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Collaboration Between Senior Design Students and Campus Facilities Staff in Creating a Viable Cogeneration Design for the Campus Wood-Fired Boiler

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Abstract

An experimental project was created within our inter-disciplinary product realization capstone course to bring together students and staff from our campus steam plant to explore the feasibility of an economical design for a cogeneration turbine, generator, and power conditioning equipment. Project activities consisted of interviewing regional consultants and electric utility staff, touring other cogeneration facilities within the region, monitoring campus-wide steam pressure, analyzing seasonal data, modeling performance of different plant configurations with Engineering Equation Solver (EES), and conducting multiple design reviews with senior facilities staff. The team proposed a comprehensive design that could save $190,000/year with an implementation cost of $1.5M. The team's solution also included instrumentation that can support laboratory studies in multiple STEM courses, is visually attractive in its layout within our historic steam plant building, and is sustainable in its use of local wood waste. The team won two awards at our 2014 Design Expo. Project outcomes were assessed through a survey of students, faculty, and facilities staff. Success factors included student connection with a DOE sponsored Industrial Assessment Center, preparation in prior course work, capstone course activities that were aligned with project needs, and a welcoming, continuous improvement mindset displayed by steam plant personnel. Recommendations are also provided for enriching future energy conservation projects done within the context of capstone design courses.

Background

Within the modern workforce there is a growing need for energy engineers to work on new and retrofit projects associated with offices, residences, and manufacturing facilities. The set of required knowledge and skills is inter-disciplinary [1,2]. Common job responsibilities include:

- Inspecting and monitoring energy systems, including heating, ventilating, and air conditioning (HVAC), boilers, furnaces, air compressors and lighting systems to determine energy use or potential energy savings.
- Providing consultation to clients or other engineers on topics such as climate control systems, energy modeling, data logging, energy management control systems, lighting design, sustainable design, and energy auditing.
- Reviewing architectural, mechanical, or electrical plans and specifications to evaluate energy efficiency or determine economic, service, or engineering feasibility.
- Compiling, analyzing, and interpreting graphical representations of energy data, using generic as well as application-specific engineering software.
- Performing energy modeling and validating results with appropriate measurements.
- Making recommendations regarding energy fuel selection.
- Preparing feasibility reports and other technical documentation.
- Promoting awareness about and use of alternative or renewable energy sources.
- Training personnel or clients in strategic energy management.

- Managing the development, design, or construction of energy conservation projects to ensure acceptability of budgets and time lines, conformance to federal and state laws, or adherence to approved specifications.
- Consulting with clients or other engineers on topics such as Leadership in Energy and Environmental Design (LEED) or Green Buildings.
- Conducting research on renewable and alternative energy systems.

To stimulate workforce development in energy engineering, the Department of Energy continues to support its 20+ year old Industrial Assessment Center (IAC) program [3]. This program provides educational experiences for engineering students in the context of energy conservation outreach to mid-sized manufacturing facilities. Nationwide, there are more than 30 university-based IAC units, one of which is based at the University of Idaho. IAC students receive inter-disciplinary training in energy auditing (air compressors, boilers, ventilation systems, lighting, and implementation of combined heat and power), hands-on experience with field instrumentation (infrared imagers, combustion analyzer, air velocity monitors, temperature, and pressure measurement devices, and current loggers), and opportunities to interact with regional clients in preparing comprehensive energy assessment reports. The IAC model is built around a full-day energy audit each month followed by data analysis and report writing. For deeper design involvement, including system optimization and preparation of detailed design documents, organizations such as the Association of Energy Engineers (AEE) endorse inter-disciplinary design project experiences [4].

The inter-disciplinary capstone design program at University of Idaho involves the departments of Biological and Agricultural Engineering, Computer Science, Electrical & Computer Engineering, and Mechanical Engineering. It provides an authentic learning experience which is recognized by the National Academy for Engineering for approximately 150 students each year and has evolved over the last twenty years through a continuous stream of projects from regional industry, equipment donations from alumni and industry supporters, and support for graduate student shop mentors [5,6,7]. Results from over 30 capstone design team projects are shared each year with the public, alumni, and industry partners at a signature university event known as the Design Expo [8]. Large-scale formative assessment of in-progress project work is provided through three Snapshot Days throughout the two semester sequence where team members informally discuss project status in a class-wide interactive poster session [9]. An archive of past project work is keep on a website that now includes course curriculum as well as over 300 previous capstone projects [10]. The overall learning environment is engaging for upperclassmen as well as enticing to prospective freshmen, transfer students, engineering underclassmen, and project sponsors. Historically, the capstone program has focused on product realization, emphasizing application of design and manufacturing skills in response to client needs [11]. This paper explores the feasibility of housing energy conservation projects within our capstone course model, even though the final product is detailed design documentation rather than finished hardware. A typical schedule of course activities is laid out in Tables 1 and 2.

Table 1. Overview of 1st Semester in Capstone Sequence

Week	Formal Instruction	Advisor Interaction	Team Activities	Deliverables
1	Presentation of project options			Submission of project bid portfolio
2	Team Assignment Logbook Guidelines		Team roles & responsibilities	Team Contract
3	Strategies for Project Learning	Instructor/team Mtg	First contact with client	
4	Writing Specifications	Client Meeting	Client Meeting	
5	Project Management	Instructor/team Mtg	Draft problem statement	Minutes from Client Meeting
6	Wiki page Workshop	Instructor/team Mtg	Draft specifications	
7		Instructor/team Mtg	Project planning	Logbook Review Project Binder
8	Problem Definition Snapshot Day (Poster Session)	Instructor/team Mtg Logbook Debrief Portfolio Debrief	Prep for Snapshot Day	Poster display - Problem Defn - Specifications - Project Learning
9	Preparing for a Design Review	Instructor/team Mtg Snapshot Feedback	Concept Development	
10		Instructor/team Mtg	Concept Development	
11	Wikipage Review	Instructor/team Mtg Logbook Debrief	Concept Selection	Logbook Review
12		Instructor/team Mtg	Prep for Design Review	1st Design Review w/client
13		Instructor/team Mtg Design Review Debrief	System Design	
14		Instructor/team Mtg	System Design	Peer Reviews
15	Conceptual Design Snapshot Day (Poster Session)	Instructor/team Mtg	Prep for Snapshot Day	Poster Display - Updated Specs - System Design - Project Plan
16		Instructor/team Mtg Snapshot Day Debrief Peer Review Debrief	Project Documentation	Project Binder Wikipage Logbook Review

