PENNSTATE

**Penn State Facilities Engineering Institute**
College of Engineering
The Pennsylvania State University
Marion Place, Suite 414
135 East Nittany Avenue
State College, PA 16801

Phone: (814) 865-7615
Fax: (814) 863-7835
Fax: (814) 865-9303

April 17, 2006

Mr. Lance Bryson
Director of Physical Plant
Shippensburg University/Reed Operations Center
1871 Old Main Drive
Shippensburg, PA 17257-2299



***Subject:*** ***Review of Abacus Steam Plant Study***
***PSFEI Report MR 05/06 - 8***

Dear Mr. Bryson:

Per your request, PSFEI has reviewed the TAC (previously Abacus) steam plant study document generated as part of their Guaranteed Energy Savings Project at your facility. Mr. Bob Becker (Mechanical Engineer: HVAC Systems) and Mr. Wayne Macafee (Mechanical Engineer: Central Heating Plants) have provided input and analysis for this report. Our review was conducted based on costs, technical accuracy, feasibility, and campus needs. Comments, discussion, recommendations, and details of alternate options are presented below. We also developed a basic scope and costs to add a central chilled water plant to provide cooling to all campus buildings. Limited discussion is provided on this subject.

## Comments on Base Document

1. In our opinion, reasonable costs are presented for the indicated scope in each of the options.
2. TAC approached the financial analysis from a savings standpoint and used NPV (Net Present Value) for project financial comparison. This method would appear to be useful only if the intent was to use a Guaranteed Energy Savings Project to cover the difference between available and required capital. If that is not the case, a more useful analysis and comparison would be based on life-cycle costs or some derivation thereof.
3. We note, as did TAC, that the capital currently allocated for the steam distribution system upgrades (Option 1) is not sufficient to cover the necessary project scope (replace all steam and condensate piping as well as install appropriately-sized piping). We estimate that an additional $3,000,000 would need to be added to cover the required scope, bringing the cost for the steam distribution project to approximately $9.7 million.
4. The list of boiler plant work is very complete and detailed for the base option (Option 1); however, there are several work items included that we do not consider to be absolutely necessary for continued plant operation over the next 25 years.

a. Extension of the coal bunker and associated conveyor. In the TAC study these items are included as part of the total cost of a group of items titled "Structural and Operational Upgrades." Currently two different sizes of coal (barley and buckwheat) are maintained in the bunker. This effectively limits storage capacity for each size of coal. Given the intent to replace the stoker on Boiler 4 and to make that grate capable of firing barley and eliminate the use of buckwheat, this will increase the storage available for barley. Therefore, addition to the bunker and coal conveyor is not considered to be necessary. We estimated the cost of bunker/conveyor work to be $500,000 leaving $975,000 for the remaining items in the Structural and Operation Upgrades group.

b. Re-tubing of Boiler 4. Based on discussions with boiler plant operating staff, Boiler 4 has not suffered the water-side scaling problems present on the other three coal boilers. As such, we do not believe that a tube replacement project is warranted at this time. It is, however, possible that tube replacement could become a need over the next 25 year period. In the case of Boiler 4, expenditure of approximately $10,000 for a tube life study would be a good investment for planning purposes. Removal of re-tubing for Boiler #4 eliminates approximately $740,000 from the boiler plant project.

c. Installation of dual or tri-fuel capability on Boilers 3 and 4. Other than adding flexibility in fuels and some amount of improved reliability, this item serves no real purpose for the plant. In fact, operating costs would increase as a function of blending in the higher costs of gas and/or oil versus that of coal. It is, therefore, our opinion that addition of multi-fuel capability can be eliminated, thereby removing approximately $1.68 million from the boiler plant project.

d. Installation of a baghouse to reduce particulate emissions from Boilers 1 and 2. Costing generated by TAC for particulate control was somewhat confusing. Extra dollars were added to the dual/tri-fuel capability items to cover particulate control for Boilers 3 and 4. The separate baghouse item was solely for Boilers 1 and 2 at a cost of approximately $773,000. The capital dollars originally planned for Boiler 4 (stoker replacement, re-tubing, and dual/tri-fuel) exceeded 50% of the estimated replacement cost (in-kind) for a boiler ($2 to $2.5 million). The cost of re-tubing and installing multi-fuel capability on Boiler 3 was also very close to 50% of estimated replacement cost. This would trigger NSR (New Source Review) for at least Boiler 4, and potentially subject the plant to NSPS (New Source Performance Standards) for emissions. Applicability of NSPS would require a baghouse to meet particulate limits and TAC included particulate controls to cover this eventuality. However, removal of multi-fuel from Boiler 3, and re-tubing and multi-fuel from Boiler 4 brings the dollars expended for both boilers below 50% of estimated replacement cost. We can also reasonably expect that the project will <u>not</u> increase total emissions, which eliminates the other potential trigger for NSR. It should also be noted that stack testing in 2003 on Boilers 1, 3, and 4 indicated average particulate emission rates that are well below the current limit of 0.4 lbs/mmbtu (Boiler 1 at 0.172 lbs/mmbtu, Boiler 3 at 0.195 lbs/mmbtu, and Boiler 4 at 0.292 lbs/mmbtu). Because Boiler 2 is the same type and construction as Boiler 1, it was deemed to be un-necessary to test Boiler 2 and reasonable to assume that emissions would be comparable to Boiler 1. Therefore, we do not believe that NSR will be triggered by the revised project scope and we consider a baghouse unnecessary. However, it will be a requirement to submit a Request for Determination for Plan Approval/Operating Permit form to PADEP (Pennsylvania Department of Environmental Protection) as soon as the boiler plant project scope is finalized. If a plan approval is ultimately determined to be required by PADEP, this will allow time for preparation, submission, and review (can take up to six months) of the application package prior to the start of work.

e. Removal of these four items from the boiler plant scope has reduced the estimated cost to approximately $5.8 million. This brings the estimated capital cost for the revised Option 1 to approximately $15.5 million.

5. TAC evaluated a total of seven options, only one of which, the original baseline option, retained the existing steam plant. All other options were based on a completely new boiler plant, primarily on the premise that the campus was growing away from the existing plant and difficulties were encountered in maintaining steam pressure at the most distant locations in high-load conditions. Based on discussions with you and your staff it was determined that the campus footprint will expand very little, and pressure difficulties are encountered only when the 8-inch main is attempting to carry all campus steam load at high load conditions. This effectively eliminates the main premise for building a new boiler plant. Additional difficulties with building a new plant include, but are not limited to, finding the land on which to build, and the plant would be subject to NSR and NSPS requirements. Attempting to retain coal as a fuel source will then require at least a baghouse for particulate control and, potentially, a scrubber for acid gas control. To escape the need for pollution control devices the primary fuel would have to be natural gas. Shippensburg University would then face significantly higher costs for fuel as well as the high level of uncertainty in natural gas pricing.

6. It is unclear in the TAC financial analysis whether or not complete operating and maintenance cost assessments have been included for the different cases. We believe that only partial utilities and deferred maintenance costs have actually been included, thereby potentially providing savings/NPV values that are not true indicators for project viability.

7. The new plants (steam to hot water) described for TAC Options 2A (coal, gas, and oil) and 2B (gas and oil) are well conceived and would bring a number of benefits to the University: improved boiler efficiencies, hot water heating with lower piping-heat losses, electrical generation, and emission controls. However, we do have questions and concerns regarding the financial and technical information provided in the report generated by TAC.

   a. As previously mentioned, location and land availability are an issue. There are only two sites at the periphery of the campus that would make the new plant cost effective by minimizing distance for pumping the hot water. These sites may not be available or suitable. The locations are at either the north or south side of the narrow section of the campus (essentially centered between the two proposed hot water heating loops). Other sites would increase distance from the heating loops and, thereby, increase piping-heat losses and the pumping power required.

   b. There will be a noticeable increase in utility usage (electric and/or steam) for pumping the hot water. While the electrical usage reduction from the new turbine generator is included in the financial calculations, we were unable to find where the pumping power consumption increase is factored in. If not included, this could make the calculated savings significantly higher than would actually be realized.

c. TAC indicates that the new plant would operate all year. It is unclear what heat load would justify operating the plant during the summer. This might be feasible if one of TAC Options 3A/B or 4A/B (adds chilled water systems) were selected and absorption chiller units were used.

d. TAC indicates that only one coal boiler would be installed in the new plant under Option 2A and all remaining boilers would be gas/oil. In order to make as much steam as possible with the lower cost fuel (coal), this would force the coal boiler capacity to be quite large. The turndown for a large capacity boiler would make it impractical or impossible to operate during transition and summer months (without absorption-based chilling), thereby forcing operations to shift to the higher-cost fuels (gas/oil). We are not convinced that a single, large coal-boiler design is the most practical or cost effective. In order to maximize coal use, two or more coal boilers of smaller or differing capacities would be necessary. This would, of course, increase the capital cost of Option 2A.

