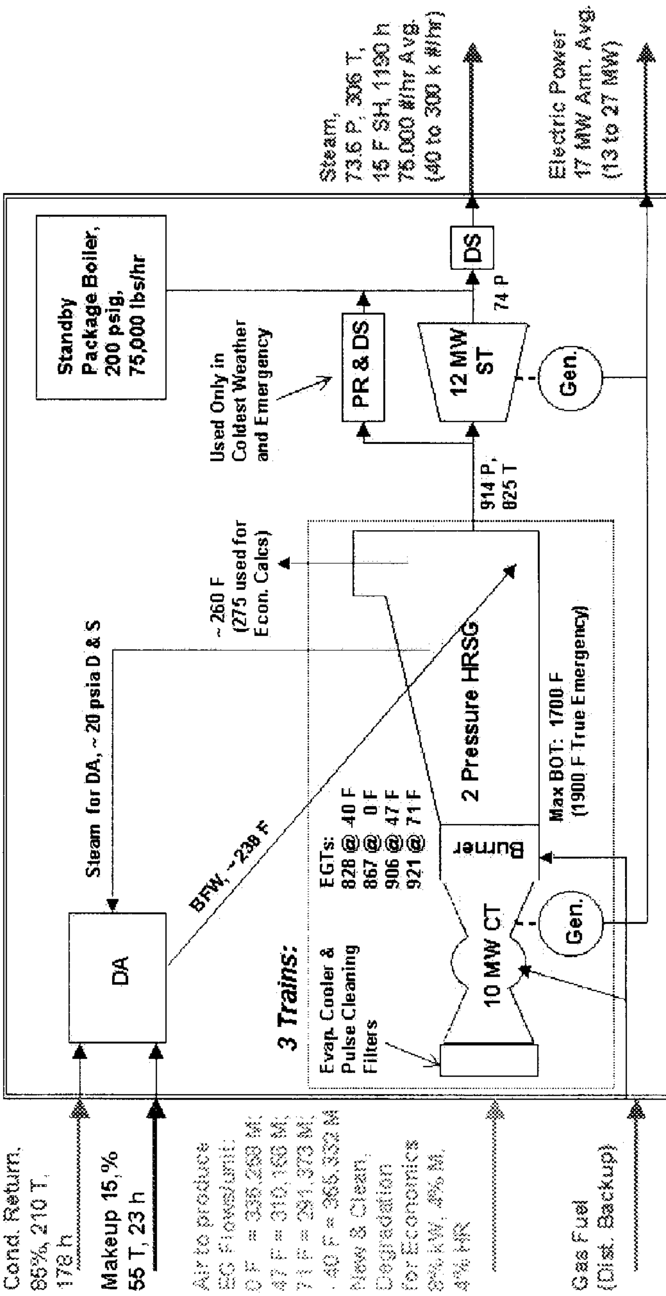
Fortunately, consideration had already been given to a phase approach and careful evaluation had been given to a "Drop in a Future CT" (and other "Future Drop in Items" as well).

As a result, a $25,000,000 "Scenario II" that preserves the benefits of CHP and avoids the very undesirable non CHP scenario that would lock WSU into conventional steam generation and purchase power for decades was avoided.

Scenario II is basically a phased implementation of Scenario III, the optimal configuration.

Summary Characteristics of Operating Periods

Operating Period:		Temps: DB, WB, Compr. Inlet (deg. F)	Steam Demand Today (lbs/hr)	Steam Average Demand Forecast (lbs/hr)	Power Average Demand Today (MW)	Power Average Demand Forecast (MW)
Shoulder	00:00 to 06:00	40, 35, **36**	**92,500**	97,000	**13.5**	*14.2*
	06:00 to 10:00	46, 39, **40**	**96,500**	101,500	**17**	*17.9*
	10:00 to 17:00	57, 49, **50**	**71,500**	75,000	**20**	*21*
	17:00 to 24:00	47, 39, **40**	**80,000**	84,000	**17**	*17.9*
Summer	00:00 to 06:00	54, 46, **47**	**42,000**	44,000	**14**	*14.7*
	06: to 10:00 &					
	18:00 to 24:00	69, 55, **57**	**42,000**	44,000	**18**	*19*
	10:00 to 18:00	79, 63, **65**	**46,000**	48,500	**22**	*23*
	Highest Peak Elec.	102, 66, **71**	**46,000**	55,000	**27**	*27*
					(New Chilling by Abs.)	
Winter	00:00 to 06:00	26, NA, **26**	**101,000**	106,000	**13**	*13.7*
	06:00 to 10:00	32, NA, **32**	**117,500**	123,500	**17.5**	*18.4*
	10:00 to 13:00	39, NA, **39**	**117,500**	123,500	**21.5**	*22.5*
	13:00 to 18:00	39, NA, **39**	**101,000**	106,000	**21.5**	*22.5*
	18:00 to 24:00	32, NA, **32**	**101,000**	106,000	**17.5**	*18.4*
	Highest Peak Elec.	–40, NA, **–40**	**307,000**	337,000	**17.5**	*18.4*