Table 2. Overview of 2nd Semester in Capstone Sequence

Week	Formal Instruction	Advisor Interaction	Team Activities	Deliverables
1	Semester Schedule Semester Expectations	Logbook Debrief Project Binder Debrief	Detail Design	
2		Instructor/team Mtg	Detail Design	
3		Instructor/team Mtg	Detail Design	
4		Instructor/team Mtg	Prep for Design Review	2nd Design Review w/client
5	Design Failure Mode Effects Analysis	Instructor/team Mtg	Design Documents	
6		Instructor/team Mtg	Fabrication	Logbook Review
7	Wikipage Review	Instructor/team Mtg Logbook Debrief	Fabrication	Peer Review
8	Detail Design Snapshot Day (Poster Design)	Instructor/team Mtg	Prep for Snapshot Day	Poster Display - System Design - Drawings - Purchasing - Work in-Progress
9		Instructor/team Mtg Peer Review Debrief	Fabrication	
10	Writing Design Reports	Instructor/team Mtg	Assembly	
11		Instructor/team Mtg	Assembly	
12	Wikipage Review	Instructor/team Mtg	Testing	
13		Instructor/team Mtg	Testing	Logbook Review
14	Expectations for Design Expo	Instructor/team Mtg Logbook Debrief	Report Writing	
15	Design Expo Day	Instructor/team Mtg Report Review	Prep for Design Expo	Booth Display Technical Talk
16		Instructor/team Mtg Report Review	Report Writing	Design Report Wikipage

Project Scoping

The University of Idaho has operated a central heating plant for over 100 years. The original heating plant burned coal to heat a much smaller campus. The Steam Plant, constructed in its present location in 1927, has utilized fuel oil, coal, natural gas, and wood chips. To meet the growing demands of an expanding campus, the plant expanded in 1940, 1963, 1975, and again in 1986, when the wood-fired boiler was added. Presently, wood chips comprise the primary fuel, and natural gas supplies backup heat. There is currently no electrical cogeneration.

Faced with budget cuts to higher education and increasing fuel costs as well as electrical rates, campus facilities personnel are continually examining opportunities for infrastructural and operational investments that have a favorable rate of return. The motivation for the project was curiosity about the ability of different configurations of a steam-driven turbine and generator to produce power as a by-product of meeting campus heating and cooling demand. The combined use of steam to supply a heating load as well as generate power is known as Combined Heat and Power (CHP), or cogeneration. A schematic of steam-driven cogeneration is shown in Figure 1.

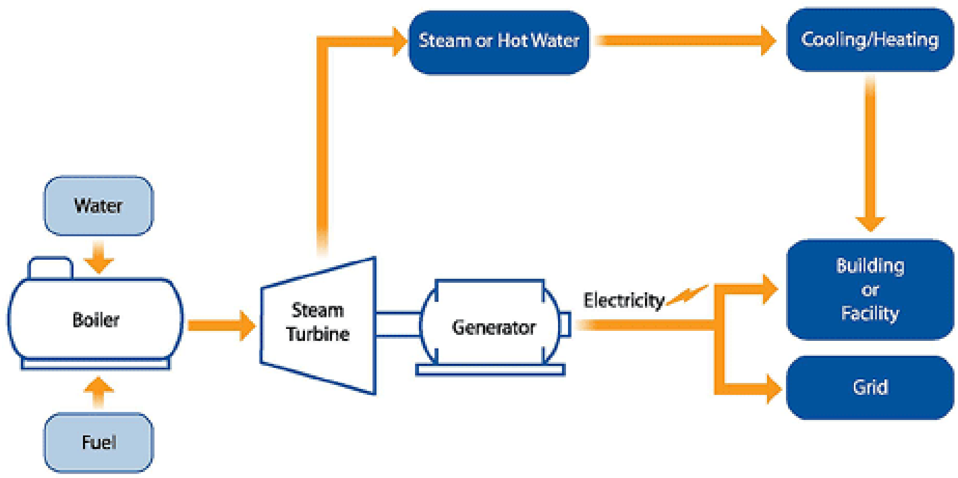

Figure 1: Steam-Driven Cogeneration

According to the Department of Energy (DOE), cogeneration is a proven, effective and underutilized energy solution that maximizes system efficiency when implemented in a suitable facility [12]. As part of the Combined Heat and Power Partnership, the Environmental Protection Agency (EPA) provides a list of several criteria that can be used to identify a suitable facility for the application of a cogeneration system [13]. These include:

- Greater than 5,000 annual operating hours
- Significant thermal loads within the facility
- The existence of a centralized plant location
- Electrical energy consumption that exceeds anticipated electrical generation

Each of these qualifications is met by the University. Next, according to the Combined Heat and Power Partnership, a technical feasibility analysis should be performed to determine whether cogeneration is a proper fit for the facility. This feasibility analysis is the subject of the experimental capstone project examined in this paper.

The University of Idaho Steam Plant Manager volunteered to be the client for this project and provided the following project description that attracted the attention of biological, mechanical, and electrical engineering students in the 2013-14 capstone design class. Ultimately four students from these disciplines were selected for the project team.

