University of Arkansas, Fayetteville
ScholarWorks@UARK

Chemical Engineering Undergraduate Honors Theses

Chemical Engineering

5-2012

Micro hydro-electric power generation

Travis Rose
University of Arkansas, Fayetteville

Micro-Hydroelectric Power Generation

An Undergraduate Honors College Thesis

in the

Department of Chemical Engineering
College of Engineering
University of Arkansas
Fayetteville, AR

by

Travis Rose

April 18, 2012

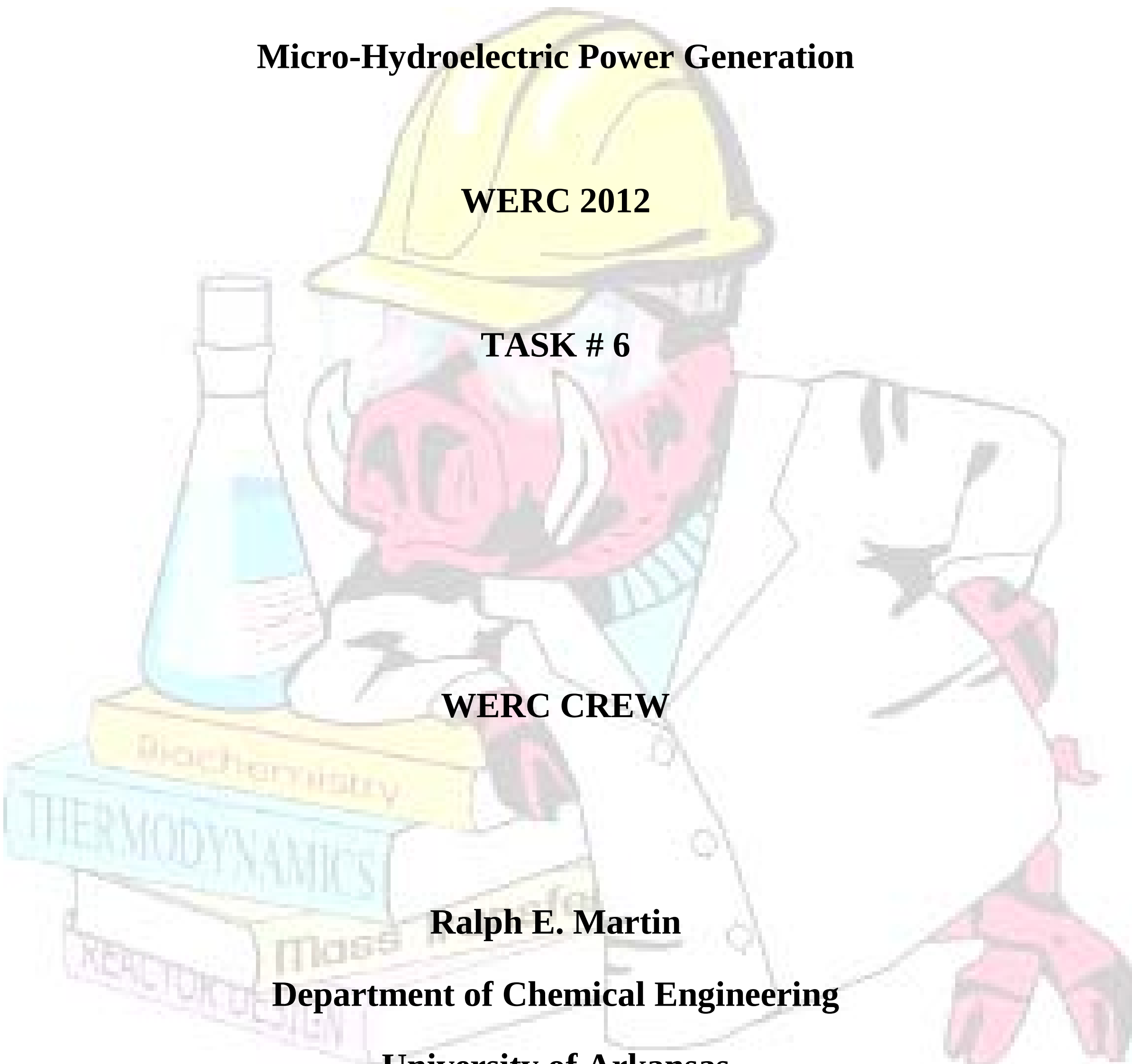
WERC Institute for Energy and the Environment Design Contest Responsibilities

Travis Rose

I participated on a team with three other individuals to design a solution to the task we chose. This task was to design a full scale system to produce 5-15 kW of electricity using a major industrial wastewater source located in New Mexico. The task also required that the project have a positive return within a five year period. A working bench scale model was also required for the contest. I participated in both the research and design aspects of the task.

My initial involvement was to help research and construct the bench scale model. This was done over a period of 6-8 weeks. Our research indicated that a Pelton Wheel turbine along with a DC generator was the best option for demonstrating the bench scale aspects of the projects. A Pelton Wheel turbine was also chosen for the full scale model. An AC generator was chosen for the full scale model to improve operation and efficiency. We were able to optimize the Pelton Wheel operation though extensive laboratory testing in order to achieve the maximum efficiency and power generation from the wheel with two separate systems on the bench scale model. One system was used to determine the efficiency of the Pelton Wheel, while the other was used to demonstrate the power production of the wheel and turbine.

For the paper that was submitted to the contest, I focused on describing the full scale model, all the components present in the model, and operation of the full scale system. I travelled to an actual site that we modeled our full scale system on, thus I was the most suited to write about that section in the contest paper. At the actual contest, I presented the work done on our task along with my three team mates to a panel of 7-10 judges. I also helped in designing and presenting the poster that we presented at the competition with our bench scale model. The presentation took place on one day, and the poster/bench scale presentations were on the next day. We were competing against two other teams in our task along with 3 other teams participating in two different tasks. We ended up taking 1st place out of a field of six teams.



Micro-Hydroelectric Power Generation

WERC 2012

TASK # 6

WERC CREW

Ralph E. Martin

Department of Chemical Engineering

University of Arkansas

Fayetteville, AR

Micro-Hydroelectric Power Generation

TASK # 6

WERC Creating Renewable Energy from Wastewater
CREW

Roberto I. Arraya
Aaron C. Hughes
Nathan S. McAlister
Travis L. Rose

Advisors: Dr. J. A. Hestekin
Dr. W. Roy Penney

Ralph E. Martin
Department of Chemical Engineering
University of Arkansas
Fayetteville, AR

TABLE OF CONTENTS

EXECUTIVE SUMMARY

A major industrial water user in New Mexico discharges approximately 3.8 million gal of wastewater per day. The topology of the site provides an elevation difference of about 150 ft between the plant site and the entrance to the municipal sewage line; this flow and elevation difference is sufficient to produce about 40 kW of electrical power using a water turbine/electrical generator set to extract power from the flowing stream.

This report includes designs and economic analyses for two distinct cases. One case is based on the written premises of the task; whereas, a second case is based on a real surrogate site, which is Intel's Rio Rancho (near Albuquerque, NM) plant, which does discharge about 3.8 million gal per day and has about 120 ft of head available for power generation.

After analyzing several turbine technologies, the Pelton wheel turbine was determined to be the most economical means for generating commercial electrical power. Pelton Wheel turbines operate most efficiently with a constant head and flow. Because the wastewater discharge for the task varies from 0.5 – 4 MM gal/day, an integrated study of the flow fluctuations determined that a surge tank of 27,000 gal was required to maintain a steady flow as input to the turbine. The task premises did not include any existing storage for the discharge stream; consequently, a 27,000 gal surge tank was provided for the task premises site. The surrogate site has a surge basin with a surface area of 17,000 ft^2. This surface area requires only a 3 in level change to accommodate 27,000 gal of surge; consequently, no surge tank was included in the surrogate site case.

The surge provides the turbine with a steady flow of 2,400 gpm and a constant head of 120 ft. The purchased turbine system selected by CREW has an overall (mechanical + electrical) efficiency of 68%. For the task premises scenario, 40 kW is produced, and for the surrogate site scenario, 30 kW is produced.

The economic analysis provides the following tabular results:

Summary	Fixed Capital Investment	Working Capital	Yearly Revenue	IROR (%)	Simple Payout (years)
WERC Task premises	$381,902	$16,676	$44,412	4.3	8.6
Surrogate Location	$346,442	$15,590	$35,011	2.4	9.9

The WERC task premises case is most economical with an IROR of 4.3%. This return is marginal for earnings projects under normal circumstances. However, interest rates are now at historically lower levels, and are projected to remain low for several years. The surrogate location IROR is about 2.4%, which is considered as a reasonable return for a minimal risk project with today's economic environment. This energy recovery initiative is a "Green" project, which inherently lowers the acceptable IROR for environmentally conscious industries.

This project will require about 12 months to complete once funds are available.

INTRODUCTION

As energy costs continue to rise, the CO_2 level in the atmosphere continues to increase, and the World's fossil fuels are depleted, reliable new sources of energy will be needed. Hydroelectric power generation is a clean, effective means of generating "green" renewable energy that will continue to be a viable supplement to energy demands long into the future. Any environmentally friendly hydroelectric possibility must be exploited to the maximum. Task 6 addresses the use of hydroelectric power in the most environmentally friendly manner by producing electricity utilizing a high efficiency Pelton Wheel turbine and generator.

In 1870, Lester Allan Pelton[1] revolutionized hydroelectric power with the invention of the Pelton Wheel, a high efficiency turbine that converts momentum of a water jet stream to mechanical power and, through an electrical generator, electricity. Pelton Wheels operate by passing a working fluid through a nozzle, which converts pressure energy to kinetic energy. The kinetic energy of the fluid is then converted to mechanical work by impingement of the fluid jet upon the buckets of the Pelton Wheel. The Pelton Wheel drives a rotating shaft, which is connected to the drive shaft of an electric generator. The speed of the Pelton Wheel, at optimum efficiency, operates at a peripheral bucket velocity of ½ the nozzle velocity[1, 12]; at this optimum condition, the fluid leaves the bucket with minimal velocity.

