IPRO 302: Zero-Liquid Discharge

Final Report

Sponsor: Sargent & Lundy: Diane Martini

Advisors

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Team Members

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1. Abstract

Our sponsor, Sargent & Lundy, is looking to create a zero-liquid discharge facility for a coal fired electricity generating plant located in Nevada. Creating a zero liquid discharge facility essentially means that all liquid waste produced in the plant is contained in the plant and none of the liquid is discharged into the environment. To achieve this task, much research needed to be done. The initial phase of research involved understanding basic operations of a coal-fired power plant to facilitate our understanding of the liquid waste stream we are dealing with. To further understand the objective, Sargent & Lundy provided our team with a simplified water balance of the power plant. Using the initial concentrations provided, the task at hand was to find out what the concentration of the contaminants was in the outlet stream. Our preliminary research included investigating technologies that are currently in use at ZLD facilities around the world and also investigating emerging technologies and their potential effectiveness in achieving zero liquid discharge while keeping in mind the concentration of contaminants in the outlet streams as a parameter. These technologies were grouped into four separate cases, which consisted of a combination of the technologies researched. These four cases were then standardized to the same effectiveness and compared by cost. Other factors used in determining feasible options for this power plant were the availability of water and land, and possible options for water reuse within the power plant.

2. Background

A. Sargent & Lundy, the sponsor of this IPRO, is a company specializing in professional service for clients seeking power and energy. The company has been exclusively serving the electric power industry and related businesses for 118 years. Its work is always on the forefront of modern technology, helping companies increase their business by serving all power needs, present and future. Sargent & Lundy provides complete consulting, engineering, and project development services for all types of fossil fuel, nuclear and renewable power generation, and power delivery projects. Its comprehensive capabilities provide clients and partners with a thoroughly reliable source of expertise. Sargent & Lundy is headquartered in Chicago, Illinois with project team locations worldwide.

B. The basic goal of this IPRO is to eliminate the waste produced by power plants that is discharged back into the environment in such a way to make it cost-effective and feasible for a plant located in Nevada. The plant is approximately 500MW in generating capacity and there are apparent space and water limitations that the project team must take into consideration. Our plant is only allowed to take in approximately 8000 gallons per minute (gpm) of water to use for the entire process. The water balance, provided to us by our sponsor, shows that we need roughly 2000gpm in addition to the 8000gpm to have enough water necessary to run the plant. For our team, this means that some of the water must be recycled so the plant can operate at full capacity. Also, some devices that would help achieve zero liquid discharge require large amounts of space. If more space is necessary to install appropriated technologies, land cost must be taken into consideration. Furthermore, the handling of devices used to achieve zero liquid discharge may require specially trained workers, therefore increasing the maintenance and operating cost of the power plant.

C. When starting with our initial research phase, our IPRO team was divided into four subgroups: brine concentrators, deep well injections, evaporation ponds, and emerging technologies. The first three options listed are historically successful methods used around the world in achieving zero liquid discharge in coal fired power plants. It was upon our own initiative that we created a team to look into other options that were alternative innovations that were not widely used in zero liquid discharge facilities.

Deep injection wells have been in use since the 1930s in the petroleum industry, and have also been used for mining, waste disposal, and water reclamation purposes. In 1974, Congress passed the Safe Drinking Water Act, which among other things gave the EPA the authority to regulate injection wells. The EPA, in turn, established the Underground Injection Control Program[1], defining 5 classes of injection well and minimum standards for each class; individual state agencies are free to enforce stricter rules. The main rule applying to all wells[2] is that no injection well may be allowed to contaminate a potential source of drinking water. In Nevada, the state's groundwater is protected by the Nevada Division of Environmental Protection. Due to both the overall scarcity of water in Nevada, and the fact that most water in the state drains into one of two basins[4,] the National Department of

Environmental Protection (NDEP) has strict standards on waste disposal and groundwater protection. In particular, the NDEP maintains that since all water can be cleaned through desalination, all aquifers (including man-made aquifers) are considered potential sources of drinking water for regulation purposes. As such, no wells for industrial waste disposal can be constructed in the state of Nevada.