> *Realize an electrical energy savings through the use of a steam turbine and generator, in parallel with the existing pressure reduction valve network while maintaining necessary steam production to meet campus heating demand based on fiscal year 2012 recorded data.*

Problem Definition

A preliminary analysis method provided by the DOE was used to estimate the potential power production of a steam-driven turbine in the steam plant [14]. Assuming inlet conditions of the turbine to be 200 psig saturated steam, and outlet conditions to be 30 psig saturated steam, Figure 2 can be used to estimate the amount of power generated per 1,000 pounds of steam flow:

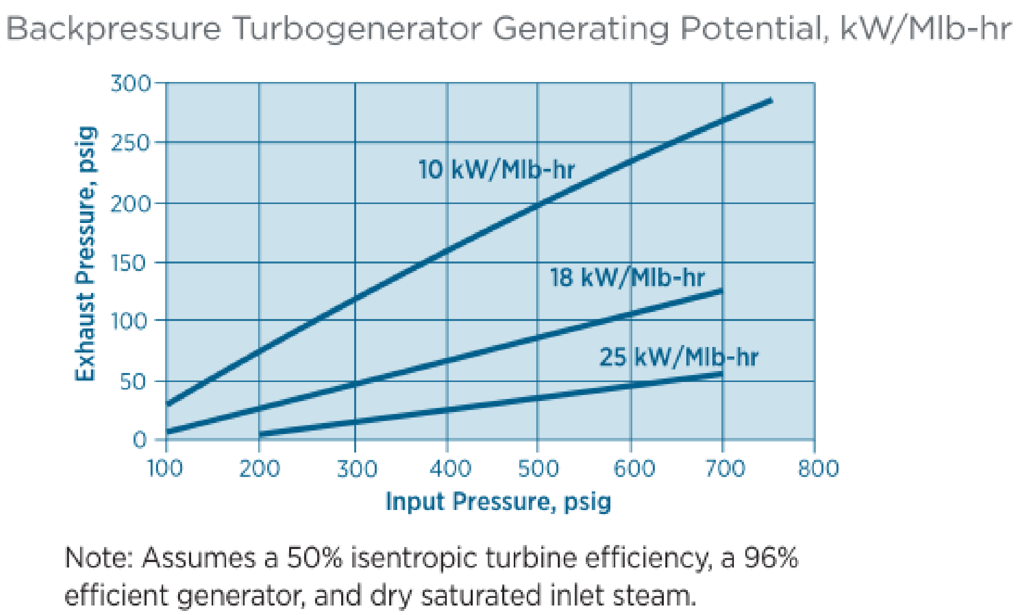

Figure 2. DOE Turbine Power Estimator [14]

The average steam flow for the Steam Plant in 2012 was about 29,000 pounds per hour. Multiplying this by the 18 kW/Mlb-hr provided above yields a projected power production of 520 kW, corresponding to annual savings of about $250,000. This calculation does not consider seasonal variation in boiler output or additional fuel costs associated with operating the turbine.

Based on client interviews, tours through the existing steam plant facility, and literature review, the team proposed the following problem statement as part of the Problem Definition Snapshot Day held in October 2013:

Perform a feasibility study on the implementation of a cogeneration turbine, to bypass the existing pressure reduction valve network, at the University of XX Steam Plant. Present six different design/construction models of which the client shall choose two for further analysis. Campus steam demand shall be established based on client supplied data from 2012. Designs may utilize an increased boiler pressure to 200psi. Presentation to client of six initial designs to include initial financial calculations highlighting: current fuel cost requirements, the additional fuel costs associated with operating a turbine, and revenue obtainable from the sale of electricity generated based on a $50/MWh valuation.

This problem statement led to discussion between the client and the team that identified the following constraints/guidelines for the energy capstone project:

- All equipment should be placed within the existing facility footprint (turbine/generator, fuel storage, and electrical equipment.
- Energy savings analysis should be based on mixed fuels (biomass and natural gas) rather than a single fuel (just biomass).
- Plan to connect to the campus electrical network/grid at 13.2 kV.
- Electrical savings should be priced using a net zero concept.
- Changes in steam plant manpower should be minimal.
- Even though boiler tubes are rated higher, system pressure should be limited to 200 psi
- Examine the impact of various cogeneration options with respect to environmental impacts (ash disposal, water effluent, and permitting requirements).
- Insure that proposed changes to the steam plant are aligned with long range campus master plan.
- Baseline current plant efficiency/energy costs as well as those of the proposed model (using steam plant data, data from nearby cogeneration facilities, as well as vendor interactions).
- Express project savings in terms of simple payback as well as return on investment (with consideration of upfront costs, life cycle operation costs, salvage value, and scenarios for fuel as well as electricity escalation).

A work plan was developed that aligned with the schedule of course activities and deliverables summarized in Tables 1 and 2. This was modified throughout the year but it stayed fairly close to the original plan envisioned by the design team. The actual project schedule appears in Figure 3.