DESIGN CONSIDERATIONS FOR TASK 6

The design considerations are to:

1. Design a flexible, scalable system using appropriate sponsor input.
2. Address the efficiencies of the hydraulic turbine and the electrical generator.
3. Generate at least 5–15 kW (20–40 is more reasonable) of electric power.
4. Designs were requested for 10–200 ft of head and ½–4 MM gal/day of hydraulic load; however, with adequate surge, head and flow are constant at 150 ft and 3.8 MM gal/day.

5. Include an economic analysis which provides proof that the project is economical.
    a. The task sponsors specified a 5 year project life. However, to receive full benefits of government subsidies, the project life must be 12 years; thus the assumed project life is 12 years.
6. One design consideration for the project was “Ability to handle solid waste”; this was interpreted to mean ‘handling dissolved solids and readily suspendible particulates.’
7. Provide a time-line, from construction to full operation, for the proposed project.
8. Discuss the risks, safety and legal, associated with the design and implementation of the project.

HYDROELECTRIC POWER GENERATION

After surveying the literature and consulting with experts in the field of hydroelectric power generation, a wide variety of turbine/generator combinations were identified that could possibly accommodate the conditions required for this design.

Turbine Technologies

Micro-hydroelectric turbine technologies, for the purposes of this report, refer to any turbine/generator system producing less than 100 kW. Technologies considered for implementation included: Gorlov helical turbines, gravitational water vortex turbines, Francis-Kaplan turbines, and Pelton Wheel turbines.

Figure 1 – Gorlov Turbines[3]

Gorlov turbines (Fig. 1) are helical bladed turbines that are primarily used in large volume, low head situations, such as a river where a dam is not a viable option. The Gorlov turbine is typically used with large free flowing water sources. Gorlov turbines were rejected for this approach primarily because of the low efficiency (≈ 35%) which is well below the effectiveness of other micro-hydroelectric power generation methods.[2] In addition, the geometry of Gorlov turbines does not fit the inlet and outlet pipe geometry of Task 6.

Figure 2 – Vortex Power Generation[4]

Gravitational water vortex turbines (Fig. 2) are a micro-hydroelectric technology used at low heads (2.5-10 ft). They create a swirling vortex that is used to drive an impeller. They were rejected primarily because of their inability to effectively handle the high heads (115-150 ft) and inlet and outlet piping particular to this task.[4]

Francis—Kaplan turbines (Fig. 3), are commonly used in hydroelectric power generation. "*Reaction turbines run fully immersed in water, and are typically used in low-head (pressure) systems with high flow*".[5] As the fluid passes through the turbine, the fluid transfers energy to the turbine blades, creating angular momentum that rotates a central shaft and generates electricity. Francis—Kaplan turbines are highly efficient (up to 90%), can be used at high and low heads, 30–2,100 ft, and are capable of handling high flow rates. These characteristics make the Francis—Kaplan turbines an excellent choice for hydroelectric power generation.[5]

Figure 3 – Francis-Kaplan Turbine[6]

Pelton Wheel turbines (Fig. 4) are impulse turbines that "*operate in air, driven by one or more high-velocity jets of water. Impulse turbines are typically used with high-head systems and use nozzles to produce the high-velocity jets*".[1] The momentum of the fluid is then captured and converted to power by a series of precisely designed buckets connected to a rotating shaft. Pelton Wheel turbines are second to the Francis-Kaplan turbines in efficiency (80-90%) and are ideal for systems with low flow rates and high heads.[7]

Figure 4 – Pelton Wheel Turbine[8]

After consulting with experts in the field of hydroelectricity, the Pelton Wheel was chosen as the preferred technology. Although the Francis—Kaplan turbine is an efficient solution that meets the demands of the project, Francis turbines are more typically used in large scale operations, such as dams. The relatively small size of the turbine for this project (40 kW) makes the Pelton Wheel the most efficient and economically viable solution for the project.

Electricity Transmission Technologies

Electricity transmission, either single or three-phase, is another design aspect of the project. The Pelton Wheel system selected for this project generates electricity via three-phase power generation. Since three-phase current is the most efficient means of transmission[9] and the electricity grid of the power company is three-phase, three-phase transmission was selected. A phase-lock loop system was selected and included in the project to align the phases of the generated power with the power of the electrical utility.

BENCH SCALE APPARATUS

Experimental Apparatus

The bench scale apparatus consisted of two independent systems mounted on a 32 in by 96 in pressboard table, which was supported by two plastic sawhorses. Figure 5 shows a Process Flow Schematic (PFS) of the experimental apparatus.

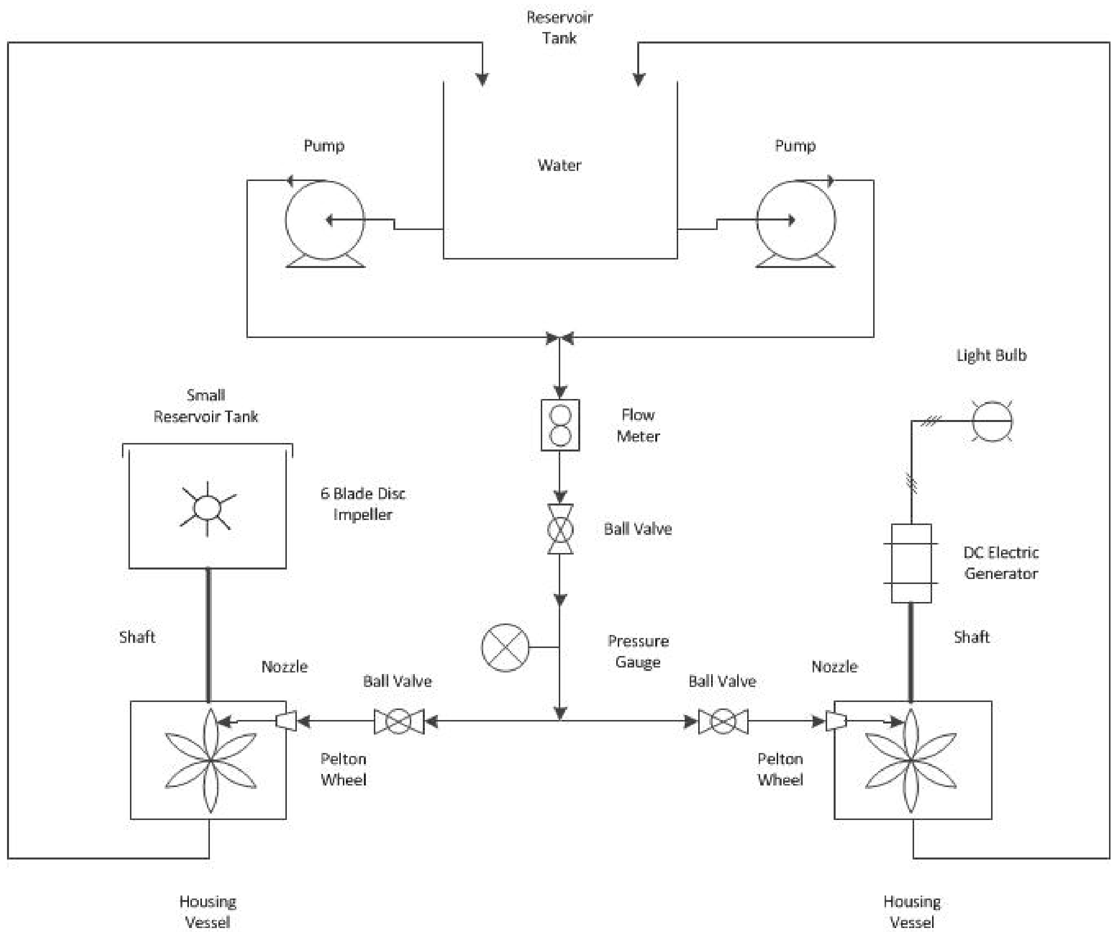


Figure 5. Bench Scale PFS

Figures 6 and 7 show the power measurement and the electrical generation portions of the bench scale apparatus, respectively.