8. In Options 3A, 3B, 4A and 4B (addition of chilled water), we are unable to find where increased pumping power consumption or the increased maintenance associated with the added equipment has been factored in. These two items will reduce the savings dollars associated with Options 3A and 4A, and make the savings more negative for Options 3B and 4B.

## Alternative Option(s)

PSFEI previously discussed a potential option with you and your staff that retained the existing steam plant and incorporated a hot water system similar to that proposed by TAC in Options 2A/B, 3A/B, and 4A/B. It was essentially a combination of the Boiler Plant work in Option 1 and the hot water generation and distribution systems in Option 2A/B. The difference being the TAC system converts to hot water at the new steam plant while the alternate system uses steam from the existing plant and generates the hot water at two satellite conversion plants on campus. Interest was expressed in that the problem with locating land to build the new plant was eliminated, it retained existing boiler plant hardware that still had serviceable life (with upgrades), and would reduce maintenance costs by eliminating the majority of the underground steam distribution system. PSFEI has examined this alternative plus construction of a single hot water conversion plant adjacent to the existing steam plant. Both of these alternatives have been analyzed with and without electrical generation. For life cost comparison purposes, we have also analyzed TAC Options 2A and 2B using the same methods as employed for our alternatives. Option designations are as follows:

1. Modified Option 1:
    a. Existing boiler plant work as listed by TAC minus the items previously discussed under Item 4 of the Comments on Base Document section.
    b. Complete steam/condensate system piping replacement (including correct sizing of steam pipe to support all loads).

   c. This option retains the current design of the boiler plant and steam heating systems.

2. Modified Option 2A (without generation):
   a. Existing boiler plant work as listed by TAC minus the items previously discussed under Item 4 of the Comments on Base Document section.
   b. Two identical hot water conversion plants near the center of a respective heating loop, each sized to handle the entire campus heat load for reliability. Includes all necessary equipment: pumps, motors with VFDs, heat exchangers, electrical, controls, etc. No back-pressure turbine generators are installed.
   c. New steam and condensate lines from the existing steam plant to each of the conversion plants. Each steam main (12 inch) is sized to handle the entire campus heat load for reliability.
   d. Two hot-water piping loops, each served by one of the conversion plants, with the ability to cross-connect for redundancy.
   e. Conversion of eleven buildings from steam heating to hydronic: Horton, Gilbert, Henderson, Shearer, Memorial, Kriner, Reed, Wright, Reisner, Heiges, Stewart.
3. Modified Option 2A (with generation):
   a. Same scope as described above except back-pressure turbine generators are installed at each of the hot water plants. It should be noted that this design is somewhat impractical from an operations standpoint (remote turbine generators) but we included it in the analysis in order to evaluate costs.
4. TAC's Option 2A (has electric generation):
   a. Completely new boiler/hot water conversion plant. One coal boiler and the remaining boilers are gas/oil. A baghouse is included for particulate control on the coal boiler. A back-pressure turbine generator is installed to perform steam pressure reduction from 300 psig to 5 psig.
   b. Hot-water piping loops.
   c. Conversion of eleven buildings from steam heating to hydronic: Horton, Gilbert, Henderson, Shearer, Memorial, Kriner, Reed, Wright, Reisner, Heiges, Stewart.
5. TAC's Option 2B (has electric generation):
   a. Same scope as TAC Option 2A, except all boilers are gas/oil.
6. Modified Option 2A-1 (without generation):
   a. Existing boiler plant work as listed by TAC minus the items previously discussed under Item 4 of the Comments on Base Document section.
   b. New hot water conversion plant constructed adjacent to the existing steam plant. Includes all necessary equipment: pumps, motors with VFDs, heat exchangers, electrical, controls, etc. No back-pressure turbine generator is installed.
   c. Two hot water piping loops served by the single conversion plant. The hot-water loops shall have the ability to be cross-connected for redundancy.

   d. Two separate piping mains to transport hot water to and from respective hot water loops. Each is sized to handle full campus heat load for reliability.

   e. Conversion of eleven buildings from steam heating to hydronic: Horton, Gilbert, Henderson, Shearer, Memorial, Kriner, Reed, Wright, Reisner, Heiges, Stewart.

7. Modified Option 2A-1 (with generation):

   a. Same scope except a back-pressure turbine generator is installed in the hot water conversion plant.

## Life Cost Analysis

In order to simplify the cost analysis effort, only those cost items which would change between options were included. Costs that were assumed to remain the same were not included; such as manpower (staffing was assumed to remain the same between the options analyzed) and water treatment chemicals. Costs included were as follows:

1. Project capital (equipment and installation only).
2. Fuel (full annual cost, TAC Option 2B is 100% gas, all other options are 100% coal).
3. Water for make-up (full annual cost).
4. Electrical use (incremental from base Option 1 for hot-water pumps).
5. Electrical generation (incremental from base Option 1).
6. Boiler Plant maintenance (full annual cost, does not include manpower).
7. Field systems maintenance (full annual cost, does not include manpower). This item includes the steam/hot water systems, and hot-water conversion plants.
8. Large NRM costs such as Boiler 4 tube replacement (retain existing steam plant) and baghouse bag change-outs under TAC Option 2A.

It was assumed that the project would be complete in 2008 and current utility rates were escalated accordingly to reflect this. Values used, as well as the annual escalation factors, are shown in the table below.

| ITEM | INITIAL MODEL UNIT COST | ANNUAL ESCALATION FACTOR |
|---|---|---|
| COAL ($ / ton) | $140.00 | 3.0% |
| GAS ($ / mcf) | $10.34 | 3.0% |
| ELECTRIC ($ / KWh) | $0.042 | 3.0% |
| ELECTRIC ($ / KW-peak) | $9.29 | 3.0% |
| WATER ($ / mgal) | $4.12 | 1.5% |
| MAINTENANCE | N/A | 3.0% |

To develop the system models, we looked at your annual steam production based on Utility Usage Report data and established an average heating season production of 115,000,000 lbs. The heating season was assumed to run from September 15 to May 15, a total of 242 days. To determine average heat delivered to the buildings we estimated piping heat losses as well as boiler plant parasitic loads and subtracted those amounts from the total production. That estimated heat delivery was then used as the starting point for all subsequent model development (TAC 2A/B, and all Modified 2A options). Piping heat losses were determined for each system design, added to the building heat requirement, and steam delivery necessary to meet those loads was determined as a function of pressure reduction method (PRV or turbine generator). Information on turbine steam outlet conditions and efficiencies was obtained from the Elliott Turbomachinery Company. Parasitic boiler plant loads were added to the field steam needs, and we then applied appropriate boiler efficiency, other applicable plant parameters, fuel heating values, and fuel pricing to determine the fuel cost for the heating season. Incremental electrical consumption and generation were also calculated as applicable. Annual costs were then determined for each utility. These utility costs were combined with capital, maintenance costs, and large NRM costs. Appropriate costs were then escalated over a period of 25 years and all costs summed to obtain what we will term as the modified life cost. The results, along with respective project capital are presented in the table below. The project capital value only covers equipment and installation; it does not include DGS costs for design and construction, contingency funds or escalation.

| **Modified Life Cost Summary** | | **Project Capital** |
|---|---|---|
| OPTION 1 | $54,613,078 | $15,492,594 |
| MOD OPT 2A (W/O GENERATION) | $56,394,595 | $19,626,556 |
| MOD OPT 2A (W/ GENERATION) | $57,725,546 | $21,526,556 |
| TAC OPT 2A (All coal) | $50,177,779 | $22,931,709 |
| TAC OPT 2B (All gas) | $61,330,757 | $21,045,672 |
| MOD OPT 2A-1 (W/O GENERATION) | $57,077,637 | $20,200,056 |
| MOD OPT 2A-1 (WITH GENERATION) | $57,851,894 | $21,347,556 |

It is interesting to note that even though it has the highest capital cost, TAC's Option 2A has a significantly lower modified life cost. This reduced cost is a function of several advantages that the TAC plant will enjoy over the existing steam plant: 1) much higher boiler efficiencies than possible with the existing plant; 2) the design placed the plant much closer to the heat loads thereby minimizing pumping power requirements and piping heat losses, and 3) operating at 300 psig steam provides much improved turbine generator performance over that obtainable with your current operating pressure. We examined potential operations at 150 psig, and unfortunately, increasing operating pressure at your existing plant efficiencies does not significantly change the modified life costs. As an aside to see how distance would impact TAC Option 2A, we also calculated the modified life cost if the new plant were to be placed where the existing steam plant is now located. This is similar in concept to Modified Option 2A-1 (with generation). The estimated added capital for piping and larger pumps was $3,000,000. The resulting life cost over 25 years was $56,346,696, which raises it above that for Option 1.