Evaporation ponds are also used as another method to achieve zero liquid discharge. Currently, there are at least three plants in Nevada using evaporation ponds to meet the state's requirements for being a zero liquid discharge facility. These ponds have been occupying their current area since the 1970's. To be a zero liquid discharge facility while using evaporation ponds, the plant must take into account the wildlife that will congregate to a large pool of water that is located in arid climate. Netting and fencing must be in place to prevent wildlife from accessing this contaminated water. Also, liners must be used on the base of the pond to prevent contamination from seeping into the groundwater. For implementing evaporation ponds, however, the team must look at evaporation rates throughout the season. The rate of evaporation will change throughout the year, but the amount of inflow into the evaporation pond will not change. The maximum values must be taken into consideration when figuring the size necessary for an evaporation pond.

Brine Concentrators, also known as vapor compression evaporators, are widely notorious for being successful in cleaning up waste water for reuse within a power plant. This operation has been used in the past in the recovery of water from heavy oil refining to the purification of drinking water. Brine concentrators are relatively new compared to evaporation ponds and deep well systems because they have only been used for zero liquid discharge purposes for the past decade. The unit operation, however, has been in implementation for the last 25 years. Brine concentrators are very efficient, removing approximately 95% of waste from the liquid water stream for recovery. There are many other factors that go into consideration of brine concentrator units: capital, maintenance, energy, construction costs. High capital costs are due to the expensive alloys that are needed to make the brine concentrator, which is a large unit, nearly 10 stories tall. High energy costs are associated with running the brine concentrator to its full capacity.

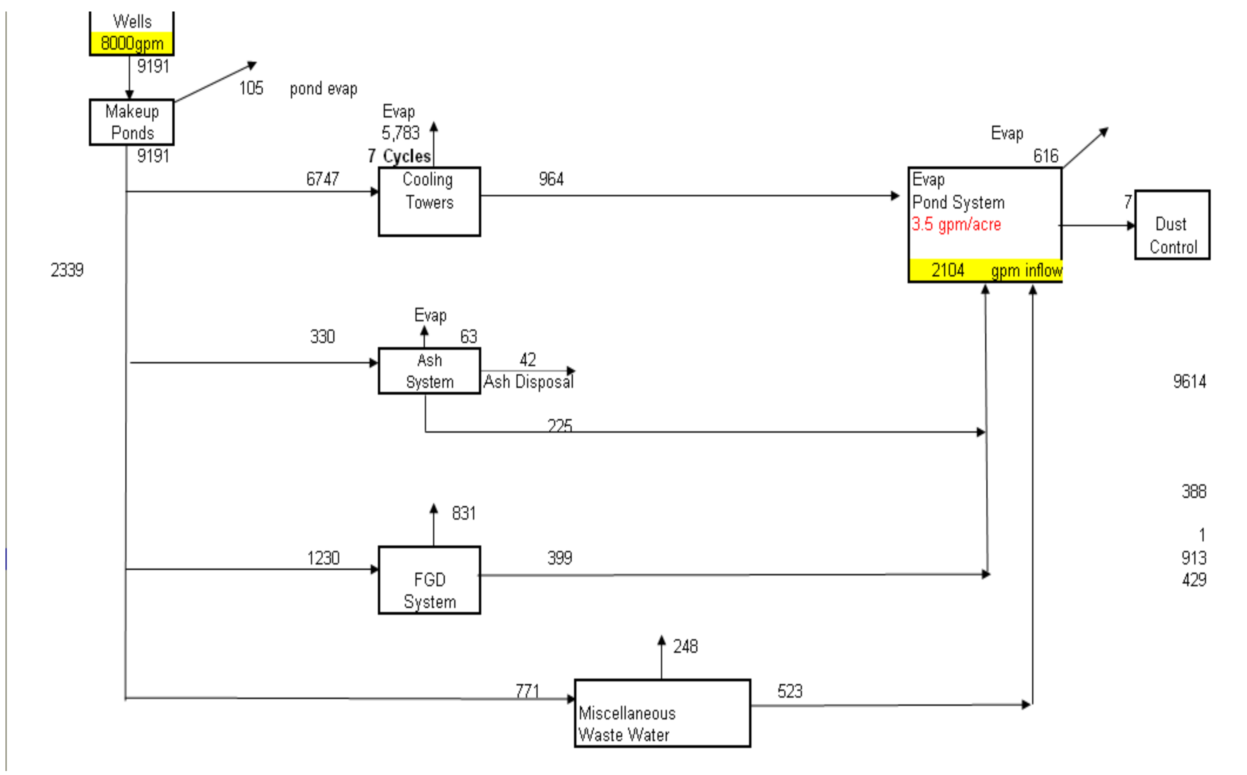
Reverse Osmosis (RO) is a method of power plant waste water treatment that has been steadily gaining acceptance. RO works by first pre-treating the waste water to prepare it for the membrane filtration. After pre-treatment, the waste water is brought to a high pressure and run through the semi-permeable membrane. Around half of the volume of water passes through the membrane and goes on while the rest of the water, and most of the waste matter in the waste water, get diverted and sent away to be dealt with by other processes. The water that passed through the membrane filter is sent through several other common water treatments (there are some very small particles that get through the membrane) and eventually comes out as clean, distilled water. RO has been implemented by a sizable number of power plants as a method for dealing with waste water. One of these plants is the Edge Moore power station in Wilmington, Del. This facility first added an RO system, in addition to the older, chemical based systems, as a more economical option for treating the waste water. The results so impressed the power facility that they removed several of their older systems in favor of having a two stage RO system instead. The facility has found this to be far more economical than the older methods by far as well as having other positive benefits.

