

INTRO

The opportunity to save \$170,000 in electrical energy costs is being missed every year at the University of Idaho.

Hello. My name is Ryan Oliver and I am a member of the senior design team consisting of Chad Dunkel, Donald Haines, and Chris Anderson. Over the past nine months we have developed a feasibility study for the implementation of a cogeneration system at the University of Idaho Steam Plant.

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The UI Steam Plant, constructed in its present location in 1927, has historically utilized—fuel oil, pulverized coal, and natural gas to operate its boilers. In 1988 a wood fired boiler was commissioned, allowing the UI combined heating and cooling facility to utilize a renewable fuel source, wood chips, in its primary boiler.

What was not done in 1988, and has still not been done due to interdisciplinary stagnation, was to implement a cogeneration system.

As a senior design team our objective was to perform a feasibility analysis for implementing such a cogeneration system at the Steam Plant. We brought together the combined engineering knowledge from the fields of Bio-Agricultural, Mechanical, and Electrical Engineering.

Additionally, significant non-engineering components were involved with this project including: communication, technical writing, ethics, business, finance, project development and politics.

Transitional Statement: Before we talk about what a cogeneration system at the UI Steam Plant would look like let's first look at the current system.

Current System

This is a block diagram representing the campus steam distribution system. As you may know, heating of campus buildings as well as some cooling is done by steam.

Approximately 90% of steam supplied to campus on a yearly basis comes from the wood boiler. The additional 10% is produced by natural gas boilers during times of maintenance on the wood boiler or during times of peak load, in mid-winter or mid-summer. Boilers in the steam plant produce steam at 135psi.

A Pressure Reducing Valve (PRV) is needed to drop the distribution pressure of steam on its way to campus. Currently system distribution pressure is 60psi.

The condenser element in the diagram represents the entirety of campus.

Heat transfer through heat exchangers and steam absorption chillers occurs around campus, as steam enters, goes through a phase change,

and leaves as liquid. A seven mile network of pipes make up the steam distribution and condensate return piping network. At the South West corner of the Steam Plant, all returned condensate is stored in a Condensate Return Tank. The condensate is then pumped into a Dearator Tank. Finally the loop is completed when a Feedwater Pump supplies the water necessary from the Dearator Tank to maintain the levels in the boiler steam drums as steam is continuously supplied to campus.

Transitional Statement: Now that we have as a reference, the operation of the current system,.....

Proposed System

I would like to draw your attention to the changes necessary to implement a cogeneration system. The new red element represents a steam turbine mated to a synchronous generator and replaces the PRV element from the previous diagram. The necessary steam pressure reduction formally achieved by the PRV, now is accomplished by the turbine with the added benefit of power generation.

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The turbine, generator and all supporting equipment can easily be placed in an unutilized space on the South side of the Steam Plant, next to Line Street.

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Initially, six different system designs were considered and presented to the University of Idaho Utilities and Engineering Director.

Being engineers, we were curious to know how much power we could make, this led to the development of the Max Generation Model capable of producing 15 MW. But due to an increased fuel cost of \$12,000,000 per year this model was rejected.

In pursuit of our project learning goals, we visited the Stimson Stud Mill in Plummer Idaho. Our second design option, the Plummer Model using saturated steam, emulates the system setup seen in Plummer, but operated at saturated conditions, as imposed by our client. However, operating the Plummer system under saturated conditions ultimately yielded a net loss of \$541,000.

Our third option involved two turbines and a reheat steam loop. This option yielded \$475,000 of annual savings, but would require the substitution of the wood boiler with one containing a reheat section.

These significant system modifications lead our client to reject this option.

Our fourth option also utilized two turbines, but without using the reheat section in the boiler. The goal with this design option was to capitalize on the different operating pressures of the wood boiler and the natural gas boilers, without requiring the replacement of the existing wood boiler. This design option yielded a total annual savings of \$260,000. However, installation requirements likely involved expansion of the Steam Plant facility into the existing parking lot.

Revisiting the cogeneration system at the Stimson Stud Mill, a second Plummer model was developed utilizing superheated conditions. Although superheat poses increased safety concerns, the client was interested in seeing the capabilities of a full condensing model. This model can produce a peak power of 6 MW, with annual savings of \$510,000. However, it would require the addition of a full condensing loop. Although this model was seriously considered, it was ultimately not selected due to uncertainties regarding its impact on the local fuel market.

Our final design, which was ultimately selected by our client for economic analysis, is the Simple Turbine Model. This design simply bypasses the PRV network with a non-condensing, back pressure turbine. It was selected for its simplicity, including minor system modifications and significant savings.

Transitional Statement: With the decision made to pursue a cogeneration system utilizing a non-condensing back pressure turbine, it

was necessary to determine the appropriate system components and contact vendors for their costs.