With the exception of the plant in Option 2B, which is 100% gas/oil, any use of gas or oil in the other plants would increase the annual fuel and life costs. Note that the life cost of Option 2B is approximately $11 million above that for Option 2A. The 2A and 2B plants are identical except for fuel, and the large cost increase is due solely to the use of higher cost gas rather than coal to produce the steam. In fact, maintenance costs for the 100% gas/oil plant were assumed to be lower than those for a coal plant. The cost calculation models are presented in Appendices A thru D.

This exercise has reaffirmed that a "central" plant will have its optimum efficiency when it is central or near central to the loads it serves. As can be seen in the life cost data, there is little difference between Modified Options 2A and 2A-1. Reductions in piping heat loss are essentially offset by greater pumping power requirements and increased initial equipment costs. Being truly central significantly reduces the distribution system losses as well as motive energy required. However, this does not mean that a distributed heating system would be a better solution for the university. In fact, we do not recommend it for Shippensburg University. While distributed systems do eliminate the distribution heat losses and reduce motive power consumption, they do not provide economy of scale and they do increase maintenance costs and complexity due to the number of separate systems. Whether or not a distributed system has better cost effectiveness over a central-type system depends upon the facility infrastructure and number of buildings. The benefits of a distributed system generally decrease as the number of buildings increases.

## Chilled Water Systems

PSFEI generated a capital cost for installation of a central chilled-water system of $8,032,000. Some reduction in total chilled-water project cost could be realized by installing the chilled-water piping along with the heating system piping. However, this would increase the cost of the heating system project that is ultimately pursued. We did not perform any detailed analysis for life costs. Addition of a chilled water system would result in significant operating cost increases both in energy and maintenance. In our opinion, it is not recommended that chilled water be pursued unless there is some strong outside driving factor.

## Final Discussion and Recommendations

Review of the life and annual O&M cost analysis results along with the current interest in energy efficiency would indicate that TAC's Option 2A is the option of choice. However, there are some significant obstacles/concerns with this path.

1. Availability of land at the optimum locations is questionable. It is likely that the plant would have to be placed at a less optimum location which would significantly increase life and annual O&M costs. It is also possible that the land would have to be purchased, also increasing the capital/life costs.
2. A plant with a single coal boiler would likely force use of gas and/or oil for some percentage of steam production. This would increase the operating costs associated with the plant. To add redundant coal boilers to maximize coal use would increase the capital required for the project. Additionally, we do not know what design basis TAC used to develop the cost for a new coal boiler. Based on discussion presented below it is highly probable that the cost for new coal boiler(s) would be higher than TAC's estimate.
3. This option has the highest capital cost, and based on Items 1 and 2 above, is likely to be significantly higher. Sufficient capital may not be available.

4. Regarding construction of a coal-fired plant:
    a. The level of knowledge and experience as well as the number of manufacturers available for relatively small coal-fired units has largely disappeared since the Commonwealth originally procured most of its fleet of boilers. This is of particular concern for anthracite firing.
    b. Most, if not all, recently installed units of this size range are consuming bio-mass so there is no real base of newer operating coal-fired units for which the operating history can be examined.
    c. While manufacturers of small solid fuel boilers do exist and regularly supply bio-mass boilers, we are not aware of any manufacturers with recent successful reference coal-fired installations of the size and type the Commonwealth requires. Additionally, aftermarket support from some of these manufacturers has been less than desirable. However, we continue to search for and welcome the opportunity to consider technologies and companies should they emerge.
    d. The current solid-fuel boilers of the desired type that we have observed do not compare at all with the ruggedness and quality of materials that the Commonwealth obtained with its original coal-boiler fleet. Many of those original boilers are 50 or 60 plus years old and still have serviceable life. We do not expect that the current, small-size boilers will ever establish that sort of track record unless one is willing to spend the capital for boilers with more rigorous design specifications.
    e. The cost of a new coal-fired plant is significant and requires a high level of due diligence as well as very detailed specifications. Given the level of knowledge and expertise required to design and construct a proper coal-fired plant, we consider the standard DGS capital project format to be unacceptable. To provide the best chance of success, the process should be proposal, screening, and design-build with a very limited number of qualified bidders. The potential bidders would need to be very carefully screened by a knowledgeable team composed of members from DGS, SSHE, and PSFEI. Likewise, this team should carefully review each proposal, with significant emphasis placed on technical treatment. It is also very likely that a significant amount of sole-sourcing will be required to obtain the desired level of quality for equipment as well as reliable manufacturers.
5. Although it is desirable to have the heating plant as close as possible to the loads served, doing so in a university environment has at least three drawbacks.
    a. If the plant consumes coal or oil, this will bring truck traffic closer to the main part of the campus.
    b. Noise levels could increase in the vicinity of the plant from truck traffic, venting steam when occurring, fans, and other exterior equipment.
    c. The visual picture presented by the plant at or near the middle of campus may not be desirable.
    d. As you may be aware, these are several of the reasons that Kutztown University is moving their heating plant away from the main part of the campus.

Based on the discussion above, it is ~~PSFEI's~~ opinion that Option 1, as modified by us, is the most sensible option for Shippensburg University to pursue. We also recommend that a tube-life study be performed on Boiler 4 to establish an estimated time frame for when tube replacement might be required. We estimate that the cost for this endeavor would be approximately $10,000. If the University chooses to pursue the tube study, PSFEI can provide contact information for a company that performs excellent work in this area.

PSFEI is pleased to provide assistance to Shippensburg University in this matter. Please do not hesitate to contact us at (814) 865-3897 or wmacafee@engr.psu.edu should you desire further discussion.

Sincerely,

Wayne R. Macafee

Wayne R. Macafee
Mechanical Engineer

C: S. Dupes
Robert Bruce
File

| | | | | |
|---|---|---|---|---|
| Steam | (saturated) Pressure: | 70 | psig | Alterable by User |
| Saturated Steam Temperature: | | 316.00 | ° F | |
| HPR | Temp | 190 | ° F | HPR = High Pressure Return |
| PCR | Temp | 180 | ° F | PCR = Pumped Condensate Return |
| Hot Water Supply | (heating) Temperature: | 180 | ° F | |
| Hot Water Return | (heating) Temperature: | 150 | ° F | |

Empirical Equation data for piping heat losses (based on fluid temperature):

| Pipe Size (") | Multiplier | Exponent |
|---|---|---|
| 3 | 5.58E-05 | 2.178908 |
| 4 | 9.45E-05 | 2.123459 |
| 6 | 1.21E-04 | 2.147857 |
| 10 | 1.16E-04 | 2.232651 |
| 12 | 1.57E-04 | 2.210578 |
| 16 | 1.88E-04 | 2.218627 |

Equations take the form: Multiplier times X raised to the Exponent, where X is the fluid temperature. The result is equivalent steam flow per 100 feed of pipe to make up for losses. Divide the result by 100 to get lbs/hr-linear foot of pipe.