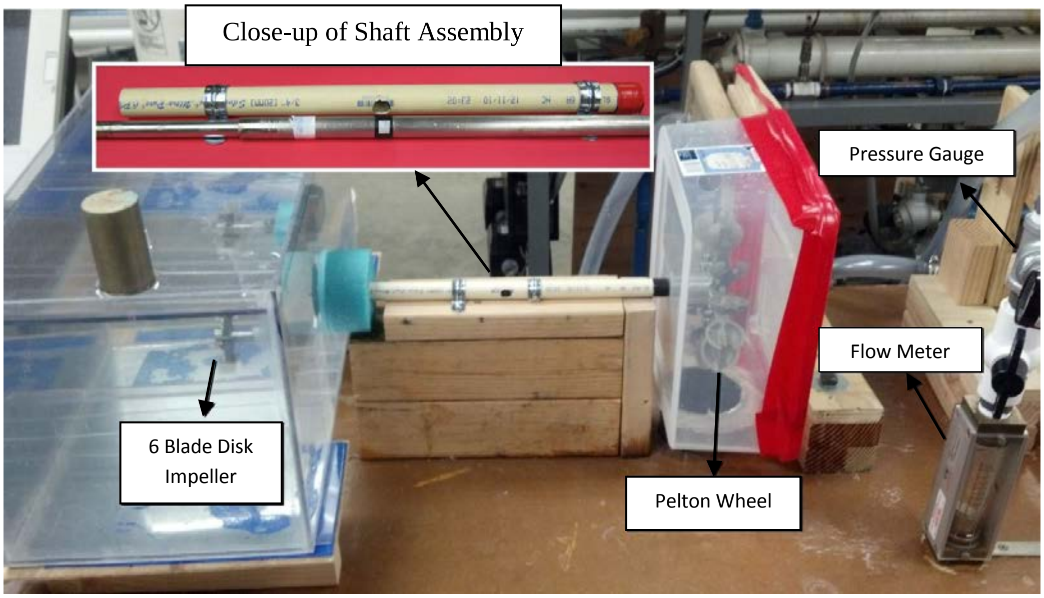


Figure 6. Power Measuring Unit

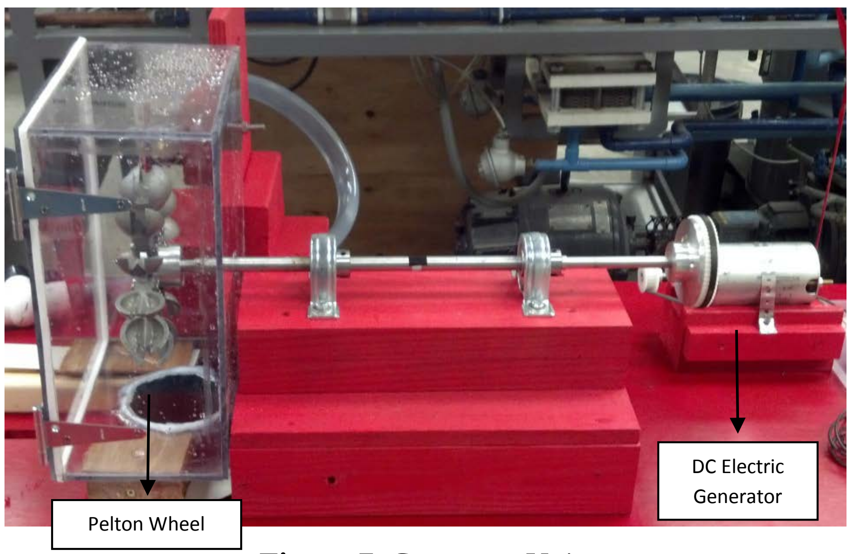


Figure 7. Generator Unit.

A 40 gal reservoir (beneath the table) provided feed for two, in parallel-centrifugal pumps (16 gpm at 10 ft head) which moved the fluid through a 15 gpm rotameter, then through a restriction valve, past a pressure gauge, and through a nozzle. These components were used to control and measure the flow and measure the nozzle inlet pressure. Downstream of the pressure gauge the flow was split, by a tee and two ball valves, so either system could be operated.

Power Measurement

The 8 in Pelton Wheel was attached to a 3 ¼ in diameter 6 blade disk impeller, which was submerged in a water tank, through a 5/8 in SS drive shaft. The drive shaft was machined to

½ in on either end to accommodate ½ in holes in the Pelton Wheel and the 6 blade disk impeller. To contain the water exiting the Pelton Wheel, a Plexiglas container (6 in x 11.5 in x 15 in) surrounded the Pelton Wheel. This shielding had a ¾ in diameter hole drilled in its shaft side to accommodate a ¾ in PVC shaft support tube and provide a water tight seal between the PVC tube and the storage container side. The short side of the storage container was fitted with a 1 3/8 in hole for the jet from the nozzle to enter, as shown in Figure 8.

The nozzle (25/64 in ID) was a brass coupling from a ½ in male pipe thread to a 3/8 in hose barb. The fitting was screwed into a galvanized steel ½ in to 1 in bushing. The bushing was screwed into a 1 in NPT to 1 in hose barb plastic coupling. The nozzle could be adjusted to any desired orientation by rotating it in a vertical plane and by lateral movement of the nozzle support stand through a slot in the support table.

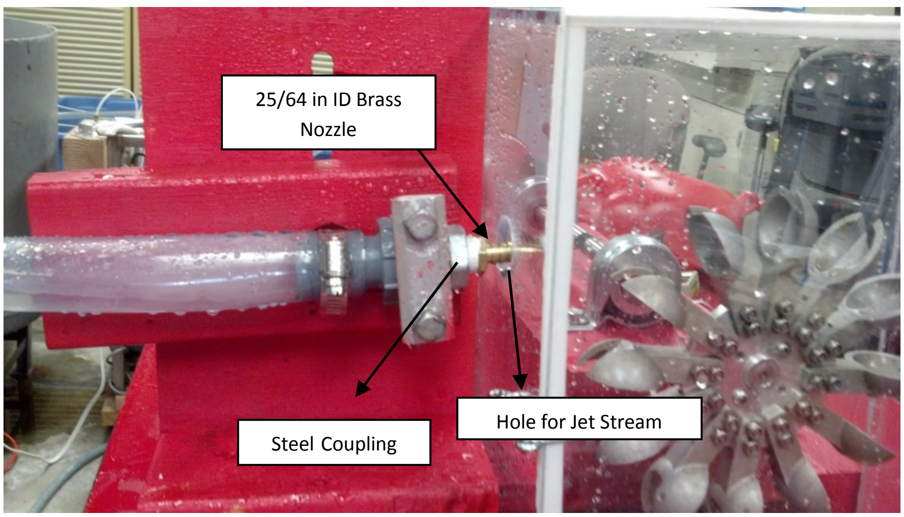


Figure 8. Nozzle with adjustable bracket.

The 5/8 in drive shaft was supported and enclosed in a 3/4 in PVC tube (Fig. 6). Near either end of the tube, the shaft was wrapped with Teflon tape which provided a low friction bearing surface between the shaft and the PVC tube. The clearance between the PVC tube and the Teflon tape was kept to a minimum to prevent shaft wobble.

The Pelton Wheel speed was measured with an electronic tachometer whose light source was focused on a section of silver tape on the rotating shaft. As explained later, the rotational speed was used to calculate the power consumed by the 6 blade disk impeller.[10]

The water tank (12 in x 12 in x 24 in) in which the 6 blade disk impeller operated was constructed from 1/8 in thick Plexiglas. It consisted of 4 built-in, 1 in wide baffles, which prevented swirl and fully baffled the vessel.

Electric Generator (Figure 7)

The generator unit was similar in design to the power measurement unit. The Pelton Wheel shield was a 6 in x 11.5 in x 15 in polypropylene storage vessel. The 5/8 in drive shaft was supported by two 5/8 in pillow block bearings. The power output of the drive shaft was attached to a 4 in diameter toothed pulley which drove a 1.5 in toothed pulley by means of a toothed belt. The electric generator drive shaft was attached to the 1.5 in toothed pulley. At the maximum rotation speed of the Pelton Wheel (1015 RPM), the generator produced 50 mA at 70 V and 3.5 W.

The power produced by the generator was made visual in Fig. 10 by lighting a bank of LED strips (5 in series) which were encased in a plastic Razorback hog hat.

Figure 10. LED Hog Hat.

Experimental Procedure

Safe operating procedures were important when using pressurized equipment and moving parts. Care was taken to ensure that the Pelton Wheels, the 6 blade disk impeller, and the DC electric generator were all clear of any obstructions before the system was powered. Since the apparatus was designed so that only one system could be operated at a time, the valves were positioned properly before operating the system. The pumps were started one at a time due to high starting currents. Once the pumps were operating, the nozzle of the desired system was adjusted to generate maximum shaft speed, producing maximum Pelton Wheel power.

The nozzle location was adjusted by moving it laterally and by rotating it around the axis of its holder to obtain the maximum operating speed. These adjustments were made by tapping either the nozzle holder or the support base with a suitable hammer.

LAB EXPERIMENTATION

Overview

Laboratory experiments were conducted using both the power measurement device and the electric generator.

Turbine and Impeller System

The bench-scale turbine and impeller system was used to determine the combination of nozzle size and 6 blade disk impeller diameter which gave the highest mechanical efficiency of the Pelton Wheel. With a specific nozzle and a specific 6 blade disk impeller installed, both pumps were started with all valves open except the appropriate system isolation valve was closed. The nozzle pressure and nozzle flow rate were recorded. The nozzle location was adjusted to produce maximum shaft speed. Table 1 presents the experimental data and reduced results for all runs made using the power measurement apparatus.

The maximum efficiency of 50% was realized using a 25/64 in nozzle and a 3.25 in diameter 6 blade disk. The efficiency results agreed with literature[11, 12] findings, both gave the optimum ratio of Pelton Wheel peripheral speed to jet velocity (Velocity Ratio in Table 1) of 50%. Power consumed by the 6 blade disk impeller was in the range of 39-49 W.

The optimum nozzle location of the nozzle exit is given by the measurements below:

1. The nozzle centerline is in a plane containing the centerline of the Pelton Wheel buckets.
2. 3 3/8 in above the drive shaft horizontal plane.
3. 5 1/2 in from the drive shaft vertical plane.
4. The nozzle centerline points slightly downward at an angle of 6 degrees with the vertical plane through the nozzle tip.

Data Reduction

The reduced data in Table 1 were calculated using the following procedure:

$A_n = \pi D_n^2/4$ [nozzle flow area, m^2] (1)

$V_j = Q/A_n$ [jet velocity, m/s] (2)

$\Delta H = V_j^2/2g$ [head to power the jet, m] (3)

$M_j = \rho Q$ [jet mass flow rate, kg/s] (4)

$P_j = M_j V_j^2/2g$ [jet power, W] (5)

$P_i = N_p \rho N^3 D_i^5$ [impeller power, W] (6)

$\eta = P_i/P_j$ [efficiency, impeller power to jet power] (7)

$V_{tw} = \pi N D_{pw}$ [Pelton Wheel peripheral speed, m/s] (8)

$\zeta = V_{tw}/V_j$ [velocity ratio] (9)

Table 1. Experimental and Reduced Results

Trial	Nozzle Dia. (in)	Impeller Dia. (in)	Pressure (psig)	Flow (gpm)	Jet Velocity (ft/s)	N (RPM)	Velocity Ratio (ζ)	Efficiency (η)	Jet Power (W)	Produced Power (W)
I	17/64	2.625	32	9.85	58.7	1119	0.519	43%	99.4	42.7
II	17/64	2.75	32	9.85	58.7	1085	0.504	49%	99.4	49.2
III	17/64	3.25	32	9.85	58.7	815	0.378	48%	99.4	48.0
IV	17/64	3.75	32	9.85	58.7	597	0.277	39%	99.4	38.6
V	25/64	2.625	18	16	44.1	1000	0.612	33%	91.1	30.5
VI	25/64	2.75	18	16	44.1	978	0.604	40%	91.1	36.0
VII	25/64	3.25	18	16	44.1	800	0.494	50%	91.1	45.4
VIII	25/64	3.75	18	16	44.1	625	0.386	49%	91.1	44.3

Turbine and Generator System

A 17/64 in nozzle was used with the turbine generator system. The nozzle was adjusted to give maximum shaft speed which produced maximum light output of the LEDs. At these conditions, the power produced was 3.5 W (50 mA at 70 V).