Optimal Plant Conceptual Design (Scenario III)

3 × 10 MW × 1 × BPST: Operating Summary

Operating Period		CTs on Line	CT Load (%)	ST Load (kW @ 100% Flow thru ST)	Duct Firing Δ T (deg. F)	Steam Gas Temp. (lbs/hr)	Stack Gas Temp. (deg. F)	Thermal Efficiency
Shoulder	00:00 to 06:00	2	51.4	4,622	457	1	270	76
	06:00 to 10:00	2	51.4	4,622	457	1	270	76
	10:00 to 17:00	2	92.9	3,572	12	0	275	72
	17:00 to 24:00	2	92.9	3,572	7	0	270	72
Summer	00:00 to 06:00	2	66.1	2,608	9	10,188	290	60
	06:00 to 10:00 & 18:00 to 17:00	2	79.4	3,001	0	56	285	70
	10:00 to 18:00	2	93.2	3,470	0	1,454	275	71
	Highest Peak Elec.	3	100.0	5,276	0	52,962	275	52
Winter	00:00 to 06:00	2	45.1	5,046	586	0	275	77
	06:00 to 10:00	2	63.7	5,971	589	0	275	77
	10:00 to 13,00	2	86.3	5,871	429	0	270	77
	13:00 to 28:00	2	90.5	5,046	266	0	275	75
	18:00 to 24:00	2	68.7	5,047	406	0	275	76
	0 F Hi Percentile Case							
	Highest Peak Steam							
Annual Average						**1,017**		

(**Note**: 8% average CT power, 4% heat rate and mass flow degradation, and 2% average ST degradation are included)

Phase I

In Phase I, the existing plant is shut down during demolition and construction. During this time, WSU makes steam using two pre-purchased packaged boilers and two rental units. One of these is on-site only during the coldest three to four months of the year as insurance against extremely cold weather. During this time, WSU will continue to buy power from the serving utility.

During the Phase I construction period, the power house asbestos is property abated and the existing equipment removed. Foundations are poured for all three of the proposed Scenario III CTs and HRSG trains.

In short, the power house interim site is made ready to accept all power island equipment required by the Scenario III plant.

One CT - HRSG train is then installed and commissioned to operate in conjunction with the existing 2 MW BPST.

Phase II

This provides the framework necessary for implementation of Phase II as required by the University to meet future growth and/or quickly react to changes in electrical rates that are anticipated when utility deregulation is fully implemented in Washington State.

And, in fact, it is not necessary to accomplish all of the Phase II at one time. There is no reason why a second CT-HRSG train, and/or a larger and more efficient BPST, and then a third deferred performance-driven item(s) couldn't be phased in a step at a time.

Though driven initially by the fiscal constraints placed on the project by the University, the phased approach also gained a great deal of support due to the flexibility that it affords the University without any major constraints to meeting future circumstances or opportunities.

This is especially true considering that the initial predesign study was limited to looking only within the "boundaries" of the power house.

THE THERMAL DISTRIBUTION SYSTEM

The University's thermal loads (heating and cooling) are served by steam and chilled water loops that connect the central plant to the various academic, administration, and research facilities as well as on-campus student housing. The loads in those facilities as well as the efficiency of energy delivery thus play a major role in determining overall thermal demand that is placed on the central power plant.

Because of the emergency situation that existed at the power plant, little or no real consideration was given to the role of either the thermal distribution system or the building loads.

However, it quickly became evident to the team that without an evaluation of opportunities to reduce end use demand and a thorough evaluation of the thermal distribution system to optimize steam and chilled water delivery, an optimum power plant design was not possible.

A parallel effort was thus commissioned to, at a minimum, evaluate the steam and chilled water distribution system. The University's steam distribution network consists of over seven miles of pipes, valves, and traps that have suffered from the same maintenance limitation that impacted the power house.

It also remains "encapsulated" in asbestos. In addition, numerous leaking heat exchangers and flooded condensate sumps seriously contaminate the condensate return resulting in serious maintenance problems. A loss of condensate as high as 25 percent is not uncommon.