Heat Loss Factors Used by Pipe Size and Fluid (lbs/hr-ft), based on above equations and fluid data.

| Pipe Size (") | Steam Pipe | HPR | PCR | Hot Water Supply | Hot Water Return |
|---|---|---|---|---|---|
| 3 | 0.16 | 0.05 | 0.05 | 0.05 | 0.03 |
| 4 | 0.19 | 0.07 | 0.06 | 0.06 | 0.04 |
| 6 | 0.28 | N/A | N/A | 0.08 | 0.06 |
| 10 | 0.44 | N/A | N/A | 0.13 | 0.08 |
| 12 | 0.53 | N/A | N/A | 0.15 | 0.10 |
| 16 | 0.66 | N/A | N/A | 0.19 | 0.13 |

[ ] Entries by User

**OPTION 1 PIPING LIST (Assumed new following complete replacement)**

| Fluid | Press (psig) | Temp (°F) | Pipe Size (inches) | Pipe Length (feet) | Loss Factor (lbs/hr-ft) | Equivalent Steam (lbs/hr) | Heat Loss (btu/hr) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Steam | 70 | 316.00 | 12 | 4,200 | 0.53 | 2,210 | 1,984,862 | | | |
| Steam | 70 | 316.00 | 6 | 6,000 | 0.28 | 1,694 | 1,521,522 | 3,506,384 | 20,365 | mmbtu (Steam Piping Losses) |
| PCR | N/A | 180.00 | 4 | 4,200 | 0.06 | 244 | 241,776 | | | |
| PCR | N/A | 180.00 | 4 | 6,000 | 0.06 | 349 | 345,394 | | | |
| HPR | N/A | 190.00 | 3 | 4,200 | 0.05 | 216 | 212,826 | | | |
| | | 0.00 | | | | 0 | 0 | | | |
| | | | | TOTAL LOSS RATE = | | 4,714 | 4,306,380 | OPERATING DAYS = | 242 | |
| | | | | | | | | TOTAL SEASON LOSS = | 25,011 | mmbtu |

**MODIFIED OPTION 2A**

| Fluid | Press (psig) | Temp (°F) | Pipe Size (inches) | Pipe Length (feet) | Loss Factor (lbs/hr-ft) | Equivalent Steam (lbs/hr) | Heat Loss (btu/hr) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Steam | 70 | 316.00 | 12 | 4,200 | 0.53 | 2,210 | 1,984,862 | | | |
| PCR | N/A | 180.00 | 4 | 4,200 | 0.06 | 244 | 241,776 | | | |
| HPR | N/A | 190.00 | 3 | 4,200 | 0.05 | 216 | 212,826 | 1,984,862 | 11,528 | mmbtu (Steam Piping Losses) |
| Hot Water Supply | N/A | 180.00 | 10 | 5,050 | 0.13 | 634 | 627,745 | 1,053,128 | 6,117 | mmbtu (HW System Losses) |
| Hot Water Return | N/A | 150.00 | 10 | 5,050 | 0.08 | 422 | 425,383 | | | |
| | | | | TOTAL LOSS RATE = | | 3,727 | 3,492,592 | OPERATING DAYS = | 242 | |
| | | | | | | | | TOTAL SEASON LOSS = | 20,285 | mmbtu |

**TAC OPTION 2A**

| Fluid | Press (psig) | Temp (°F) | Pipe Size (inches) | Pipe Length (feet) | Loss Factor (lbs/hr-ft) | Equivalent Steam (lbs/hr) | Heat Loss (btu/hr) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hot Water Supply | N/A | 180.00 | 10 | 5,050 | 0.13 | 634 | 627,745 | | | |
| Hot Water Return | N/A | 150.00 | 10 | 5,050 | 0.08 | 422 | 425,383 | | | |
| Hot Water Supply | N/A | 180.00 | 12 | 1,000 | 0.15 | 152 | 150,116 | | | |
| Hot Water Return | N/A | 150.00 | 12 | 1,000 | 0.10 | 101 | 102,136 | | | |
| | | | | TOTAL LOSS RATE = | | 1,309 | 1,305,382 | OPERATING DAYS = | 242 | |
| | | | | | | | | TOTAL SEASON LOSS = | 7,582 | mmbtu |

**MODIFIED OPTION 2A-1 and 2A-2**

| Fluid | Press (psig) | Temp (°F) | Pipe Size (inches) | Pipe Length (feet) | Loss Factor (lbs/hr-ft) | Equivalent Steam (lbs/hr) | Heat Loss (btu/hr) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hot Water Supply | N/A | 180.00 | 12 | 5,050 | 0.15 | 766 | 758,098 | | | |
| Hot Water Return | N/A | 150.00 | 12 | 5,050 | 0.10 | 512 | 515,766 | | | |
| Hot Water Supply | N/A | 180.00 | 16 | 4,200 | 0.19 | 798 | 789,645 | | | |
| Hot Water Return | N/A | 150.00 | 16 | 4,200 | 0.13 | 532 | 536,461 | | | |
| | | | | TOTAL LOSS RATE = | | 2,608 | 2,599,990 | OPERATING DAYS = | 242 | |
| | | | | | | | | TOTAL SEASON LOSS = | 15,101 | mmbtu |

| OPTION 1 | |
|---|---|
| **Fuel Use and Cost** | |
| Base stm production per heating season (lbs) | 115,000,000 |
| Boiler Steam Pressure (psig) | 75 |
| Nominal Boiler Efficiency | 69% |
| Feedwater Header Pressure (psig) | 150 |
| Feedwater Temperature (°F) | 225 |
| Boiler delta-h (btu/lb) | 991.88 |
| Coal HHV (btu/lb) | 12,000 |
| Coal use for heating season (tons) | 6,888 |
| Coal Price ($/ton) | $140.00 |
| Coal cost for heating season ($) | **$964,324** |
| | |
| **Building heat load determination** | |
| % Make-up | 25% |
| Make-up Water (lbs) | 28,750,000 |
| Make-up Water inlet Temperature (°F) | 55 |
| Nominal returned condensate temperature (°F) | 180 |
| DA Tank Heat Load (mmbtu) | 8,769 |
| DA Tank Operating Pressure (psig) | 5 |
| DA Tank Steam Use (lbs) | 8,856,720 |
| Est Piping Heat Losses (equiv lbs of steam) | 22,754,000 |
| Steam to buildings (lbs) | 83,389,280 |
| Building steam use pressure (psig) | 15 |
| Available heat at 15 psig (btu/lb) | 967.16 |
| Calculated heat to buildings (mmbtu) | **80,651** |
| | |
| Water Cost ($/mgal) | $4.12 |
| Make-up Water Cost for heating season | **$14,220** |

| | |
|---|---|
| Fuel and Utilities Cost for Season | $978,544 |

| MODIFIED OPTION 2A (without turbine generator) | |
|---|---|
| | |
| Nominal Building Heat Load (mmbtu) | 80,651 |
| | |
| HW piping heat loss (mmbtu) | 6,117 |
| Total heat needed from heat exchangers (mmbtu) | 86,767 |
| Steam pressure to heat exchangers (psig) | 5 |
| Heat available from steam @ pressure (btu/lb) | 990.07 |
| Steam needed at heat exchangers (lbs) | 87,637,574 |
| Steam piping heat losses (equivalent lbs steam) | 12,880,379 |
| Necessary steam delivered to field (lbs) | 100,517,953 |
| | |
| % Make-up | 15% |
| Make-up Water (lbs) | 16,074,205 |
| Make-up Water inlet Temperature (°F) | 55 |
| Nominal returned condensate temperature (°F) | 180 |
| Feedwater Header Pressure (psig) | 150 |
| Feedwater Temperature (°F) | 225 |
| DA Tank Heat Load (mmbtu) | 6,577 |
| DA Tank Operating Pressure (psig) | 5 |
| DA Tank Steam Use (lbs) | 6,643,413 |
| | |
| Total Boiler steam production (lbs) | 107,161,366 |
| Coal use for heating season (tons) | 6,419 |
| Coal cost for heating season ($) | **$898,594** |
| | |
| | |
| Water Cost ($/mgal) | $4.12 |
| Make-up Water Cost for heating season | **$7,950** |
| | |
| **HW Pumping Power Cost** | |
| Max power each heating loop (HP) | 40 |
| Number of heating loops | 2 |
| Average capacity use over heating season | 62.5% |
| Average HP use over season (HP) | 50.0 |
| KW consumption per HP | 1.000 |
| Operating Days in season | 242 |
| KWh consumption over season | 290,400 |
| Average electric rate ($/kwh) | 0.0420 |
| Incremental KWh cost over season | **$12,197** |
| Incremental KW demand cost over season | **$4,181** |
| Fuel and Utilities Cost for Season | $922,921 |

| | |
|---|---|
| KW demand rate ($ / kw-peak) | $9.29 |
| Billing cycles over season | 9 |