FULL SCALE DESIGN

Overview

In accordance with the theme of the task, two sites were considered for full scale design: (1) a site based on task premises and (2) a real site based on the Intel Rio Rancho plant.

WERC Task Premises Site

The full scale WERC task premise design consisted of a 27,000 gallon surge tank, an elevation change of 150 ft, a level control system for the tank, approximately 1,300 ft of 14 in rigid PVC piping, a Pelton Wheel turbine/generator unit producing 43.5 kW, 900 ft of 6 gauge electrical wire, and a 3-phase lock loop system.

Intel Site

The full scale Intel design consisted of a 17,000 ft^2 pre-existing basin, a level control system for the basin, approximately 1,600 feet of 14 in rigid PVC piping, a 34 kW turbine/generator unit, 900 ft of 6 gauge electrical wire, and a 3-phase lock loop system.

Intel's manufacturing facility FAB 11X was chosen as a surrogate site for the full scale design. This facility was selected because (1) it is a major industrial water user in the state of

New Mexico, using approximately 3.8 million gal per day and (2) it contains an elevation drop of 120 ft inside Intel's property, both within the range of the sponsor specifications. Figure 11 shows one possible placement for the turbine system, as well as necessary piping and wiring routes. As shown in Figure 11, the elevation profile of the water pipe from Intel to the turbine unit shows an elevation drop of 105 ft, as shown in blue. This could be easily increased to 120 ft by installing the turbine unit below grade. The water would then flow northeast to a sewer line, shown in green. The electric power line routes are shown in yellow.

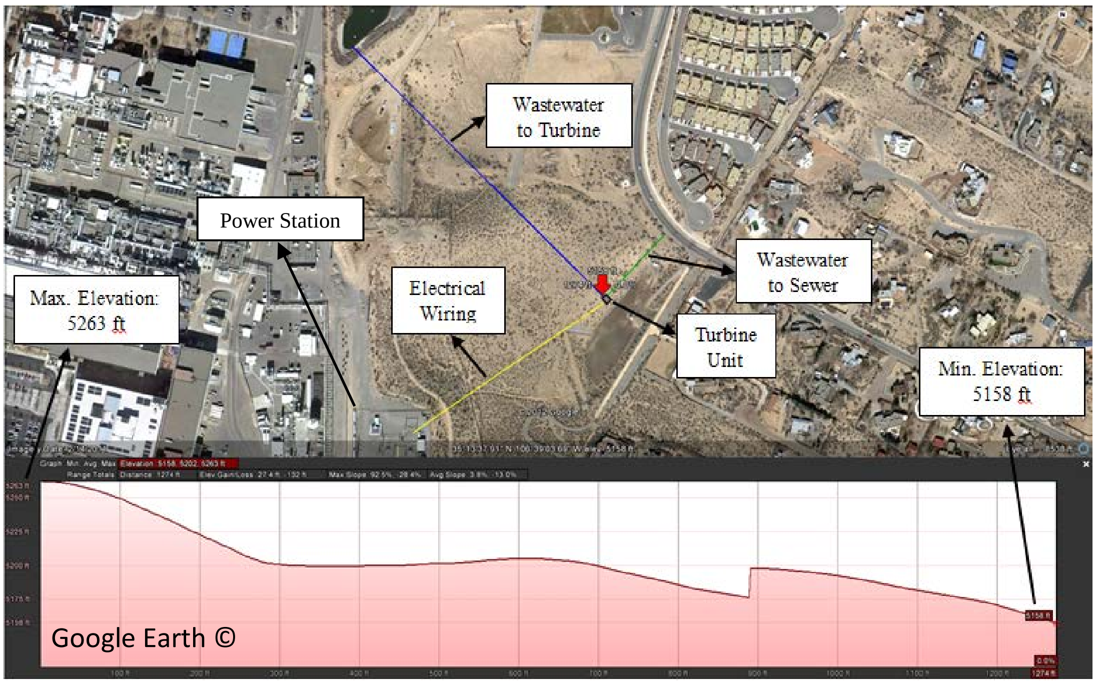


Figure 11. Overhead View of Turbine Unit at Intel New Mexico in Rio Rancho, NM.

Based on the parameters of the surrogate site and the turbine, a Bernoulli balance shows that 110 ft of head is available at the turbine. With an efficiency of 68%, the turbine will produce 34 kW. These calculations are shown in Tables A3 and A4 in the appendix.

Turbine

The turbine/generator for both scenarios consisted of a commercially available, quoted Pelton Wheel turbine/generator unit. The turbine has a 15 in diameter SS wheel and dual, hydraulically actuated nozzles. The generator is a 56 kW, 600 RPM, 480 VAC, 3 phase, 60 Hz, brushless, induction machine. The control package for the turbine integrates the power produced into the local electrical utility and provides protective relays up to North American utility grid standards. It is PLC based, including automated head level control, and is designed to automatically restart following a grid failure. A schematic of the turbine unit is shown in Figure 12. The overall efficiency of the turbine, from nozzle to electricity, is approximately 68%.

The turbine was designed for 2,430 gpm and 150 ft of head. Six gauge electrical wiring is required.

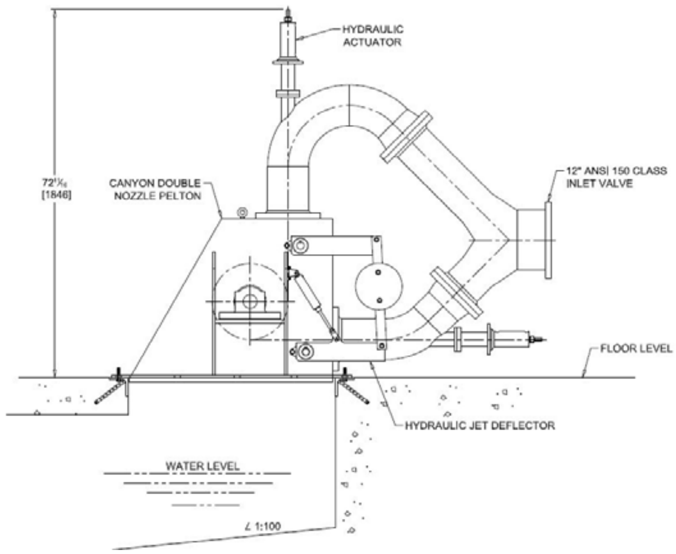


Figure 12. Manufacturer’s Schematic-Pelton Wheel Turbine

Surge Tank

The surge tank for the theoretical site was designed using flow data provided by the task sponsor. Seven months of flow data were provided, at five minute intervals. An Excel computer program was written to determine surge tank requirements. A 27,000 gal tank with a set point level of 36% delivered the surge requirements. The use of this tank supplied a constant flow of 2,430 gpm to the turbine. The surge tank will never exceed a level of 90% nor drop below a level of 10%. Figure 13 shows volume within the tank over time.

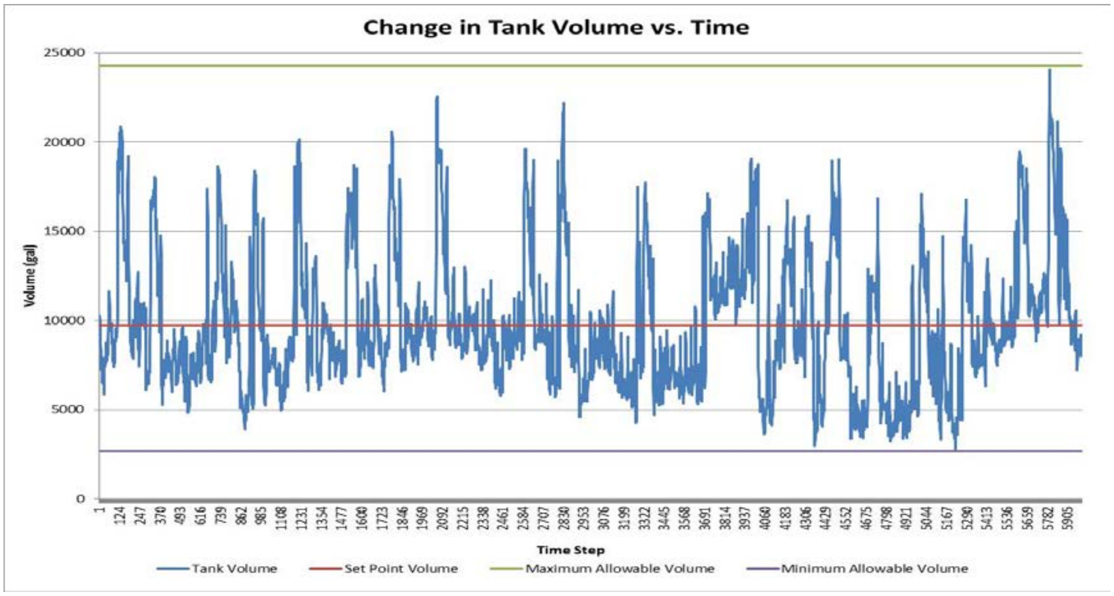


Figure 13. Fluctuations in surge tank volume over time.