D. Not Applicable.

E. All of our solutions to achieve zero liquid discharge involve amending the current layout of the power plant. It is our moral and ethical responsibility to stay within legal limits when considering the implementation of any of our researched technologies. The evaporation pond involves the placement of all wastewater into a shallow dugout so it may be evaporated. With an arid climate like Nevada, it is our moral responsibility to ensure that all wildlife in the area is not harmed by the placement of the evaporation pond. It is potentially harmful for animals to consume the water that is placed in the evaporation pond and therefore we must ensure that nets and fences are put into place to prevent this from occurring.

   The amount of water available to the area also plays a role in the decision that is made. The project team wants a solution that is most cost effective to reach our objective. The amount of water available is an important factor to take into account. In such a climate as Nevada is located, water resources are not abundantly available and considering this observation must be evident in our final results. Also, for any major change to occur at a power plant, the team must ensure that a notice of public hearing is held to inform the public of changes that will be made to the existing power plant. Before construction can begin, all zoning ordinances must be taken into consideration and all proper permits must be obtained. By doing this, we seek public support for making this improvement.

F.



3. Objectives

1. Do preliminary research on possible technical options used to achieve zero liquid discharge
    - Understand basic operations of a coal-fired power plant

      -Visit a local power plant and speak with experts to understand important concepts
    - Research potential technologies to achieve zero liquid discharge