| MODIFIED OPTION 2A (with turbine generator) | |
|---|---|
| | |
| Nominal Building Heat Load (mmbtu) | 80,651 |
| | |
| HW piping heat loss (mmbtu) | 6,117 |
| Total heat needed from heat exchangers (mmbtu) | 86,767 |
| Steam Pressure to turbine (psig) | 75 |
| Steam pressure at turbine exhaust (psig) | 5 |
| Delta-h across turbine (btu/lb) | 29.59 |
| Heat available from steam in heat exchangers (btu/lb) | 960.47 |
| Steam needed at heat exchangers (lbs) | 90,337,863 |
| Steam piping heat losses (equivalent lbs steam) | 12,880,379 |
| Necessary steam delivered to field (lbs) | 103,218,242 |
| | |
| % Make-up | 15% |
| Make-up Water (lbs) | 16,506,018 |
| Make-up Water inlet Temperature (°F) | 55 |
| Nominal returned condensate temperature (°F) | 180 |
| Feedwater Header Pressure (psig) | 150 |
| Feedwater Temperature (°F) | 225 |
| DA Tank Heat Load (mmbtu) | 6,754 |
| DA Tank Operating Pressure (psig) | 5 |
| DA Tank Steam Use (lbs) | 6,821,880 |
| | |
| Total Boiler steam production (lbs) | 110,040,122 |
| Coal use for heating season (tons) | 6,591 |
| Coal cost for heating season ($) | **$922,734** |
| Water Cost ($/mgal) | $4.12 |
| Make-up Water Cost for heating season | **$8,164** |
| | |
| **HW Pumping Power Cost** | |
| Max power each heating loop (HP) | 40 |
| Number of heating loops | 2 |
| Average capacity use over heating season | 62.5% |
| Average HP use over season (HP) | 50.0 |
| KW consumption per HP | 1.000 |
| Operating Days in season | 242 |
| KWh consumption over season | 290,400 |
| Average electric rate ($/kwh) | 0.0420 |
| Incremental KWh cost over season | **$12,197** |
| Incremental KW demand cost over season | **$4,181** |
| **Turbine Generation (electrical purchase reduction)** | |
| Steam thru turbine (lbs) | 103,218,242 |
| Delta-h thru turbine (btu/lb) | 29.59 |
| Turbine generator efficiency | 89% |
| Electrical production / reduced purchase (kwh) | 796,578 |
| Average electric rate ($/kwh) | 0.0420 |
| KWh cost reduction over season | **($33,456)** |
| KW cost reduction over season | **($11,467)** |
| Fuel and Utilities Cost for Season | $902,351 |

| TAC OPTION 2A | |
|---|---|
| | |
| Nominal Building Heat Load (mmbtu) | 80,651 |
| | |
| HW piping heat loss (mmbtu) | 7,582 |
| Total heat needed from heat exchangers (mmbtu) | 88,232 |
| Steam Pressure to turbine (psig) | 300 |
| Steam pressure at turbine exhaust (psig) | 5 |
| Delta-h across turbine (btu/lb) | 47.87 |
| Heat available from steam in heat exchangers (btu/lb) | 960.47 |
| Steam needed at heat exchangers (lbs) | 91,863,250 |
| Steam piping heat losses (equivalent lbs steam) | 0 |
| Necessary steam delivered to field (lbs) | 91,863,250 |
| | |
| % Make-up | 8% |
| Make-up Water (lbs) | 7,775,937 |
| Make-up Water inlet Temperature (°F) | 55 |
| Nominal returned condensate temperature (°F) | 180 |
| Feedwater Header Pressure (psig) | 350 |
| Feedwater Temperature (°F) | 225 |
| DA Tank Heat Load (mmbtu) | 5,125 |
| DA Tank Operating Pressure (psig) | 5 |
| DA Tank Steam Use (lbs) (steam from turbine exhaust) | 5,335,961 |
| | |
| Total Boiler steam production (lbs) | 97,199,210 |
| Boiler Steam Pressure (psig) | 300 |
| Delta-h across boiler (btu/lb) | 1,009.72 |
| Boiler Efficiency | 80% |
| Coal use for heating season (tons) | 5,112 |
| Coal cost for heating season ($) | **$715,631** |
| Water Cost ($/mgal) | $4.12 |
| Make-up Water Cost for heating season | **$3,846** |
| | |
| **HW Pumping Power Cost** | |
| Max power each heating loop (HP) (Estimated) | 50 |
| Number of heating loops | 2 |
| Average capacity use over heating season | 62.5% |
| Average HP use over season (HP) | 62.5 |
| KW consumption per HP | 1.000 |
| Operating Days in season | 242 |
| KWh consumption over season | 363,000 |
| Average electric rate ($/kwh) | 0.0420 |
| Incremental KWh cost over season | **$15,246** |
| Incremental KW demand cost over season | **$5,226** |
| **Turbine Generation (electrical purchase reduction)** | |
| Steam thru turbine (lbs) | 97,199,210 |
| Delta-h thru turbine (btu/lb) | 47.87 |
| Turbine generator efficiency | 89% |
| Electrical production / reduced purchase (kwh) | 1,213,370 |
| Average electric rate ($/kwh) | 0.0420 |
| KWh cost reduction over season | **($50,962)** |
| KW cost reduction over season | **($17,467)** |
| Coal and Utilities Cost for Season | $671,520 |

**Using Gas:**

| | |
|---|---|
| Total Boiler steam production (lbs) | 97,199,210 |
| Boiler Steam Pressure (psig) | 300 |
| Delta-h across boiler (btu/lb) | 1,009.72 |
| Boiler Efficiency | 90% |
| Gas HHV (btu / cf) | 1,030 |
| Gas Use for heating season (mcf) | 105,872 |
| Gas cost ($ / mcf) | $10.34 |
| Gas cost for heating season ($) | **$1,094,720** |

| MODIFIED OPTION 2A-1 (without turbine generator) | |
|---|---|
| | |
| Nominal Building Heat Load (mmbtu) | 80,651 |
| | |
| HW piping heat loss (mmbtu) | 15,101 |
| Total heat needed from heat exchangers (mmbtu) | 95,751 |
| Main Steam Pressure (psig) | 75 |
| Steam pressure to HX thru PRV (psig) | 5 |
| | |
| Heat available from steam in heat exchangers (btu/lb) | 990.07 |
| Steam needed at heat exchangers (lbs) | 96,711,882 |
| | |
| | |
| % Make-up | 10% |
| Make-up Water (lbs) | 10,242,673 |
| Make-up Water inlet Temperature (°F) | 55 |
| Nominal returned condensate temperature (°F) | 180 |
| Feedwater Header Pressure (psig) | 125 |
| Feedwater Temperature (°F) | 225 |
| DA Tank Heat Load (mmbtu) | 5,658 |
| DA Tank Operating Pressure (psig) | 5 |
| DA Tank Steam Use (lbs) | 5,714,849 |
| | |
| Total Boiler steam production (lbs) | 102,426,732 |
| Boiler Steam Pressure (psig) | 75 |
| Delta-h across boiler (btu/lb) | 991.93 |
| Boiler Efficiency | 69% |
| Coal use for heating season (tons) | 6,135 |
| Coal cost for heating season ($) | **$858,939** |
| Water Cost ($/mgal) | $4.12 |
| Make-up Water Cost for heating season | **$5,066** |
| | |
| **HW Pumping Power Cost** | |
| Max power each heating loop (HP) (Estimated) | 150 |
| Number of heating loops | 2 |
| Average capacity use over heating season | 62.5% |
| Average HP use over season (HP) | 187.5 |
| KW consumption per HP | 1.000 |
| Operating Days in season | 242 |
| KWh consumption over season | 1,089,000 |
| Average electric rate ($/kwh) | 0.0420 |
| Incremental KWh cost over season | **$45,738** |
| Incremental KW demand cost over season | **$15,677** |
| **Turbine Generation (electrical purchase reduction)** | |
| Steam thru turbine (lbs) | 102,426,732 |
| Delta-h thru turbine (btu/lb) | 0.00 |
| Turbine generator efficiency | 89% |
| Electrical production / reduced purchase (kwh) | 0 |
| Average electric rate ($/kwh) | 0.0420 |
| KWh cost reduction over season | **$0** |
| KW cost reduction over season | **$0** |
| Fuel and Utilities Cost for Season | $925,420 |