Adding a surge tank to the system eliminates the problem of variable flow rates and available head to the turbine, conditions which reduce turbine efficiency. The surge tank also serves as a settling vessel, removing particulates from the wastewater. The existing wastewater line should serve as a bypass line should the surge tank begin to overflow.

Figure 14. - Photograph using Google Earth© of the nearby basin at the surrogate location.

Google Earth© was used to estimate the surface area covered by the basin and the depth that was required to serve as an alternate surge tank. The values estimated for the length of the base and height of the triangular shaped basin are shown in Fig. 14. The volume required for the surge tank is approximately 27,000 gal. The basin has a surface area of 17,000 ft^2; thus, a depth of only 0.2 ft (2.5 in.) is required to handle a surge of 27,000 gal (3,600 ft^3). Conservatively, at least 1 ft of depth would compensate for evaporation.

ECONOMICS

Two scenarios were analyzed in order to determine the incremental economics. The case scenarios included: 1) The Rio Rancho Intel plant location and 2) The WERC task 6 premises site.

The revenue for this project consists of produced electricity purchased by PNM, the New Mexico electric utility. A nearby power station is visible in Figure 11. This location is where the electricity enters the power grid. The return of electrical power to the grid qualifies the project under the U.S. Department of Energy's incentive programs. The specific applicable incentive program is called the *Small and Medium System Renewable Energy Certificate Purchase Program* [13]. The criteria for eligibility is that the system produces between 10-100kW, that the system be installed after January 1, 2012, and that the project life must be at least 12 years.[13] The selling price for produced electricity is mandated at $0.12/kW-hr. Other incentives were investigated, however, none were discovered which met all eligibility criteria. The revenue associated with both scenarios is shown in Table 3.

Table 3: Revenue estimations for both scenarios

Revenue Estimations					
Revenue	Head (ft)	Power Output (kW)	Unit Price for Electricity ($/kWhr)	Operating time (hrs/year)	Revenue ($/year)
WERC Task premises	150	43.54	0.12	8500	44,412
Surrogate Location	120	34.32	0.12	8500	35,011

An incremental economic analysis of all capital costs incurred along with a description of each item is outlined in Tables 4 and 6, for the surrogate and WERC task premise scenarios, respectively. The major components of the capital cost include the turbine, generator, control system, surge tank, and piping, plus installation of these items.

Intel Location Scenario

The surrogate case scenario utilizes wastewater from the Rio Rancho Intel plant. The project involves a battery limits unit; this type of profitability analysis is called retrofitting.[14] Implementation of the described technology at the specified location would include the purchase of a turbine, generator, and control system. The specifications for the system were a gross head of 150 ft and a design flow of 5.4 ft^3/s (3.5 MM gal/day). The net head across the turbine was 142 ft with an output of 43.5 kW.

The delivery time for the turbine/generator system is 20 weeks. The project can be implemented about 1 year after funding is available. The lifetime of the turbine/generator set is at least 12 years (100,000 hr).

The surge tank need not be purchased at the surrogate location, since the actual location has a nearby basin next to a water treatment plant, with sufficient depth to handle the required surge capacity of 27,000 gal.

The total equipment and material costs for the surrogate location is approximately $312,000. Direct costs include delivery, installation, and construction. Installation costs were determined using the total number of required workers, their average pay, an average 8 hr workday (unless otherwise noted), and specified time duration. Indirect costs are comprised of engineering, supervision, and legal consultation. Legal costs were estimated as 4% of the purchased equipment cost. Within the year required to build the project, a 2 to 3 month period is assumed for engineering work. For the proposed technology, a project manager would be responsible for directing all design, engineering, and supervision. Working capital is required to operate a plant and finance the first few months of operation before revenues begin.[14] Working capital was included as 5% of the purchased equipment cost.

The incremental cost of land is negligible because the location of the project is within the Intel plant. The operating costs for this project are minimal because there is no cost for the wastewater. Labor costs are negligible because an existing operator can monitor the operation within an existing control room. Maintenance costs for the turbine/generator set are negligible. On-stream time for the unit was assumed to be 97%.

Intel is a profitable public company[15], consequently their incremental income tax rate is 35%; this tax rate was used in the economic analysis. The equipment depreciation schedule is based on the federal tax depreciation currently in use in the United States. The system uses a 5-year Modified Accelerated Cost Recovery System (MACRS).[14] Business incentives exist to reduce taxable income. The IRS allows certain assets to have an accelerated depreciation schedule in order to encourage capital investment. A standard MACRS depreciation schedule allows only 20% of the depreciable capital in the first year. However, this energy saving project qualifies for 50% depreciation in the first year. The following years must follow the standard MACRS depreciation schedule.[16]

A discounted cash flow method was used to perform the economic analysis. This method discounts all cash flows year by year back to time zero. The interest rate of return (IROR, or sometimes referred to as the internal rate of return) is determined when the discounted net present value of the project is zero.[14] A cash flow for both scenarios is presented below in Tables 5 and 7 for the task premise scenario and the surrogate location, respectively.

Table 4. Outlined summary of costs for the surrogate location

Surrogate Location Capital Costs		
Item	Description	Cost
Equipment		
Turbine/Generator/Control System	PeltonTurbine, 56 kW, 600rpm, 480 VAC, 3 phase, 60 Hz, control panel to parallel generator	$150,000
Housing for Turbine Materials	Slabs, cinder blocks supports	$1,000
Piping	Total 1600 ft in place, unit price $100/ft	$160,000
Electrical	Total 900 ft, unit price $89.3/100ft , Gauge 6AWG, OD 0.249 in. , Amps 65 , Jacket Nylon, PVC	$804
Total Equipment Costs		**$311,804**
Direct Costs		
Delivery Costs		
Electrical	1 truckload, 9 spools, 100ft/spool, electrical wire	$2,000
Construction Materials	Local supplier, housing for turbine	$200
Installation Costs		
Piping and Electric	10 workers, $20/hr, 8hr/day, 4 days	$6,400
Surge tank	4 craftsmen, $30/hr, 8hr/day, 5 days	$4,800
Turbine	Included in Price quote	$0
Contractor's Fees		
Construction	5 days, backhoe rental ($150/day) and gas costs, $4/gal Diesel, 1 tank/day, 20 gal/tank	$1,150
Total Delivery Cost		**$2,200**
Total Installation Costs		**$11,200**
Total Construction Costs		**$1,150**
Total Direct Costs		**$14,550**
Indirect Costs		
Engineering/Supervision	$100,000/year salary for project manager and supervisors, assuming 2 to 3 months time	$20,000
Legal	4% of Purchased Equipment Cost	$88
Total Indirect Costs		**$20,088**
Working Capital		
Contingency	5% of Purchased Equipment Cost	$15,590
Total Capital Costs for the surrogate location		
Fixed Capital Investment	Sum of Equipment, Direct Costs and Indirect Costs	**$346,442**
Total Capital Investment	Sum of Fixed Capital Investment and Working Capital	**$362,032**

Table 5. Discounted cash flow table for the surrogate location

End of year	Investment	Depreciation	Revenue	Taxable Income	Manufacture Costs	After Tax Net Income	After Tax Cash Flow	Non-Discounted Cash Flow	Cummulative Sum	Discounted Cash Flow	Discounted Sum
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	-362.03	0.00	0.00	0.00	0.00	0.00	0.00	-362.03	-362.03	-353.56	-353.56
2	0.00	173.22	35.01	-138.21	0.00	256.61	83.38	83.38	-278.65	79.53	-274.03
3	0.00	69.29	35.01	-34.28	0.00	116.30	47.01	47.01	-231.64	43.79	-230.25
4	0.00	41.57	35.01	-6.56	0.00	78.88	37.31	37.31	-194.33	33.94	-196.31
5	0.00	24.94	35.01	10.07	0.00	56.43	31.49	31.49	-162.84	27.97	-168.34
6	0.00	24.94	35.01	10.07	0.00	56.43	31.49	31.49	-131.36	27.32	-141.02
7	0.00	12.47	35.01	22.54	0.00	39.59	27.12	27.12	-104.23	22.98	-118.04
8	0.00	0.00	35.01	35.01	0.00	22.76	22.76	22.76	-81.48	18.83	-99.21
9	0.00	0.00	35.01	35.01	0.00	22.76	22.76	22.76	-58.72	18.39	-80.81
10	0.00	0.00	35.01	35.01	0.00	22.76	22.76	22.76	-35.96	17.96	-62.85
11	0.00	0.00	35.01	35.01	0.00	22.76	22.76	22.76	-13.21	17.54	-45.31
12	0.00	0.00	35.01	35.01	0.00	22.76	22.76	22.76	9.55	17.13	-28.18
13	0.00	0.00	35.01	35.01	0.00	47.90	47.90	38.35	47.90	28.19	0.01

All values except years in thousands ($)

WERC Task Premises Scenario

The total cost for the WERC task premises includes a surge tank. The overall equipment and material costs are estimated to be $223,000. The surrogate scenario was used as a basis for the assumptions made in the WERC task premise scenario. All parameters involved should essentially remain the same. The following assumptions are to be noted:

1) The length of pipe chosen is the same for both scenarios to maintain a comparable basis.

2) The cost of land is negligible in both scenarios.

Table 6. Purchased equipment cost for the WERC task premise location.