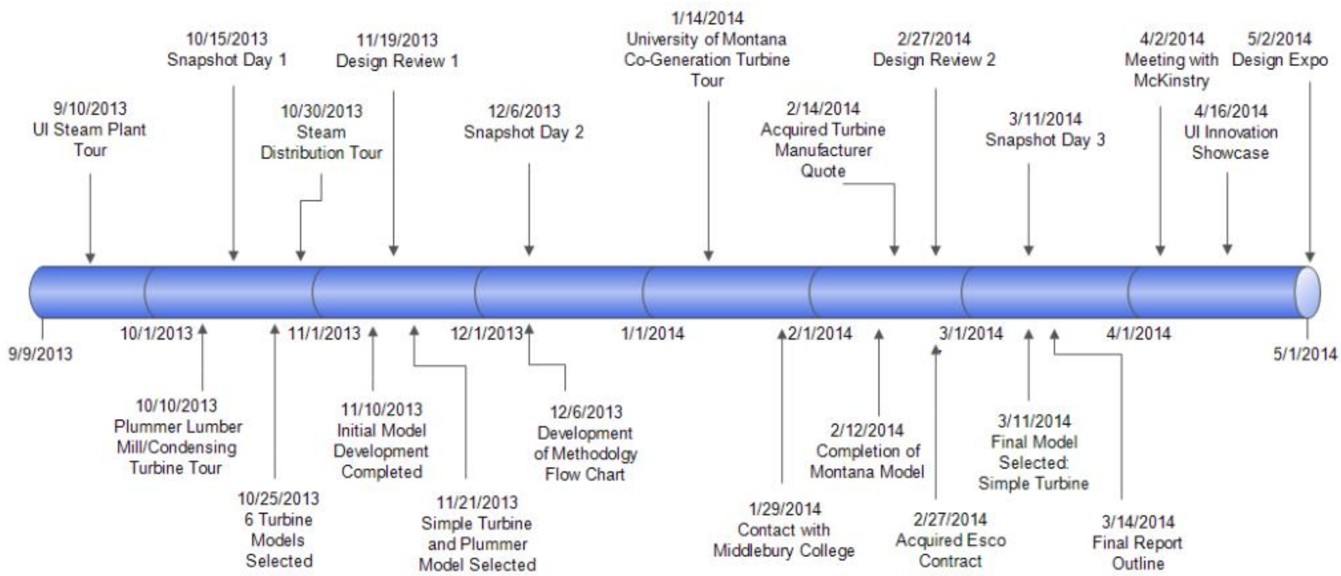

Figure 3. Energy Engineering Project Timeline (as implemented)

Conceptual Design

The feasibility and economic analysis for the implementation of a cogeneration system at the Steam Plant included compiling data for annual steam production and fuel consumption, and using the data to develop numerical values for the campus heating load and the approximate energy required per bone dry ton of fuel on a monthly basis. Then, taking these two values to be constant, six distinct turbine models were compared. Figure 4 details the analysis process used by the design team.

Data for the fiscal year of 2012 was recorded hourly by employees, and totaled on a daily basis for the wood boiler and the three natural gas boilers. Boiler pressure output varies to meet campus demand, but was set at about 135 psig for every month except July and August, when it was set to 120 psig. Figures 5 and 6 detail the quantity of fuel purchased and consumed by the Steam Plant, including biomass and natural gas; the quantity of steam produced by each boiler type (natural gas or biomass); and finally the derived values for the monthly campus heating requirement and the amount of heat extracted per bone dry ton of fuel.

Using the current system as the baseline, six different cogeneration models were compared based on predicted power generation, fuel consumption, and annual savings. Thermodynamic property states as well as system modeling was conducted with Engineering Equation Solver (EES). Thermal system analysis conducted throughout the project is summarized on the design team's wikipage [15].