Economic Analysis

The turbine selected was a Dresser-Rand K Frame model, rated at 50,000 lbs/hr of flow. Enough torque is produced by this turbine to operate a generator of 1 Mega Watt.

When retrofitting an existing system into a cogeneration system, additional fuel costs are important to consider. As you may recall, the turbine has the desirable benefit of reducing the steam pressure to the campus distribution level. However, it also extracts energy from the steam, resulting in less heating energy available within the steam to meet campus demand. To compensate for this reduction in energy, more steam must be produced, translating to more fuel consumed.

The Current Fuel Costs, represented by the blue bars on the graph, come from Steam Plant records from the fiscal year of 2012. The red bars on the graph represent the additional fuel necessary to meet campus demand and the green bars represent the amount of revenue associated with the generation.

Numerous vendors were contacted regarding capital cost estimates. The most forthcoming of these was the Dresser-Rand supplier Courtney and Nye. Interconnection costs were developed based on communication with Avista and McKinstry. The total implementation

cost for the proposed cogeneration system is approximately \$1,500,000.

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For the college, as a public institution, all projects considered should have a Simple Payback Period of 15 years or less. This means the project should pay for all costs associated with it within that timeframe. However, a more accepted business practice is to calculate the Internal Rate of Return achievable from a project. In this case, the decision criteria for whether to proceed with a project or not is whether the IRR exceeds the Minimum Annual Rate of Return for the business or institution in question.

This decision making process is easiest to understand in a Cash Flow Diagram.

Transitional Statement: This economic analysis relied upon a fluids and thermodynamic engineering study to develop the values for fuel costs and turbine revenue.

Methodology

This figure represents a flowchart of the engineering study. Working our way down from the top of the diagram, we start with recorded data from Steam Plant operation for the fiscal year of 2012. This data was used to generate values for Boiler Efficiency and Campus Heating Requirement. Boiler Efficiency and Campus Heating Requirement were the foundational pieces, used to calculate everything from Fuel Requirement to Turbine Power Output, to Fuel Costs and Savings.

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These calculated values for Boiler Efficiency and Campus Heating Requirement are for the current system, but will remain constant with the implementation of a cogeneration system because campus will always need the same heat regardless of what type of system is operating in the Steam Plant.

On initial inspection, one might think a mistake was made if the fuel content of wood is changing throughout the year. However, these wood chips are supplied by lumber mills, and the moisture content varies seasonally, as log decks and chip stacks are kept outside.

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One pivotal term, the elephant in room, remains to be explained. Turbine isentropic efficiency is a measure of a turbine's effectiveness at extracting energy from steam, and is an essential term in predicting the performance of the turbine in the system. However, this value is specific to each turbine and is measured via a test bench at the time of manufacturing, and is considered proprietary information, and therefore unavailable to students like us. In other words, using the assumed value of 0.65 from your Thermodynamics textbook, you will estimate a higher power generation than is realistic.

Transitional Statement: Coordinating with the University of Montana Associate Director of Engineering and Utilities, our team visited the Montana cogeneration facility in Missoula to acquire data and validate our model for predicting a turbine's actual isentropic efficiency.

Montana Data Validation

We developed a model for predicting power generation, but needed to validate that our results were representative of what happens in the real world. Inputting the operational data from Montana into our model we developed the operating points, represented as blue dots, for Power Output vs. Flow Rate. We were very fortunate to have access to the actual manufactures Power Output vs. Flow Rate curve, represented as the red, green and purple stepped curve, for the UM

system. As you can see the operating points calculated in our model, fit very well over the manufacture curve.

Transitional Statement: Being comfortable with our ability to predict power output we can turn our attention to turbine isentropic efficiency.

The tricky thing about isentropic efficiency is that it varies with flow rate. And, as you may recall from the Campus Heating Requirement, a turbine at a University will be operating under a variable flow rate throughout the year. Using the data from the previous figure along with known operating pressures of the system, we generated an Isentropic Efficiency vs. Flow Rate curve. Note that the average flow rate is around 20,000 lbs/hr which corresponds to the highest isentropic efficiency of about 53%. This is how a turbine should be sized to a system.

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Conclusion

In summary, throughout our efforts to model the current system and develop cogeneration alternatives we discovered the University of Idaho is a strong candidate for renewable energy implementations. \$170,000 in annual savings can be achieved from a project which will pay for itself in 8 years. Locally, a near identical system successfully

operates at the University of Montana, and can serve as a knowledge base for operational concerns.

However, if this is such a good idea, why was it not done in 1988 at the time of upgrade to a wood boiler? Our conclusion is that the most significant obstacles to project implementation lie beyond engineering and in the fields of Law, Business and Politics.

We would like thank all of our sponsors, advisors and contacts for working with us and helping us complete this project. We will be manning our booth for the remainder of EXPO and would love to provide an answer to any in depth, technical questions you might have.

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Now we would like to now open up the floor to a brief questions and answers session.