WERC Task Premise Capital Costs		
Item	Description	Cost
	Equipment	
Turbine/Generator/Control System	PeltonTurbine, 56 kW, 600rpm, 480 VAC, 3 phase, 60 Hz, control panel to parallel generator	$150,000
Surge Tank	27,000 gallon Galvanized Tank: FRB	$21,708
Housing for Turbine Materials	Slabs, cinder blocks supports	$1,000
Piping	Total 1600 ft in place, unit price $100/ft	$160,000
Electrical	Total 900 ft, unit price $89.3/100ft , Gauge 6AWG, OD 0.249 in. , Amps 65 , Jacket Nylon, PVC	$804
Total Equipment Costs		**$333,512**
	Direct Costs	
Delivery Costs		
Electrical	1 truckload, 9 spools, 100ft/spool, electrical wire	$2,000
Surge Tank	Materials required for surge tank, use local supplier	$500
Construction Materials	Housing materials required for housing	$200
Installation Costs		
Piping and Electric	10 workers, $20/hr, 8hr/day, 4 days	$6,400
Surge tank	4 craftsmen, $30/hr, 8hr/day, 5 days	$4,800
Turbine	Included in Price quote	$0
Contractor's Fees		
Construction	5 days, backhoe rental ($150/day) and gas costs, $4/gal Diesel, 1 tank/day, 20 gal/tank	$1,150
Total Delivery Cost		**$2,700**
Total Installation Costs		**$11,200**
Total Construction Costs		**$1,150**
Total Direct Costs		**$15,050**
	Indirect Costs	
Engineering/Supervision	$100,000/year salary for project manager and supervisors, assuming 2 to 3 months time	$20,000
Legal	4% of Purchased Equipment Cost	$13,340
Total Indirect Costs		**$33,340**
	Working Capital	
Contingency	5% of Purchased Equipment Cost	$16,676
	Total Capital Costs for WERC task premise	
Fixed Capital Investment	Sum of Equipment, Direct Costs and Indirect Costs	**$381,902**
Total Capital Investment	Sum of Fixed Capital Investment and Working Capital	**$398,578**

Table 7. Discounted cash flow table for the WERC task premise location.

End of year	Investment	Depreciation	Revenue	Taxable Income	Manufacture Costs	After Tax Net Income	After Tax Cash Flow	Non-Discounted Cash Flow	Cummulative Sum	Discounted Cash Flow	Discounted Sum
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	-398.58	0.00	0.00	0.00	0.00	0.00	0.00	-398.58	-398.58	-382.11	-382.11
2	0.00	190.95	44.41	-146.54	0.00	286.65	95.70	95.70	-302.88	87.96	-294.15
3	0.00	76.38	44.41	-31.97	0.00	131.98	55.60	55.60	-247.28	48.99	-245.16
4	0.00	45.83	44.41	-1.42	0.00	90.74	44.91	44.91	-202.37	37.93	-207.23
5	0.00	27.50	44.41	16.92	0.00	65.99	38.49	38.49	-163.88	31.17	-176.06
6	0.00	27.50	44.41	16.92	0.00	65.99	38.49	38.49	-125.39	29.88	-146.18
7	0.00	13.75	44.41	30.66	0.00	47.43	33.68	33.68	-91.71	25.07	-121.11
8	0.00	0.00	44.41	44.41	0.00	28.87	28.87	28.87	-62.84	20.60	-100.52
9	0.00	0.00	44.41	44.41	0.00	28.87	28.87	28.87	-33.97	19.75	-80.77
10	0.00	0.00	44.41	44.41	0.00	28.87	28.87	28.87	-5.10	18.93	-61.84
11	0.00	0.00	44.41	44.41	0.00	28.87	28.87	28.87	23.77	18.15	-43.69
12	0.00	0.00	44.41	44.41	0.00	28.87	28.87	28.87	52.63	17.40	-26.29
13	0.00	0.00	44.41	44.41	0.00	28.87	28.87	45.54	98.18	26.31	0.02

Summary

An acceptable interest rate for large corporations has traditionally been in the range of 8%-11%.[17] The WERC task premises case is the more economical of the two cases considered here with an IROR of 4.3%. This return is marginal for earnings projects under normal circumstances. However, interest rates are now at historically lower levels, and are projected to remain low for several years. The surrogate location IROR is about 2.4%. The project involves minimal risk and gives an attractive margin over the interest payments for borrowed funds. This energy recovery initiative is a “Green” project, which inherently lowers the acceptable IROR for environmentally conscious industries.

Table 8. Summary of the most pertinent values of the economic analysis.

Summary	Fixed Capital Investment	Working Capital	Yearly Revenue	IROR (%)	Simple Payout (years)
WERC Task premises	$381,902	$16,676	$44,412	4.3	8.6
Surrogate Location	$346,442	$15,590	$35,011	2.4	9.9

REGULATIONS

Environmental and Legal Considerations

Installation of the proposed system must comply with all state and federal laws. The construction of the pipelines and connection of the new pipelines to existing sewer lines must comply with the New Mexico Department of Health, the New Mexico Environmental department, and must abide by all plumbing codes.

The proposed technology will comply with the environmental regulations of New Mexico. These regulations can be found under the *New Mexico Environmental Protection Ground and Surface Water Protection (Title 20, Chapter 6, Part 2, Sec. 20.6.2.1- 20.6.2.5299)* issued by the *Water Quality Control Commission*. The current discharge of wastewater from the plant is approximately 3.8 million gal per day.[19] The *Ground Water Quality Bureau* and the *Surface Water Quality Bureau must be notified of the intent to alter the character of any existing water contaminant discharge, and must file plans and specifications of the modifications or construction involved (Title 20, Chapter 6, Part 2, Sec. 20.6.2.1201-20.6.2.1203).* For more information on applicable laws, refer to the references section[20,21].

The toxicity of the wastewater is high and could be deleterious if exposed to the general public[20]. If the areas nearby are residential, and they are residential near the Intel Rio Rancho plant, the pollution of drinking water sources in the vicinity could be catastrophic. Therefore, pipeline integrity must be continuously monitored. Pathogens in waste water can produce illness through ingestion, inhalation or even dermal absorption (skin contact). Sewage water contains various harmful toxicants, including, but not limited to, inorganic chemicals (ex. arsenic, chromium), organic chemicals (ex. acrylamide, benzene), radionuclides (ex. radium 226), disinfectants (ex. chlorine dioxide), disinfection byproducts (ex. bromate, trihalomethanes) and others.[20] Even minimal exposures could be potentially hazardous to nearby residents. To control possible problems with erosion and sediment control, a storm water pollution prevention plan must be in place prior to construction.

Worker Safety

Worker safety is paramount. Accident prevention and proper training are essential during the installation and operation of the proposed system. The system utilizes high flow rates and achieves moderately high pressures. For this reason, operators must be knowledgeable about the operation and maintenance requirements for the turbine and generator systems. Operation, cleaning, and maintenance must comply with the following OSHA regulations; *Occupational Safety and Health Standards (Sec. 1910.1-1910.1450), Construction Regulations Sec. 1926.1-1926.1501, Recordkeeping Regulations (Sec. 1904.4.0 – 1904.46), Personal Protective Equipment and Training (Sec. 1910, 1915, 1917, 1918, 1926) and Electrical Installations (1910, Subpart S).* Personal protective equipment shall be provided to all employees (when required by federal, state, and city laws) working on machinery. The system is automated; therefore, workers must be aware of electrical dangers and moving parts. Material Safety Data Sheets (MSDS) must be readily available to inform workers of the toxicants in the wastewater streams. Before operation on equipment, a safety lock-out/tag-out system must be in place, and all electrical connections with the machinery must be severed.

Community Involvement

A town hall meeting will be held prior to beginning construction on the project to inform the public of the potential hazards associated with the implementation of the project. Warning signs will clearly mark dangerous areas during and after construction. A pamphlet will be distributed in the surrounding areas communicating the potential hazards related to the project. Also, a representative from the parent corporation will be made available to answer any and all questions pertaining to the installation of this project. To further inform the public, a newspaper advertisement will be placed in the local newspaper (ex: Rio Rancho observer). Due to the relatively small scale of the project, the cost of this community outreach program will be negligible.

CONCLUSIONS AND RECOMMENDATIONS

1. Extensive research of potential technologies that apply to the concept of hydroelectric renewable energy was conducted. The technology that was best suited for WERC Task # 6 was determined to be a Pelton-Wheel type turbine.
2. The bench-scale apparatus adequately modeled the ability to convert kinetic energy produced from a wastewater stream to usable electric power by means of a turbine/generator system. The apparatus also demonstrated that the efficiency of Pelton Wheel turbine can be measured and quantified.
3. The efficiency of the Pelton Wheel system is highly dependent on the location of the impinging jet stream on the buckets. To maximize the efficiency, the nozzle velocity and bucket speed must be selected to yield a velocity ratio (bucket peripheral velocity/jet velocity) of ½.
4. A 27,000 gal surge tank is required to smooth the wastewater flow fluctuations into a constant flow, which optimizes the Pelton Wheel efficiency.
5. Incentives are essential to improve the project economics. Currently, the only available incentives allow electricity to be returned to a nearby electrical grid for a price of $0.12/kW-hr. The project is considered "Green", making it highly desirable by U.S. industry.
6. The project is minimal risk. Consequently, the most environmentally friendly U.S. companies would find the means to implement the project.
7. The revenues for project are $35,000 and $44,000 per annum for the surrogate location and WERC task premises location, respectively.
8. The total capital costs incurred, including direct costs, indirect costs, working capital, and fixed capital investment for the surrogate and the WERC task premise scenarios are $346,400 and $382,000, respectively.
9. The overall interest rate of return for the surrogate and the WERC task premises scenarios are 4.3% and 2.4%, respectively. The current low interest rates provide a basis for careful consideration of the projects' economic viability.
10. The simple payout for the surrogate and the WERC task premises scenarios are 8.6 and 9.9 years, respectively.

11. As it is reasonable, it is recommended that the equipment or materials be purchased locally to minimize transportation and delivery costs.
12. All applicable laws (Federal, City, and State) must be researched, reviewed, and properly considered before implementing the proposed technology.
13. All calculations are estimates and are subject to change depending on the different conditions or locations where the technology may be applied. Extensive analysis of the specific circumstances is necessary to optimize the efficiency of the equipment and to reduce the economic and environmental impact of the venture.