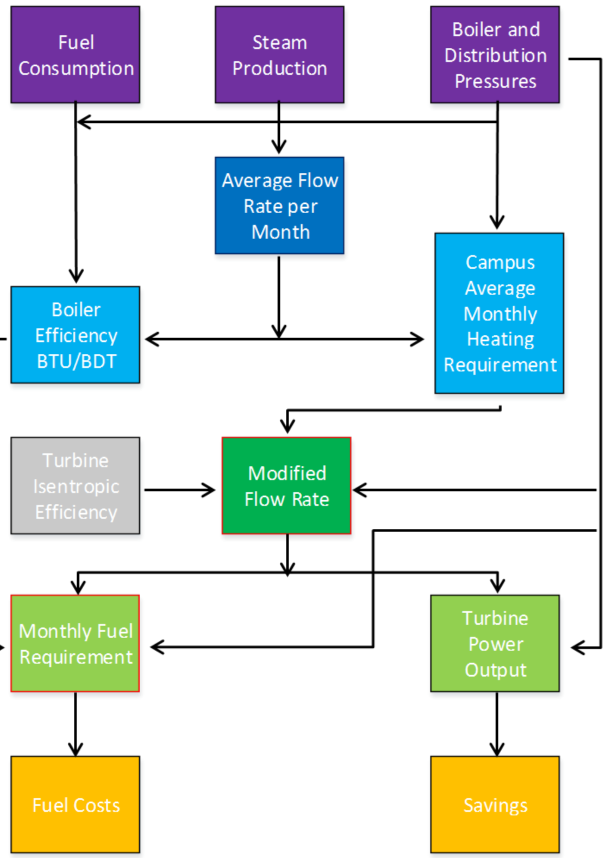

Figure 3. Design Analysis Flowchart

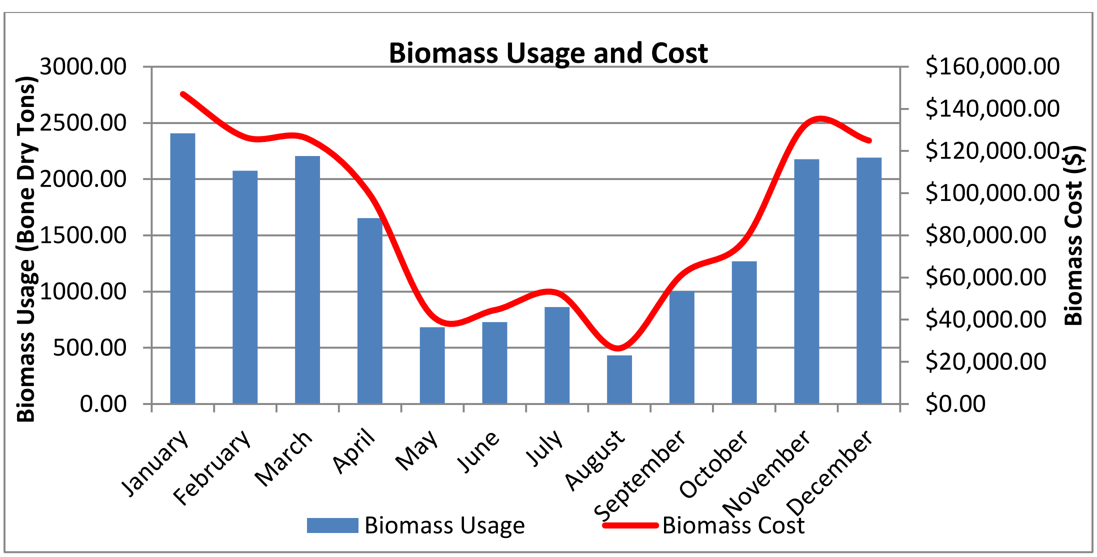

Figure 5. Biomass Usage and Cost

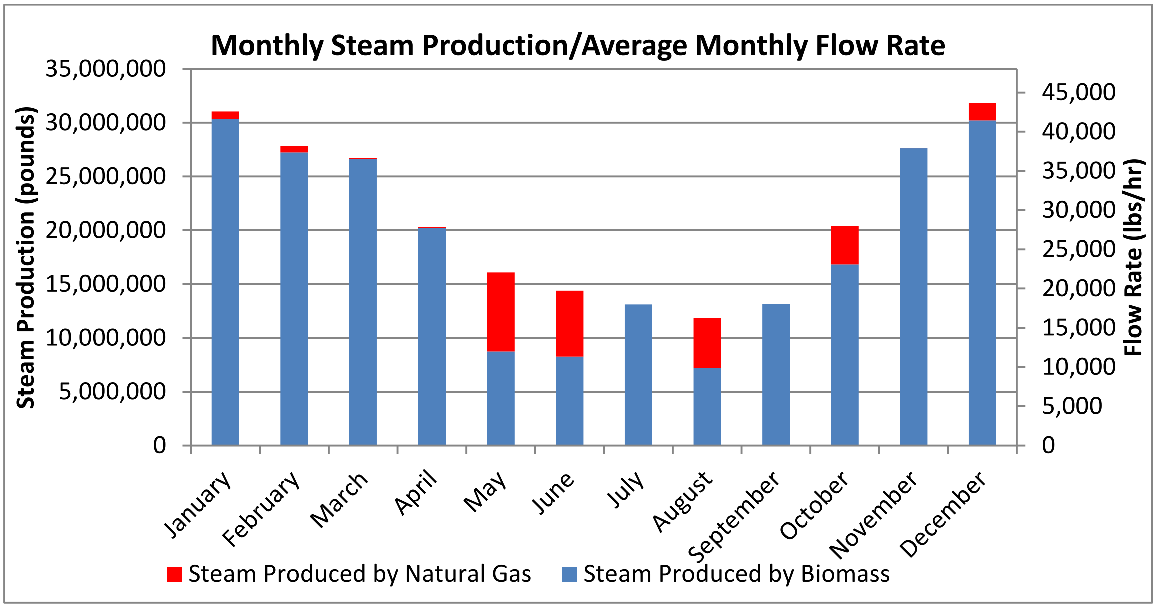

Figure 6. Total Monthly Steam Production and Average Monthly Flow Rate

The six design models summarized in Table 3 were presented to the University of Idaho facilities department as part of the first design review. Criteria for selecting a model included all of the elements from the table. The 'Operational Profile' row includes two criteria, with steam following campus demand being preferable as it more closely resembles the current system. Additional considerations also contributed to the selection of models for further study. For example, the installation of a turbine in the steam plant will affect the work environment. Existing employees may need to be trained and new employees may need to be hired. Safety concerns were paramount. When operating at higher pressures, water tube ruptures inside of the firebox can result in the blowing off of boiler doors. Personal protection blast barriers would need to be installed for operator protection. Therefore, the Simple Turbine was considered the most desirable because it involves the smallest changes and is also the safest. There are also significant differences between models in maintenance and implementation costs. Preliminary estimates did not include a full economic analysis, but starting from the left side of the table and working right, costs increase significantly.

During the first design review, the list of six options was narrowed down to two, including the Simple Turbine Model and the Reheat Turbine Model. However, given the significant increase in fuel consumption of the Reheat Turbine Model (21,000 BDTs of biomass), it was determined likely that the local market is not robust enough to handle such an increase in demand. Therefore, the Simple Turbine Model was selected as the option that should be the focus of detailed design. Results at this stage of the project were shared in the Conceptual Design Snapshot held in December 2013.

Table 3. Performance Analysis of Different Cogeneration Configurations

Attribute	Non-Condensing Options			Condensing Options		
	Simple Turbine Model Single Back-Pressure Turbine	**Two Turbine Model** Two Back-Pressure Turbines	**Reheat Turbine Model** Reheat Back-Pressure Turbine	**Multi-Stage Saturated Model** Condensing w/saturated steam	**Multi-Stage Superheat Model** Condensing w/superheated steam	**Maxi Model** Max Generation
Peak Generation	940 kW	1800 kW	2200 kW	2000 kW	5800 kW	15000 kW
Average Generation	580 kW	1100 kW	1400 kW	1700 kW	5500 kW	14500 kW
Annual Savings	$185,000	$324,000	$475,000	-$541,000	$510,000	-$5,680,000
Operational Profile	Steam Flow Follows Campus Demand	Steam Flow Follows Campus Demand	Steam Flow Follows Campus Demand	Imposes Constant Flow Rate	Imposes Constant Flow Rate	Imposes Constant Flow Rate
System Modifications and Additions	Turbine	Two Turbines	Two Turbines	Turbine	Turbine	Turbine
			Facility Expansion	Facility Expansion	Facility Expansion	Facility Expansion
		Facility Expansion	New Boiler	New Boiler	New Boiler	New Boiler
				Full Condensing Loop	Full Condensing Loop	Full Condensing Loop
Additional Fuel Consumption and Costs	1,300 BDTs	3,350 BDTs	3,800 BDTs	19,000 BDTs	21,000 BDTs	35,000 BDTs
	24,000 Therms	80,000 Therms	100,000 Therms	1,500,000 Therms	1,750,000 Therms	2,900,000 Therms
	$110,000	$260,000	$300,000	$2,100,000	$2,300,000	$12,000,000