| MODIFIED OPTION 2A-2 (with turbine generator) | |
|---|---|
| | |
| Nominal Building Heat Load (mmbtu) | 80,651 |
| | |
| HW piping heat loss (mmbtu) | 15,101 |
| Total heat needed from heat exchangers (mmbtu) | 95,751 |
| Steam Pressure to turbine (psig) | 75 |
| Steam pressure at turbine exhaust (psig) | 5 |
| Delta-h across turbine (btu/lb) | 29.59 |
| Heat available from steam in heat exchangers (btu/lb) | 960.47 |
| Steam needed at heat exchangers (lbs) | 99,691,769 |
| Heat losses, steam & Cond piping (equivalent lbs steam) | 0 |
| Necessary steam delivered to field (lbs) | 99,691,769 |
| | |
| % Make-up | 10% |
| Make-up Water (lbs) | 10,576,749 |
| Make-up Water inlet Temperature (°F) | 55 |
| Nominal returned condensate temperature (°F) | 180 |
| Feedwater Header Pressure (psig) | 125 |
| Feedwater Temperature (°F) | 225 |
| DA Tank Heat Load (mmbtu) | 5,836 |
| DA Tank Operating Pressure (psig) | 5 |
| DA Tank Steam Use (lbs) (steam from turbine exhaust) | 6,075,717 |
| | |
| Total Boiler steam production (lbs) | 105,767,486 |
| Boiler Steam Pressure (psig) | 75 |
| Delta-h across boiler (btu/lb) | 991.93 |
| Boiler Efficiency | 69% |
| Coal use for heating season (tons) | 6,335 |
| Coal cost for heating season ($) | **$886,954** |
| Water Cost ($/mgal) | $4.12 |
| Make-up Water Cost for heating season | **$5,231** |
| | |
| **HW Pumping Power Cost** | |
| Max power each heating loop (HP) (Estimated) | 150 |
| Number of heating loops | 2 |
| Average capacity use over heating season | 62.5% |
| Average HP use over season (HP) | 187.5 |
| KW consumption per HP | 1.000 |
| Operating Days in season | 242 |
| KWh consumption over season | 1,089,000 |
| Average electric rate ($/kwh) | 0.0420 |
| Incremental KWh cost over season | **$45,738** |
| Incremental KW demand cost over season | **$15,677** |
| **Turbine Generation (electrical purchase reduction)** | |
| Steam thru turbine (lbs) | 99,691,769 |
| Delta-h thru turbine (btu/lb) | 29.59 |
| Turbine generator efficiency | 89% |
| Electrical production / reduced purchase (kwh) | 769,362 |
| Average electric rate ($/kwh) | 0.0420 |
| KWh cost reduction over season | **($32,313)** |
| KW cost reduction over season | **($11,075)** |
| Fuel and Utilities Cost for Season | $910,212 |

$9.7M DIST
+5.8M PLANT

| ESCALATOR FACTORS | |
|---|---|
| COAL | 3.0% |
| ELECTRIC | 3.0% |
| MAINT | 3.0% |
| WATER | 1.5% |
| GAS | 3.0% |

| Modified Life Cost Summary | | 1st yr O&M | Project Capital | |
|---|---|---|---|---|
| OPTION 1 | $54,613,078 | $1,053,544 | $15,492,594 | Upgrade of exiting steam and boiler systems. |
| MOD OPT 2A (W/O GENERATION) | $56,394,595 | $987,921 | $19,626,556 | Upgrade boiler systems, two satellite hot water conversion plants. |
| MOD OPT 2A (W/ GENERATION) | $57,725,546 | $972,351 | $21,526,556 | Upgrade boiler systems, two satellite hot water conversion plants. |
| TAC OPT 2A (All coal) | $50,177,779 | $731,520 | $22,931,709 | Plant at optimum location. |
| TAC OPT 2B (All gas) | $61,330,757 | $1,105,609 | $21,045,672 | Plant at optimum location. |
| MOD OPT 2A-1 (W/O GENERATION) | $57,077,637 | $990,420 | $20,200,056 | Upgrade boiler systems, hot water conversion plant adjacent to existing steam plant. |
| MOD OPT 2A-1 (WITH GENERATION) | $57,851,694 | $980,212 | $21,347,556 | Upgrade boiler systems, hot water conversion plant adjacent to existing steam plant. |

**OPTION 1**

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Cost | $15,492,594 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| Fuel | $964,324 | $993,254 | $1,023,052 | $1,053,743 | $1,085,355 | $1,117,916 | $1,151,454 | $1,185,997 | $1,221,577 | $1,258,224 | $1,295,971 | $1,334,850 | $1,374,896 | $1,416,143 | $1,458,627 | $1,502,386 | $1,547,457 | $1,593,881 | $1,641,697 | $1,690,948 | $1,741,677 | $1,793,927 | $1,847,745 | $1,903,177 | $1,960,273 | |
| Electric | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| Water | $14,220 | $14,433 | $14,649 | $14,869 | $15,092 | $15,319 | $15,548 | $15,782 | $16,018 | $16,259 | $16,503 | $16,750 | $17,001 | $17,256 | $17,515 | $17,778 | $18,045 | $18,315 | $18,590 | $18,869 | $19,152 | $19,439 | $19,731 | $20,027 | $20,327 | |
| Electric Savings | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| Boiler Systems Maint | $45,000 | $46,350 | $47,741 | $49,173 | $50,648 | $52,167 | $53,732 | $55,344 | $57,005 | $58,715 | $60,476 | $62,291 | $64,159 | $66,084 | $68,067 | $70,109 | $72,212 | $74,378 | $76,609 | $78,908 | $81,275 | $83,713 | $86,225 | $88,811 | $91,476 | |
| Field Systems Maint | $30,000 | $30,900 | $31,827 | $32,782 | $33,765 | $34,778 | $35,822 | $36,896 | $38,003 | $39,143 | $40,317 | $41,527 | $42,773 | $44,056 | $45,378 | $46,739 | $48,141 | $49,585 | $51,073 | $52,605 | $54,183 | $55,809 | $57,483 | $59,208 | $60,984 | |
| Large one-time Maint | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $800,000 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| First year O&M | $1,053,544 | | | | | | | | | | | | | | | | | | | | | | | | | |
| TOTALS | $16,546,138 | $1,084,937 | $1,117,269 | $1,150,567 | $1,184,861 | $1,220,180 | $1,256,556 | $1,294,019 | $1,332,603 | $2,172,341 | $1,413,267 | $1,455,418 | $1,498,829 | $1,543,539 | $1,589,586 | $1,637,011 | $1,685,855 | $1,736,160 | $1,787,970 | $1,841,330 | $1,896,287 | $1,952,888 | $2,011,183 | $2,071,223 | $2,133,059 | $54,613,078 |

**MODIFIED OPTION 2A (without backpressure turbine generator)**

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Cost | $19,626,556 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| Fuel | $898,594 | $925,552 | $953,318 | $981,918 | $1,011,375 | $1,041,717 | $1,072,968 | $1,105,157 | $1,138,312 | $1,172,461 | $1,207,635 | $1,243,864 | $1,281,180 | $1,319,615 | $1,359,204 | $1,399,980 | $1,441,979 | $1,485,239 | $1,529,796 | $1,575,690 | $1,622,961 | $1,671,649 | $1,721,799 | $1,773,453 | $1,826,656 | |
| Electric (KWh + KW) | $16,377 | $16,869 | $17,375 | $17,896 | $18,433 | $18,986 | $19,555 | $20,142 | $20,746 | $21,369 | $22,010 | $22,670 | $23,350 | $24,051 | $24,772 | $25,515 | $26,281 | $27,069 | $27,881 | $28,718 | $29,579 | $30,467 | $31,381 | $32,322 | $33,292 | |
| Water | $7,950 | $8,070 | $8,191 | $8,313 | $8,438 | $8,565 | $8,693 | $8,824 | $8,956 | $9,090 | $9,227 | $9,365 | $9,505 | $9,648 | $9,793 | $9,940 | $10,089 | $10,240 | $10,394 | $10,550 | $10,708 | $10,868 | $11,032 | $11,197 | $11,365 | |
| Elec Savings (KWh + KW) | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| Boiler Systems Maint | $45,000 | $46,350 | $47,741 | $49,173 | $50,648 | $52,167 | $53,732 | $55,344 | $57,005 | $58,715 | $60,476 | $62,291 | $64,159 | $66,084 | $68,067 | $70,109 | $72,212 | $74,378 | $76,609 | $78,908 | $81,275 | $83,713 | $86,225 | $88,811 | $91,476 | |
| Field Systems Maint | $20,000 | $20,600 | $21,218 | $21,855 | $22,510 | $23,185 | $23,881 | $24,597 | $25,335 | $26,095 | $26,878 | $27,685 | $28,515 | $29,371 | $30,252 | $31,159 | $32,094 | $33,057 | $34,049 | $35,070 | $36,122 | $37,206 | $38,322 | $39,472 | $40,656 | |
| Large one-time Maint | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $800,000 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| First year O&M | $987,921 | | | | | | | | | | | | | | | | | | | | | | | | | |
| TOTALS | $20,614,477 | $1,017,440 | $1,047,842 | $1,079,154 | $1,111,404 | $1,144,620 | $1,178,830 | $1,214,065 | $1,250,354 | $2,087,730 | $1,326,226 | $1,365,874 | $1,406,710 | $1,448,769 | $1,492,087 | $1,536,703 | $1,582,655 | $1,629,983 | $1,678,729 | $1,728,935 | $1,780,645 | $1,833,904 | $1,888,758 | $1,945,255 | $2,003,445 | $56,394,595 |