APPENDIX

Table A1. Calculations for the efficiency of the Pelton Wheel.

Stat	Rule
Co	;CALCULATE THE VOLUMETRIC FLOW RATE
Sa	M=(GPM*ρ_e)/(7.48*60*2.205)
Sa	Vol = GPM/60/7.48
Sa	M_e=(GPM*ρ_e)/(7.48*60)
Co	;CALCULATE THEORETICAL NOZZLE VELOCITY
Sa	Anoz = pi()*(Dnoz/12)^2/4
Sa	Vol = v_t*Anoz
Sa	v = v_t*1.03
Co	;HEAD BALANCE
Sa	ΔH = v^2/(2*g)
Co	;CALCULATE PELTON WHEEL SHAFT TO TURBINE RATIO
Sa	Vt = VelRatio*v ; http://en.wikipedia.org/wiki/Pelton_wheel - See Subsection Optimal wheel speed
Co	;CALCULATE THE POWER OUTPUT
Sa	Pjet = P/η
Co	;CALCULATE THE REVOLUTIONS PER SECOND
Sa	Vt = Pi()*N*2*(r/12)
Co	;CALCULATE THE REVOLUTIONS PER MINUTE
Sa	RPM = N*60
Co	;CALCULATE THE DIAMETER OF THE IMPELLER REQUIRED
Sa	Din = D/0.0254 ; meters to inches
Sa	D = (P/(Np*ρ*N^3))^(1/5)
Co	;CALCULATE THE MASS FLOW RATE
Sa	Pjet = (745/550)*M_e*v^2/(2*gc)

Table A2. Variables involved in efficiency calculations.

Sta	Input	Name	Output	Un	Comment
					PROPERTIES
	32.2	g			Gravitational acceleration, ft/s^2
	32.2	gc			Gravitational constant (English), lbm ft/s^2 lbf
	62.4	ρ_e			Density of water, lbm/ft^3
	1000	ρ			Density of Water, kg/m^3
					RADIUS
	3.125	r			Radius of pelton wheel (turbine), in
		R			Radius of pelton wheel (turbine), m
					DIAMETERS
	.265625	Dnoz			Diameter of nozzle, in
	2.75	Din			Diameter of impeller, in
		D	.06985		Diameter of impeller, m
					AREAS
		Anoz	.00038		Nozzle cross-sectional area, ft^2
					HEAD
		ΔH	53.583		Recoverable head, ft
					VELOCITIES
		v_t	57.032		Theoretical velocity of impinging jet stream, ft/s
		v	58.743		Actual jet stream velocity, ft/s
		Vt	29.589		Optimal shaft speed, ft/s
		VelRatio	.5037		Velocity Ratio
					REVOLUTIONS
	1085	RPM			Revolutions per minute, RPM
		N	18.083		Revolutions per second, RPS
					POWER
	5	Np			Power Number for impeller
		P	49.163		Power of impeller, W
		Pjet	99.4		Power of jet stream, W
					EFFICIENCY
		η	.4946		Energy Transfer Efficiency
					FLOW RATES
		M	.6211		Mass flowrate, kg/s
		M_e	1.3695		Mass flowrate, lb/s
	9.85	GPM			Volumetric flowrate, gpm
		Vol	.02195		Volumetric flowrate, ft^3/s

Table A3. Calculations for the power produced by the turbine.

Rule
A = pi() * (D/12)^2 / 4; Pipe flow area
koD = k / (D/12); Relative roughness
a = .094 * koD^.225 + 0.53 * koD; Constant in Wood equation
b = 88 * koD^.44; Constant in Wood equation
c = 1.62 * koD^.134; Constant in Wood equation
IF Nre > 2200 THEN f = (a + b * Nre^(-c))/4 ELSE f = 16/Nre;Wood Equation for f
Mdot = V * A * ρ; Mass flow rate
Pterm = (Pb - Pa) * 144 / ρ; Pressure term in Bernoulli equation
Zterm = (g/gc) * (Zb - Za); Elevation term in Bernoulli equation
Va = V;Velocity at system entrance
Vb = V; Velocity at system exit
Vterm = (Vb^2 - Va^2) / (2*gc);Velocity term in Bernoulli equation
NuWp = -(Pterm + Zterm + Vterm + hf); Available head at the turbine
Wp = NuWp * η; Turbine specific power
P_turb = Wp*Mdot/550*0.735; Power produced by the turbine

Table A4. Variables involved in the power calculations.

St	Input	Name	Output	Un	Comment
	32.2	g			Gravity, ft/s^2
	32.2	gc			Gravitational constant, lbm/lbf ft/s^s
	1	μ			Viscosity, cp
	62.4	ρ			Density, lbm/ft^3
	2430	GPM			Volumetric flow rate of waste water, gpm
		Nre	585127		Reynolds number in pipe
		A	.93942		Pipe flow area, ft^2
	.000005	k			Pipe roughness, ft
		koD	4.57E-6		Relative roughness, k/D
		a	.005913		Constant in Wood Eq.
		b	.393478		"
		c	.311865		"
F		f	.003042		Fanning friction factor
		V	5.7636		Velocity at point in system, ft/s
		Va	5.7636		Velocity at system entrance, ft/s
		Vb	5.7636		Velocity at system exit, ft/s
	120	Za			Elevation of system entrance, ft
	0	Zb			Elevation of system exit, ft
	0	Pa			Pressure at system entrance, psia
	0	Pb			Pressure at system exit, psia
		Pterm	0		Pressure head, ft
		Zterm	-120		Elevation head, ft
		Vterm	0		Velocity head, ft
		Mdot	337.861		Mass flow rate, lbm/s
	13.124	D			Pipe diameter, in
	1300	L			Length of straight pipe, ft
		Wp	75.1231		Turbine specific power, (ft-lbf/s)/lbm/s
		NuWp	110.475		Available head at the turbine, ft
	.68	η			Turbine efficiency
		P_turb	33.9184		Power produced by turbine, kW

REFERENCES

1. “Pelton Wheel.” *Wikipedia*. Wikimedia Foundation, 03 Feb. 2012. Web. 02 Mar. 2012. <http://en.wikipedia.org/wiki/Pelton_wheel>.
2. “Gorlov Helical Turbine.” *Wikipedia*. Wikimedia Foundation, 13 Feb. 2012. Web. 02 Mar. 2012. <http://en.wikipedia.org/wiki/Gorlov_helical_turbine>.
3. “Department of Ocean Engineering.” *College of Engineering*. Web. 02 Mar. 2012. <http://www.oce.uri.edu/course_web_pages/oce311/index.html>.
4. “Gravitation Water Vortex Power Plant.” *Wikipedia*. Wikimedia Foundation, 26 Feb. 2012. Web. 02 Mar. 2012. <http://en.wikipedia.org/wiki/Gravitation_water_vortex_power_plant>.
5. “Francis Turbine.” *Wikipedia*. Wikimedia Foundation, 26 Feb. 2012. Web. 02 Mar. 2012. <http://en.wikipedia.org/wiki/Francis_turbine>.
6. “Francis Turbine Runner Products.” *Alibaba*. Web. 02 Mar. 2012. <http://www.alibaba.com/product-gs/220085406/Francis_Turbine_Runner.html>.
7. Raja, A. K., Dwivedi Manish, and Amit Prakash. Srivastava. *Power Plant Engineering*. New Delhi: New Age International, 2006. Electronic.
8. “Turbines Info.” *What Is a Turbine?* Web. 02 Mar. 2012. <http://www.turbinesinfo.com/what-is-a-turbine/>.
9. “Three-phase Electric Power.” *Wikipedia*. Wikimedia Foundation, 03 Feb. 2012. Web. 02 Mar. 2012. <http://en.wikipedia.org/wiki/Three-phase_electric_power>.
10. Armenante, Piero M., and Gwo-Ming Chang. “Power Consumption in Agitated Vessels Provided with Multiple-Disk Turbines. “*Industrial & Engineering Chemistry Research”* 37.1 (1998): 284-91. *ACS Publications*. Web. 02 Mar. 2012. <http://http://pubs.acs.org/doi/pdf/10.1021/ie970583u>.
11. Sawhney, G.S. “Thermal And Hydraulic Machines, 1/e.” *Google Books*. PHI Learning Private Limited, 2010. Web. 01 Mar. 2012. <http://books.google.com/books?id=WIH5mB6BefwC>.
12. Dunn, D. J. “Fluid Mechanics Tutorial No.8A Water Turbines.” 1-19. Web. 03 Mar. 2012. <http://www.freestudy.co.uk/fluid%20mechanics/t8a203.pdf>.

13. “El Paso Electric Company - Small and Medium System Renewable Energy Certificate Purchase Program.” *DSIRE USA*. U.S. Department of Energy. Web. 02 Mar. 2012. <http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=NM26F>.
14. Turton, Richard, Richard C. Bailie, Wallace B. Whiting, and Joseph A. Shaeiwitz. *Analysis, Synthesis and Design of Chemical Processes*. Upper Saddle River, NJ: Prentice-Hall, 1998. Print.
15. “Intel's Profit Beats Wall Street Expectations.” *CNNMoney*. Cable News Network, 14 Jan. 2010. Web. 02 Mar. 2012. <http://money.cnn.com/2010/01/14/technology/intel_fourth_quarter_earnings/>.
16. “Financial Incentives.” *DSIRE: Incentives/Policies by State: Incentives/Policies for Renewables & Efficiency*. U.S. Department of Energy. Web. 02 Mar. 2012. <http://www.dsireusa.org/incentives/index.cfm?state=NM>.
17. “Minimum Acceptable Rate of Return.” *Wikipedia*. Wikimedia Foundation, 23 Feb. 2012. Web. 02 Mar. 2012. <http://en.wikipedia.org/wiki/Minimum_acceptable_rate_of_return>.
18. “Task 6: Microhydro Power Generation.” *Institute for Energy & the Environment.* New Mexico State University. Web. 02 Mar. 2012. <http://www.ieenmsu.com/werc-2/design-contest-2012/tasks-2/task-6-microhydro-power-generation/>.
19. “Ground Water & Drinking Water.” *U.S. Environmental Protection Agency*. EPA, 10/18/2006. Web. 25 Feb 2012. <http://www.epa.gov/cgi-bin/epaprintonly.cgi>.
20. “Transportation-Pipeline Safety.” *New Mexico Public Regulation Commission*. Web. 02 Mar. 2012. <http://www.nmprc.state.nm.us/transportation/pipeline-safety.html>.