Detail Design

In the simple turbine model, a steam turbine mated to a synchronous generator is added in parallel to the pressure reducing valve (PRV) element in the existing system. The necessary steam pressure reduction formally achieved by the PRV, in the proposed design is accomplished by the turbine with the added benefit of power generation. This includes a back pressure, non-condensing turbine. Inlet pressure for the turbine is increased by raising the boiler output pressure from the existing 135psig to 200psig. Additionally, the campus distribution pressure shall be lowered from 60psig to 30psig. The change of pressures results in a greater pressure differential across the turbine and an increased power generation ability. Satisfactory system performance at a decreased distribution pressure was assessed during a practical test over the winter break. During the test, system distribution pressure was lowered to 30psig and no adverse effects were recorded in the system.

Accurate calculation of fuel costs and revenue relies upon knowing the turbine isentropic efficiency. 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. It is often considered proprietary information, and not publicly available to students. Fortunately, the performance information necessary to develop isentropic efficiency estimates for University of Idaho implementation was provided by our Dresser-Rand equipment supplier. Using this data in conjunction with the campus heating requirement derived from Figure 6 values for isentropic efficiency of the K Frame back pressure turbine were determined for each month of operation in the Steam Plant. Results were validated against a similar turbine installation at the University of Montana. Part load isentropic efficiency predictions are shown in Figure 7.

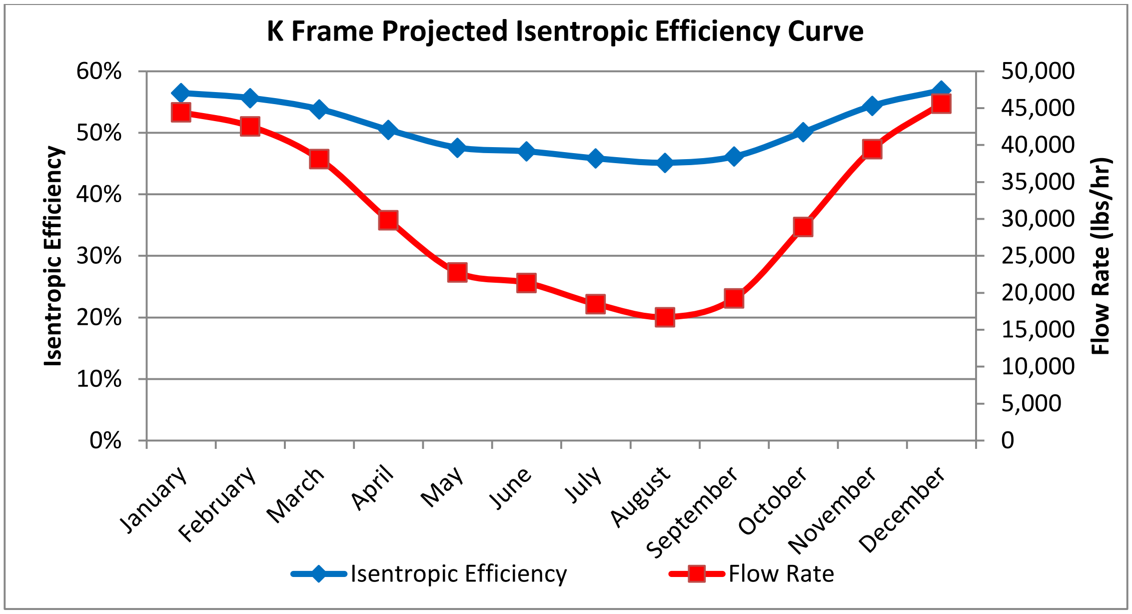

Figure 7. Derived K-Frame Isentropic Efficiency for year 2012

When retrofitting an existing system into a cogeneration system, additional fuel costs need to be determined. 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 additional fuel costs of operating this proposed system amount to $86,003 per year. Revenue, as the offset of university electrical consumption valued at $0.0586 per kWh, amounts to $278,045. The value of $0.0586 per kWh for calculating revenue is variable and will be determined contractually with the utility when the system is installed.

For the university, as a public institution, all projects considered should have a Simple Payback Period (SPP) 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 (IRR) 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 (MARR) for the business or institution in question.

Capital expense cost estimates were obtained from the turbine equipment supplier, the local electrical utility, and an energy consultant to the university. These costs are summarized in Table 5. Accounting for additional fuel costs, annual maintenance, and the average of the five year maintenance, the annual savings achieved by the K Frame design amount to $175,042. This estimate was presented at the Detailed Design Snapshot held in March 2014.

Table 5. Component and Implementation Costs

	Capital Cost
Turbine	$480,000
Base, Couplings, Lube System	$85,000
Generator	$45,000
Generator Controls and Contactor	$75,000
1800 RPM Reduction Gear	$315,000
Installation Cost	$250,000
Interconnect Cost	$250,000
System Total	**$1,500,000**

Project Finale

Since three of the four engineering students on this project were also part of our IAC unit and they chose to write up their design report according to DOE guidelines for an industrial assessment report. The final product was over 80 pages long [16]. The annual power generation of the proposed K-Frame turbine generator set is 4,745,000 kWh, which amounts to 9.97% of the total University electrical consumption, and translates to $192,000 in annual savings. The implementation costs associated with this recommendation are approximately $1,500,000. The Simple Payback Period is 7.68 years, with an Internal Rate of Return of 11%, compared to the University Minimum Annual Rate of Return of 6%. The team recommended that the cogeneration turbine be placed in one of the bays next to one of the windows on 6th Street as shown in Figure 7. Recommendations were also given for additional information could be added to the existing self-guiding sign next to the historic steam plan building, generating awareness of energy conservation implications associated with this infrastructure enhancement. The team won awards for their booth display and technical presentation at the 2014 Design Expo. They also received kudos from the client and all of their external consultants.