**MODIFIED OPTION 2A (with backpressure turbine generators in each hot water conversion plant)**

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Cost | $21,526,556 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| Fuel | $922,734 | $950,416 | $978,928 | $1,008,296 | $1,038,545 | $1,069,701 | $1,101,792 | $1,134,846 | $1,168,891 | $1,203,958 | $1,240,077 | $1,277,279 | $1,315,597 | $1,355,065 | $1,395,717 | $1,437,589 | $1,480,716 | $1,525,138 | $1,570,892 | $1,618,019 | $1,666,559 | $1,716,556 | $1,768,053 | $1,821,094 | $1,875,727 | |
| Electric (KWh + KW) | $16,377 | $16,869 | $17,375 | $17,896 | $18,433 | $18,986 | $19,555 | $20,142 | $20,746 | $21,369 | $22,010 | $22,670 | $23,350 | $24,051 | $24,772 | $25,515 | $26,281 | $27,069 | $27,881 | $28,718 | $29,579 | $30,467 | $31,381 | $32,322 | $33,292 | |
| Water | $8,164 | $8,286 | $8,411 | $8,537 | $8,665 | $8,795 | $8,927 | $9,061 | $9,197 | $9,334 | $9,474 | $9,617 | $9,761 | $9,907 | $10,056 | $10,207 | $10,360 | $10,515 | $10,673 | $10,833 | $10,996 | $11,160 | $11,328 | $11,498 | $11,670 | |
| Elec Savings (KWh + KW) | -$44,924 | -$46,271 | -$47,659 | -$49,089 | -$50,562 | -$52,079 | -$53,641 | -$55,250 | -$56,908 | -$58,615 | -$60,373 | -$62,185 | -$64,050 | -$65,972 | -$67,951 | -$69,989 | -$72,089 | -$74,252 | -$76,479 | -$78,774 | -$81,137 | -$83,571 | -$86,078 | -$88,660 | -$91,320 | |
| Boiler Systems Maint | $45,000 | $46,350 | $47,741 | $49,173 | $50,648 | $52,167 | $53,732 | $55,344 | $57,005 | $58,715 | $60,476 | $62,291 | $64,159 | $66,084 | $68,067 | $70,109 | $72,212 | $74,378 | $76,609 | $78,908 | $81,275 | $83,713 | $86,225 | $88,811 | $91,476 | |
| Field Systems Maint | $25,000 | $25,750 | $26,523 | $27,318 | $28,138 | $28,982 | $29,851 | $30,747 | $31,669 | $32,619 | $33,598 | $34,606 | $35,644 | $36,713 | $37,815 | $38,949 | $40,118 | $41,321 | $42,561 | $43,838 | $45,153 | $46,507 | $47,903 | $49,340 | $50,820 | |
| Large one-time Maint | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $800,000 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| First year O&M | $972,351 | | | | | | | | | | | | | | | | | | | | | | | | | |
| TOTALS | $22,498,907 | $1,001,399 | $1,031,317 | $1,062,130 | $1,093,866 | $1,126,552 | $1,160,217 | $1,194,889 | $1,230,600 | $2,067,380 | $1,305,262 | $1,344,277 | $1,384,461 | $1,425,849 | $1,468,478 | $1,512,379 | $1,557,597 | $1,604,170 | $1,652,137 | $1,701,541 | $1,752,425 | $1,804,833 | $1,858,810 | $1,914,405 | $1,971,665 | $57,725,546 |

**TAC OPTION 2A**

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Cost | $22,931,709 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| Fuel | $715,631 | $737,100 | $759,213 | $781,989 | $805,449 | $829,612 | $854,501 | $880,136 | $906,540 | $933,736 | $961,748 | $990,600 | $1,020,319 | $1,050,928 | $1,082,456 | $1,114,930 | $1,148,377 | $1,182,829 | $1,218,314 | $1,254,863 | $1,292,509 | $1,331,284 | $1,371,223 | $1,412,359 | $1,454,730 | |
| Electric (KWh + KW) | $20,472 | $21,086 | $21,718 | $22,370 | $23,041 | $23,732 | $24,444 | $25,178 | $25,933 | $26,711 | $27,512 | $28,338 | $29,188 | $30,063 | $30,965 | $31,894 | $32,851 | $33,836 | $34,852 | $35,897 | $36,974 | $38,083 | $39,226 | $40,403 | $41,615 | |
| Water | $3,846 | $3,904 | $3,962 | $4,022 | $4,082 | $4,143 | $4,205 | $4,268 | $4,332 | $4,397 | $4,463 | $4,530 | $4,598 | $4,667 | $4,737 | $4,808 | $4,880 | $4,954 | $5,028 | $5,103 | $5,180 | $5,258 | $5,337 | $5,417 | $5,498 | |
| Elec Savings (KWh + KW) | -$68,429 | -$70,482 | -$72,596 | -$74,774 | -$77,017 | -$79,328 | -$81,708 | -$84,159 | -$86,684 | -$89,284 | -$91,963 | -$94,721 | -$97,563 | -$100,490 | -$103,505 | -$106,610 | -$109,808 | -$113,102 | -$116,495 | -$119,990 | -$123,590 | -$127,298 | -$131,117 | -$135,050 | -$139,102 | |
| Boiler Systems Maint | $35,000 | $36,050 | $37,132 | $38,245 | $39,393 | $40,575 | $41,792 | $43,046 | $44,337 | $45,667 | $47,037 | $48,448 | $49,902 | $51,399 | $52,941 | $54,529 | $56,165 | $57,850 | $59,585 | $61,373 | $63,214 | $65,110 | $67,064 | $69,076 | $71,148 | |
| Field Systems Maint | $25,000 | $25,750 | $26,523 | $27,318 | $28,138 | $28,982 | $29,851 | $30,747 | $31,669 | $32,619 | $33,598 | $34,606 | $35,644 | $36,713 | $37,815 | $38,949 | $40,118 | $41,321 | $42,561 | $43,838 | $45,153 | $46,507 | $47,903 | $49,340 | $50,820 | |
| Large one-time Maint | $0 | $0 | $0 | $0 | $0 | $0 | $200,000 | $0 | $0 | $0 | $0 | $0 | $0 | $200,000 | $0 | $0 | $0 | $0 | $0 | $0 | $200,000 | $0 | $0 | $0 | $0 | |
| First year O&M | $731,520 | | | | | | | | | | | | | | | | | | | | | | | | | |
| TOTALS | $23,663,229 | $753,408 | $775,951 | $799,170 | $823,085 | $847,716 | $1,073,086 | $899,215 | $926,128 | $953,847 | $982,396 | $1,011,801 | $1,042,087 | $1,273,281 | $1,105,409 | $1,138,500 | $1,172,583 | $1,207,687 | $1,243,844 | $1,281,084 | $1,519,440 | $1,358,945 | $1,399,635 | $1,441,544 | $1,484,709 | $50,177,779 |