GARVER
2049 E. Joyce Blvd.
Suite 400
Fayetteville, AR 72703
TEL 479.527.9100
FAX 479.527.9101
www.GarverUSA.com

March 12, 2012

Nathan McAlister
University of Arkansas
Department of Chemical Engineering
Fayetteville, Arkansas 72701

Re: Micro-Hydroelectric Power Generation
Task #6

Dear Mr. McAlister:

Thank you for the opportunity to review you team report for the referenced competition. With the uncertainty of energy costs, your proposal is an exciting solution. Based upon my review, I offer the following comments for consideration.

- Consider elaborating and quantifying on why the Pelton Wheel turbine was selected over the Francis Kaplan turbine and bench scale testing was not performed for both turbines.
- In addition to the amount of flow, what are the effluent characteristics with respect to the design for pipe and equipment material corrosion and solids handling? Also, do they have a pre-treatment program and discharge limitations?
- In addition to "Green" technology being environmentally friendly and the payback period, state and federal grants are available for "Green" technology. Consider elaborating on available grants to further reinforce the project benefits.
- Consider enlarging Figure 5, Bench Scale Process Flow Diagram.
- Where did the $0.12/kWh come from?
- In addition to compliance and permits from state and federal agencies, local city compliance and permits will be required. Also, consider adding environmental clearance should be coordinated with state agencies for potential historic sites, wetlands, waters, and so on.

Great Job! Please call me if you have any questions.

Sincerely,

GARVER, LLC

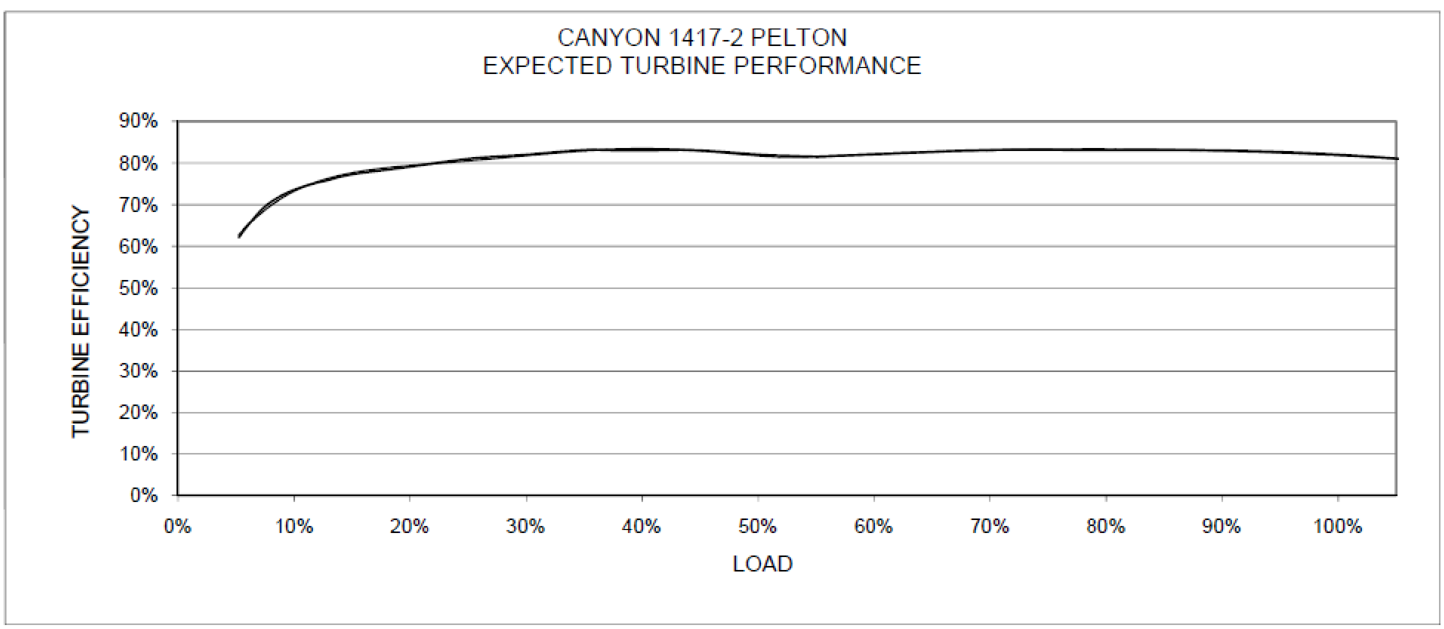
Chris Buntin, P.E.
Project Manager

March 5th, 2012

Task #6 – Micro-Hydroelectric Power Generation
Department of Chemical Engineering
University of Arkansas
Fayetteville, AR 72701

As requested I have reviewed your paper entitled "Micro-Hydroelectric Power Generation" for the development of a small scale hydroelectric power generation. I offer the following comments.

1. The main issue I see is repeated reference to the Pelton turbine not handling flow/head variation. The Pelton turbine design handles flow variation on a relatively flat efficiency curve. I have attached an example for you. The Pelton turbine design does not handle large variations in head. If you will have large variations in head without the surge tank, then the tank or impoundment is useful. If the tank or impoundment is intended to eliminate the need to adjust flow across the turbine it is not necessary. We can control the level in the tank/impoundment by adjusting flow across the turbine. A level sensor would be installed in the tank/impoundment and the turbine will automatically adjust flow to maintain a constant pool level in the tank/impoundment.
2. The turbine cannot pass solid waste. We can pass suspended solids as you have indicated. If solids are actually present they will have to be removed.
3. We cannot pipe out of a Pelton turbine unless a tank is used to catch the turbine water release and then pipe is run out of the tank. The tank and piping must be designed to ensure water does not backup higher than the turbine runner's minimum clearance requirement.
4. If it matters at this stage I estimate efficiency at 68% for the 1525-2 and a 3 phase induction generator.
5. Chemical analysis of the waste water may be required.



Canyon Hydro– the water power division of Canyon Industries, Inc. • 5500 Blue Heron Lane • P.O. Box 36 • Deming WA 98244
360.592-5552 • Fax: 360.592.2235 • email: turbines@canyonhydro.com • www.canyonhydro.com

The study focuses on an interesting site for hydro development. Please contact us if we may be of assistance in the future.

Sincerely,

Eric Melander

Canyon Hydro– the water power division of Canyon Industries, Inc. • 5500 Blue Heron Lane • P.O. Box 36 • Deming WA 98244
360.592-5552 • Fax: 360.592.2235 • email: turbines@canyonhydro.com • www.canyonhydro.com

City of Rio Rancho
Department of Public Works
Engineering Division
3200 Civic Center Circle, NE
Rio Rancho, New Mexico 87144-4501
(505) 891-5016 Fax (505) 891-5203

Mayor
Thomas Swisstack

City Manager
James Jimenez

Acting Director of
Public Works
Scott Sensanbaugher

March 9, 2012

Task #6 – Micro-Hydroelectric Power Generation
Department of Chemical Engineering
University of Arkansas
Fayetteville, AR 72701

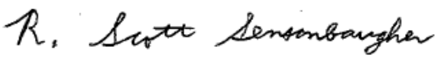
As requested, I have reviewed your paper titled "Micro-Hydroelectric Power Generation" for the development of a small-scale hydroelectric power generation. I have a few comments I suggest for your consideration:

1. With regards to the scope from the client, you generally don't want to leave things to interpretation if you're a consultant doing an economic analysis. If the client isn't clear, you have to hound them until you clearly know what they want.
2. I know this may be out of the scope of what you're doing but a wide shallow basin here in our climate makes for a lot of evaporation. The amount of water lost might be significant enough to make it worth it to use an enclosed steel water tank.
3. Very good that you looked into the cost of land. These kinds of costs can really bite us if we forget them.
4. Just some thoughts on the costs: I'm certain that they're way too low based on what we see here. For a really rough budgetary number, we use $100 per foot for the cost of pipe, complete in place (meaning materials, labor, and equipment). The labor costs you've listed are especially low. Also, the engineering costs typically run a lot higher than you have listed. There will be more hours involved than just those of the project manager.
5. The industry competitive interest rate seems a little high but I'll defer to you on this. I'm not a financial guy.
6. The water quality issues you mention are very important to consider as to the effects on the equipment. If it's corrosive, it's important to design for it. Some of the stuff coming out of the plant is definitely loaded with things that can affect the system. Because of this, emergency bypass pumping and overflow systems will have to be included in the design. I'm actually not sure if this sewage is industrial waste only, domestic waste (from all the employee restrooms), or both. If it has domestic waste, some industrial pretreatment might be needed. Some of the things contained in domestic sewage could get hung up on the Pelton wheel or plug the jets causing a real problem.
7. The strongest indicator of this proposal being viable is that these devices actually are selling commercially. Do some of the manufacturers have data on what the efficiencies

are and what power can be generated from them? That would be helpful information to a person trying to decide on whether or not to go forward.

8. Nothing's really zero risk. But, you did a good job of talking about the risk of sewer overflows. That's the biggest risk I see.

Overall, this paper is a good analysis and written very well . I find the idea to be very intriguing and am interested to see how it progresses. If there is anything else I can help you with, please contact me at 505-896-8736 or ssensanbaugher@ci.rio-rancho.nm.us .



R. Scott Sensanbaugher, PE
Acting Public Works Director
Department of Public Works
City of Rio Rancho, New Mexico