The primary question for the power plant design was what steam pressure would be required to meet the thermal demand of the entire campus. The initial assumption that 200 lbs. was necessary was based on a lack of capacity at some buildings during peak heating periods.

However, increasing most of the steam lines from 60 lbs. to 200 lbs. would cause major safety problems, result in a significant outlay of capitol, and result in a significant reduction in electrical generation by extracting steam at 200 lbs. from the BPST.

In order to model the entire system, it was loaded onto WSU-developed software that allows for a complete hydraulic analysis of flows, pressures, and temperature, and also allows for accounting for both thermal and fluid loss.

The results of the model indicated that the minimum supply pressure required for the campus steam plant at 264 Mlbs./hr. peak demand with a switch to a single pressure system is approximately 110 psig after applying a 10 percent safety factor. The model returns a 56 psig required at a 120 Mlbs./hr. part load, after adding the 10 percent safety factor.

The model also identified a number of bottlenecks that, if corrected, could result in further decreases in required steam supply pressure. Of course, additional savings can be expected if there is an aggressive program initiated to maintain traps, minimize thermal lows by installing proper insulation, and repair leaking heat exchangers.

The chilled water system was analyzed not so much to determine areas for savings, but instead to identify the capability to support increased amounts of thermally activated chiller equipment. The proposed CHP plant would have significant amounts of excess steam available during summer operation to be used to drive either steam centrifugal or absorption chillers, thus reducing the need to operate electrically driven chillers.

This could result in a 3-5 MW reduction in summer peak demand for electricity as well as improve fuel use efficiency at the power plant. The chilled water system was modeled using the same model used for the steam system.

Results from the chilled water model indicate that once again there were considerable bottlenecks in the system, and that if it should become desirable to supply 50 percent or more of the system load during peak conditions from the thermal storage unit, several runs of pipe would have to be replaced with larger diameter pipes.

To date, no evaluation has been made as to reductions in load that could be accomplished through conservation or better load management. **However, early projections based on similar studies at the University of Washington indicate that a 5-7 percent decrease in end use consumption is feasible.**

Although it would have been preferable to take a systematic approach to the entire system, the emergency nature of the situation precluded this.

It is hoped that, prior to commencing with final design, considerably more attention will be given to optimizing thermal distribution and to seriously evaluating opportunities for load reduction.

THE BOTTOM LINE

The Optimal Plant fulfills all Needs and Constraints, and the most important University Wants. The CHP solution saves MANY tens of millions of dollars in TLCC^2 for the University over the next 20 years. The phased approach to implementing the project provides maximum flexibility, preserves a CHP option, and allows the utility to

easily respond to increases in load, major utility rate increases, or unforeseen circumstances.

References

1. One occurred while we were observing power house operation and did considerable equipment damage; after brief investigation we immediately recommended that a study covering protection philosophy and relay application and coordination is needed.
2. Because negotiations, including procurement discussions are underway as we write this, we are presenting approximate economic figures and sensitivity information on a relative basis.

About the Authors

R. Gordon Bloomquist, Ph.D., Washington State, manages the university's geothermal, CHP, and integrated community energy systems programs. He began working for the Washington State Energy Office in 1980 (now the Washington State University Energy Program). He has been a visiting professor at the School of Geothermics in Pisa, and an adjunct professor at Evergreen State College where he teaches energy and the environment.

Dr. Bloomquist is a member of the International District Energy Association. He served as board member and president of the Geothermal Resources Council. He is chairman of the Education Committee, International Geothermal Association . Dr. Bloomquist has authored over 100 articles and books. He received his masters and Ph.D. degrees in geology and geochemistry from the University of Stockholm.

Washington State University Energy Program, P.O. Box 43165, Olympia, WA 98504-3165; (p) 360-956-2016, (f) 360-956-2016, (e) bloomquistr@energy.edu.wsw.

Fred Hazard, Principal, Valu Tek, is an independent consultant in economically optimizing power generation and CHP design, operation, maintenance, and reliability. He also helps clients prepare for market deregulation, and with other technical and strategic planning issues.

His expertise ranges across electric power and steam generation, distribution, and control design, crossing many industrial and geographic regions.

Prior to becoming an independent consultant, Fred had a long career with Westinghouse Electric, progressing through a series of management positions in strategic planning, application engineering, marketing, and design optimization.

8634 Amber Oak Dr., Orlando, FL 32817; (p) (f) 407-679-7007; (e) hazardfred@aol.com