**MODIFIED OPTION 2A-1 (without backpressure turbine generator)**

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Cost | $20,200,056 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| Fuel | $858,939 | $884,707 | $911,249 | $938,586 | $966,744 | $995,746 | $1,025,618 | $1,056,387 | $1,088,078 | $1,120,721 | $1,154,342 | $1,188,973 | $1,224,642 | $1,261,381 | $1,299,222 | $1,338,199 | $1,378,345 | $1,419,695 | $1,462,286 | $1,506,155 | $1,551,340 | $1,597,880 | $1,645,816 | $1,695,191 | $1,746,046 | |
| Electric (KWh + KW) | $61,415 | $63,257 | $65,155 | $67,110 | $69,123 | $71,197 | $73,333 | $75,533 | $77,799 | $80,132 | $82,536 | $85,013 | $87,563 | $90,190 | $92,896 | $95,682 | $98,553 | $101,509 | $104,555 | $107,691 | $110,922 | $114,250 | $117,677 | $121,208 | $124,844 | |
| Water | $5,066 | $5,142 | $5,219 | $5,297 | $5,377 | $5,458 | $5,539 | $5,622 | $5,707 | $5,792 | $5,879 | $5,967 | $6,057 | $6,148 | $6,240 | $6,334 | $6,429 | $6,525 | $6,623 | $6,722 | $6,823 | $6,926 | $7,029 | $7,135 | $7,242 | |
| Elec Savings (KWh + KW) | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| Boiler Systems Maint | $45,000 | $46,350 | $47,741 | $49,173 | $50,648 | $52,167 | $53,732 | $55,344 | $57,005 | $58,715 | $60,476 | $62,291 | $64,159 | $66,084 | $68,067 | $70,109 | $72,212 | $74,378 | $76,609 | $78,908 | $81,275 | $83,713 | $86,225 | $88,811 | $91,476 | |
| Field Systems Maint | $20,000 | $20,600 | $21,218 | $21,855 | $22,510 | $23,185 | $23,881 | $24,597 | $25,335 | $26,095 | $26,878 | $27,685 | $28,515 | $29,371 | $30,252 | $31,159 | $32,094 | $33,057 | $34,049 | $35,070 | $36,122 | $37,206 | $38,322 | $39,472 | $40,656 | |
| Large one-time Maint | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $800,000 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| First year O&M | $990,420 | | | | | | | | | | | | | | | | | | | | | | | | | |
| TOTALS | $21,190,476 | $1,020,057 | $1,050,581 | $1,082,020 | $1,114,401 | $1,147,753 | $1,182,104 | $1,217,484 | $1,253,924 | $2,091,456 | $1,330,113 | $1,369,928 | $1,410,936 | $1,453,173 | $1,496,676 | $1,541,483 | $1,587,633 | $1,635,165 | $1,684,122 | $1,734,547 | $1,786,482 | $1,839,974 | $1,895,070 | $1,951,816 | $2,010,264 | $57,077,637 |

**MODIFIED OPTION 2A-2 (with backpressure turbine generator)**

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Cost | $21,347,556 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| Fuel | $886,954 | $913,563 | $940,970 | $969,199 | $998,275 | $1,028,223 | $1,059,070 | $1,090,842 | $1,123,567 | $1,157,274 | $1,191,992 | $1,227,752 | $1,264,585 | $1,302,522 | $1,341,598 | $1,381,846 | $1,423,301 | $1,466,000 | $1,509,980 | $1,555,280 | $1,601,938 | $1,649,996 | $1,699,496 | $1,750,481 | $1,802,996 | |
| Electric (KWh + KW) | $61,415 | $63,257 | $65,155 | $67,110 | $69,123 | $71,197 | $73,333 | $75,533 | $77,799 | $80,132 | $82,536 | $85,013 | $87,563 | $90,190 | $92,896 | $95,682 | $98,553 | $101,509 | $104,555 | $107,691 | $110,922 | $114,250 | $117,677 | $121,208 | $124,844 | |
| Water | $5,231 | $5,310 | $5,389 | $5,470 | $5,552 | $5,636 | $5,720 | $5,806 | $5,893 | $5,981 | $6,071 | $6,162 | $6,255 | $6,348 | $6,444 | $6,540 | $6,638 | $6,738 | $6,839 | $6,942 | $7,046 | $7,151 | $7,259 | $7,368 | $7,478 | |
| Elec Savings (KWh + KW) | -$43,389 | -$44,690 | -$46,031 | -$47,412 | -$48,834 | -$50,299 | -$51,808 | -$53,363 | -$54,964 | -$56,612 | -$58,311 | -$60,060 | -$61,862 | -$63,718 | -$65,629 | -$67,598 | -$69,626 | -$71,715 | -$73,866 | -$76,082 | -$78,365 | -$80,716 | -$83,137 | -$85,631 | -$88,200 | |
| Boiler Systems Maint | $45,000 | $46,350 | $47,741 | $49,173 | $50,648 | $52,167 | $53,732 | $55,344 | $57,005 | $58,715 | $60,476 | $62,291 | $64,159 | $66,084 | $68,067 | $70,109 | $72,212 | $74,378 | $76,609 | $78,908 | $81,275 | $83,713 | $86,225 | $88,811 | $91,476 | |
| Field Systems Maint | $25,000 | $25,750 | $26,523 | $27,318 | $28,138 | $28,982 | $29,851 | $30,747 | $31,669 | $32,619 | $33,598 | $34,606 | $35,644 | $36,713 | $37,815 | $38,949 | $40,118 | $41,321 | $42,561 | $43,838 | $45,153 | $46,507 | $47,903 | $49,340 | $50,820 | |
| Large one-time Maint | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $800,000 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| First year O&M | $980,212 | | | | | | | | | | | | | | | | | | | | | | | | | |
| TOTALS | $22,327,768 | $1,009,540 | $1,039,746 | $1,070,858 | $1,102,901 | $1,135,905 | $1,169,898 | $1,204,909 | $1,240,969 | $2,078,110 | $1,316,363 | $1,355,763 | $1,396,344 | $1,438,140 | $1,481,189 | $1,525,528 | $1,571,196 | $1,618,232 | $1,666,678 | $1,716,576 | $1,767,969 | $1,820,902 | $1,875,422 | $1,931,576 | $1,989,413 | $57,851,894 |

**TAC OPTION 2B**

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Cost | $21,045,672 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| Fuel | $1,094,720 | $1,127,562 | $1,161,388 | $1,196,230 | $1,232,117 | $1,269,081 | $1,307,153 | $1,346,368 | $1,386,759 | $1,428,361 | $1,471,212 | $1,515,349 | $1,560,809 | $1,607,633 | $1,655,862 | $1,705,538 | $1,756,704 | $1,809,405 | $1,863,688 | $1,919,598 | $1,977,186 | $2,036,502 | $2,097,597 | $2,160,525 | $2,225,340 | |
| Electric (KWh + KW) | $20,472 | $21,086 | $21,718 | $22,370 | $23,041 | $23,732 | $24,444 | $25,178 | $25,933 | $26,711 | $27,512 | $28,338 | $29,188 | $30,063 | $30,965 | $31,894 | $32,851 | $33,836 | $34,852 | $35,897 | $36,974 | $38,083 | $39,226 | $40,403 | $41,615 | |
| Water | $3,846 | $3,904 | $3,962 | $4,022 | $4,082 | $4,143 | $4,205 | $4,268 | $4,332 | $4,397 | $4,463 | $4,530 | $4,598 | $4,667 | $4,737 | $4,808 | $4,880 | $4,954 | $5,028 | $5,103 | $5,180 | $5,258 | $5,337 | $5,417 | $5,498 | |
| Elec Savings (KWh + KW) | -$68,429 | -$70,482 | -$72,596 | -$74,774 | -$77,017 | -$79,328 | -$81,708 | -$84,159 | -$86,684 | -$89,284 | -$91,963 | -$94,721 | -$97,563 | -$100,490 | -$103,505 | -$106,610 | -$109,808 | -$113,102 | -$116,495 | -$119,990 | -$123,590 | -$127,298 | -$131,117 | -$135,050 | -$139,102 | |
| Boiler Systems Maint | $30,000 | $30,900 | $31,827 | $32,782 | $33,765 | $34,778 | $35,822 | $36,896 | $38,003 | $39,143 | $40,317 | $41,527 | $42,773 | $44,056 | $45,378 | $46,739 | $48,141 | $49,585 | $51,073 | $52,605 | $54,183 | $55,809 | $57,483 | $59,208 | $60,984 | |
| Field Systems Maint | $25,000 | $25,750 | $26,523 | $27,318 | $28,138 | $28,982 | $29,851 | $30,747 | $31,669 | $32,619 | $33,598 | $34,606 | $35,644 | $36,713 | $37,815 | $38,949 | $40,118 | $41,321 | $42,561 | $43,838 | $45,153 | $46,507 | $47,903 | $49,340 | $50,820 | |
| Large one-time Maint | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | |
| First year O&M | $1,105,609 | | | | | | | | | | | | | | | | | | | | | | | | | |
| TOTALS | $22,151,281 | $1,138,719 | $1,172,822 | $1,207,948 | $1,244,126 | $1,281,388 | $1,319,768 | $1,359,298 | $1,400,013 | $1,441,948 | $1,485,141 | $1,529,628 | $1,575,449 | $1,622,643 | $1,671,252 | $1,721,319 | $1,772,886 | $1,826,000 | $1,880,706 | $1,937,051 | $1,995,066 | $2,054,861 | $2,116,428 | $2,179,841 | $2,245,155 | $61,330,757 |