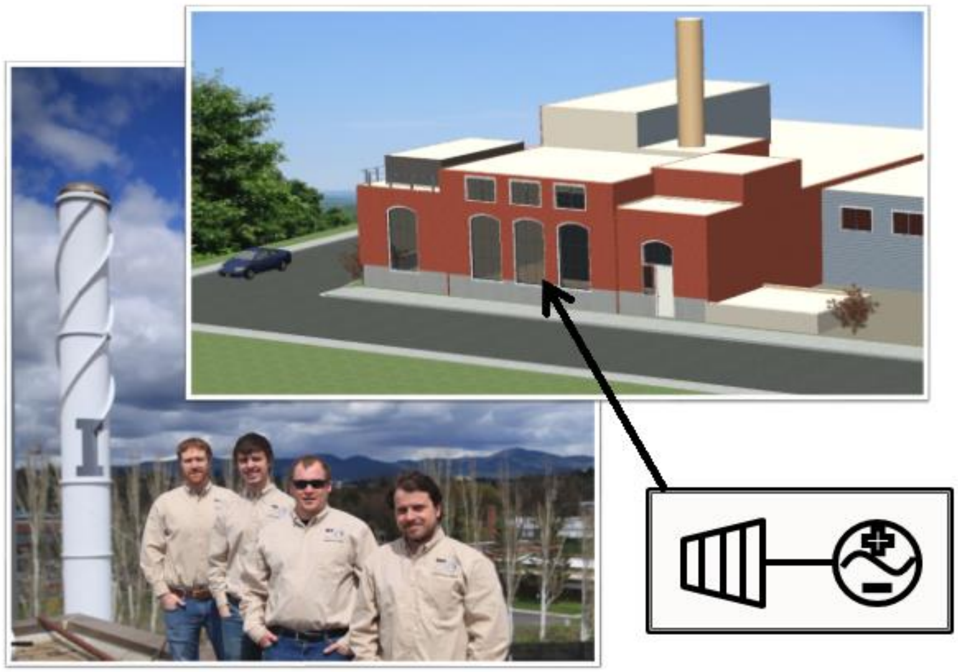

Figure 7. Design Team on Steam Plant Roof and Proposed Site for Backpressure Turbine

Outcome Assessment

Three research questions were formulated to analyze the success of the foregoing energy engineering case study within our existing capstone design program.

a) What growth in knowledge and skills is possible in an energy engineering capstone project?
b) What portion of this knowledge and skill is ideally derived through pre-capstone coursework?
c) What capstone course elements are essential for a successful energy engineering project?

These research questions were translated into the three-page stakeholder survey that appears in Appendix A. The survey contained five parts and was given to student team members, faculty advisors, and project clients. Students and faculty completed all five parts. The survey was designed for easy adaptation to other energy engineering capstone projects within any capstone program. Table 6 summarizes findings related to knowledge and skills needed for an energy engineering capstone project. The top portion of this table highlights technical skills, the middle band (**in bold**) highlights design skills, and bottom portion (*in italics*) highlights communication skills. Student and faculty perspectives were closely aligned. The client perspective was similar, but it reflected what was important in intermediate and final work products rather than what transpired in day to day team activities. What was valued by students and faculty was similar to traditional capstone projects, but there was heavier weight given to thermodynamics, engineering economics, computer modeling, interaction with external stakeholders, and greater emphasis on technical presentations as well as report writing.

Table 6. Summary of Survey Data from Stakeholders about Pilot Project Knowledge/Skills

Performance Area	**Students**	**Faculty**	**Client**	**Key Skills**
Machine Design	N	N	D	
Materials Science	N	N	D	
Thermodynamics	A	SA	SA	fluid properties, 1st law, isentropic efficiencies
Heat Transfer	A	A	N	Insulation, temperature distribution
Fluid Mechanics	A	A	A	fluid velocity, head loss, pipe and pump sizing
Engineering Economics	SA	SA	SA	cashflow analysis, simple payback
Power Systems	A	A	A	generator design, power conditioning
Circuit Design	N	N	N	
Building Computer Models	SA	SA	SA	EES, parametric studies
Compiling/Analyzing Data	SA	SA	A	Accounting for seasonal variation in design data
Writing Specifications	**A**	**A**	**N**	**clarifying requirements and identifying constraints**
Exploring Alternative Solutions	**A**	**A**	**N**	**understanding system layouts**
Selecting Solution Concepts	**A**	**A**	**N**	**based on computer modeling**
Conducting Design Reviews	**A**	**A**	**A**	**preparing handouts, asking/responding to questions**
Working on a Project Team	**A**	**A**	**N**	**similar to other capstone teams**
Planning/Project Management	**A**	**A**	**N**	**similar to other capstone teams**
Interacting with Clients	**A**	**SA**	**A**	**working with vendors**
Selecting & Sizing Components	**A**	**A**	**N**	
Making Manufacturing Plans	**D**	**D**	**N**	
Evaluating Solution Impacts	**A**	**A**	**A**	**awareness of legal and sustainability issues**
Report Writing	*A*	*SA*	*A*	*high stakes product*
Giving Technical Presentations	*SA*	*A*	*A*	*similar to other capstone teams*
Using a Logbook	*SA*	*A*	*N*	*similar to other capstone teams*
Creating a Project Wikipage	*N*	*A*	*N*	*similar to other capstone teams*

Ratings: SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree

The most important performance areas for the success of the pilot energy engineering capstone were compiling and analyzing a large volume of steam plant data, building and studying computer models for different plant configurations, working within an authentic engineering team, and communicating findings on a periodic basis to clients via oral and written communication. More than half the value-added in each of these areas could be attributed to informal activities within the design. The remaining source of value was perceived to come from previous coursework (especially thermodynamics, energy/power systems, engineering economics, and technical writing) as well as formal capstone course activities.

All of the capstone course elements were rated positively by students with client/consultant interactions, design reviews and the Design Expo rated most highly because of the way these reflected professional expectations on the job. The project bid portfolio was viewed as an effective vetting process for assigning team members. The Problem Definition Snapshot was a catalyst for developing big picture understanding of the project. The Conceptual Design and Detail Design Snapshots provided diverse inputs about project status from peers and engineering professionals. The Design Expo was a public examination of project deliverables and a celebration of engineering accomplishment. The Design report was much more involved than originally conceived and stressed the importance having deadlines for drafts of different sections within the report. Team member peer reviews documented accountability of team members to the group/project. Logbooks were a convenient tool to organize informal thoughts and personal learning throughout the project. Members who kept better logbooks were observed to have a much easier time composing their sections of the final report. Instructor feedback was valued throughout the entire capstone experience and this led to special responsibilities within the University of Idaho IAC program because of relationships developed as well as trust earned.

Conclusions

The design for our product realization capstone course (formal activities and deliverables) is compatible with the needs of an energy engineering capstone project. In an energy engineering project, manufacturing activities in the second half of our product realization capstone course are replaced with production of detailed design/cost documentation. The largest portion of value-added activity in the pilot energy engineering capstone project was attributable to informal team activities, but prior coursework in thermodynamics, energy/power systems, engineering economics, and technical writing was deemed very beneficial. Collaboration with campus facilities staff was found to be a rich source of options for authentic energy engineering experience as well as mentoring on equipment operation, data acquisition, cost estimating, and selection of vendors for large capital items.

We have created a survey for assessing the effectiveness of an energy engineering capstone project that can be applied in conjunction with future projects and can be easily adapted to other programs. All parts of the survey are appropriate for students and faculty who shared similar perspectives in this pilot study. Parts 1, 2, and 5 are suited for clients/consultants who interact with the team via intermediate work products. Analysis of survey results from stakeholders in the pilot energy engineering capstone project validated the utility of this assessment tool for other energy engineering capstone project implementations.

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APPENDIX A: Energy Engineering Capstone Project Assessment

1. What was your course role (circle one)? **Student** **Instructor** **Client/Consultant**

2. Based on your experience, rate the importance of each of the following performance areas in an energy capstone project. **Circle your rating: SD=strongly disagree; D=disagree; N=neutral; A=agree; SA=strongly agree.** For each area you assign A (agree) or SA (strongly agree), list one or more key skills in these performance areas.

Performance Area	Importance in Energy Capstone	Key Skills
Machine Design	SD D N A SA	
Materials Science	SD D N A SA	
Thermodynamics	SD D N A SA	
Heat Transfer	SD D N A SA	
Fluid Mechanics	SD D N A SA	
Engineering Economics	SD D N A SA	
Power Engineering	SD D N A SA	
Circuit Design	SD D N A SA	
Building Computer Models	SD D N A SA	
Compiling/Analyzing Data	SD D N A SA	
Writing Engineering Specs	SD D N A SA	
Exploring Alternative Solutions	SD D N A SA	
Conducting Design Reviews	SD D N A SA	
Working on a Project Team	SD D N A SA	
Planning/Project Management	SD D N A SA	
Interacting with Clients	SD D N A SA	
Selecting & Sizing Components	SD D N A SA	
Making Manufacturing Plans	SD D N A SA	
Evaluating Solution Impacts	SD D N A SA	
Report Writing	SD D N A SA	
Giving Technical Presentations	SD D N A SA	
Using a Personal Logbook	SD D N A SA	
Creating a Project Wikipage	SD D N A SA	

3. Identify the five most important performance areas from the list above with respect to your energy capstone project. For each area, estimate the fraction of required knowledge and skill that obtained (a) in previous coursework, (b) through classwide capstone course activities, (c) through informal capstone team activities. Each row should add to 100%.

Performance Area	% from previous coursework (primary course)	% from formal capstone course activities	% from informal capstone team activities

4. Comment on each of the following course elements as being essential for your energy capstone project. Briefly explain your rationale for each rating.

Course Element	Importance in Energy Capstone	Rationale
Project Bid Portfolio	SD D N A SA	
Problem Definition Snapshot	SD D N A SA	
Conceptual Design Snapshot	SD D N A SA	
Detail Design Snapshot	SD D N A SA	
Design Expo	SD D N A SA	
Design Report	SD D N A SA	
Wikipage	SD D N A SA	
Instructor/Team Meetings	SD D N A SA	
Client/Consultant Interactions	SD D N A SA	
Design Reviews	SD D N A SA	
Team Member Peer Reviews	SD D N A SA	
Logbook Reviews	SD D N A SA	

5. What was a positive action by (a) instructors, (b) students, and (c) clients that added value to your project? Similarly cite an additional action that could increase the success of future energy engineering projects. Explain the desirable impact of each action.

Actions by Instructors	**Impact of Instructor Actions**
a) Positive action taken in this project b) Additional helpful action possible	a) b)
Actions by Students	**Impact of Student Actions**
a) Positive action taken in this project b) Additional helpful action possible	a) b)
Actions by Clients/Consultants	**Impact of Clients/Consultant Actions**
a) Positive action taken in this project b) Additional helpful action possible	a) b)