      -Brine Concentrator

      -Evaporation Pond

      -Deep Well Injections

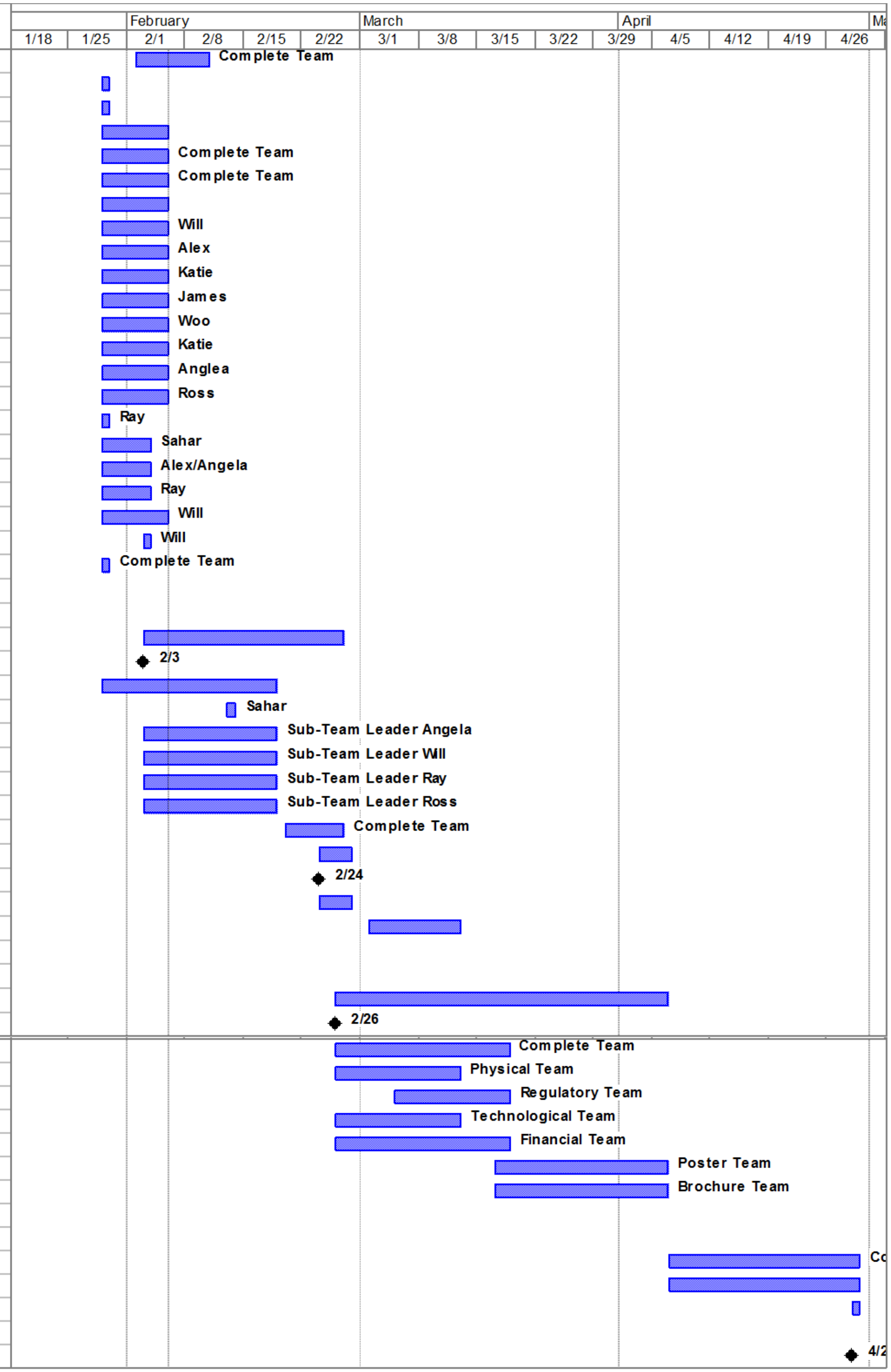
      -Emerging Technologies
    - Research Nevada state regulations
    - Evaluate these technologies based on their effectiveness in the scope of our IPRO
2. Perform a water balance on the facility
    - Calculate the concentration of the exit streams of the power plant to know the level of contamination of our liquid discharge we are trying to eliminate.
3. Come up with technical options (cases) to evaluate
    - Combine the technologies we have decided to use into several different cases and calibrate them at the same effectiveness so the cases can be evaluated based on cost and performance.
    - Obtain and use design equations as a numerical means of comparison among the systems.

4. Choose a case as our “best option”
    - Use our criteria to choose one case to be the option we recommend to our sponsor based on approximate cost.
5. Create Deliverables
    - Assign a group to work on the final presentation for IPRO Day
    - Have another sub-team working on creating the final brochure and poster for our exhibit
    - Create a final report that encompasses all the work done throughout the semester

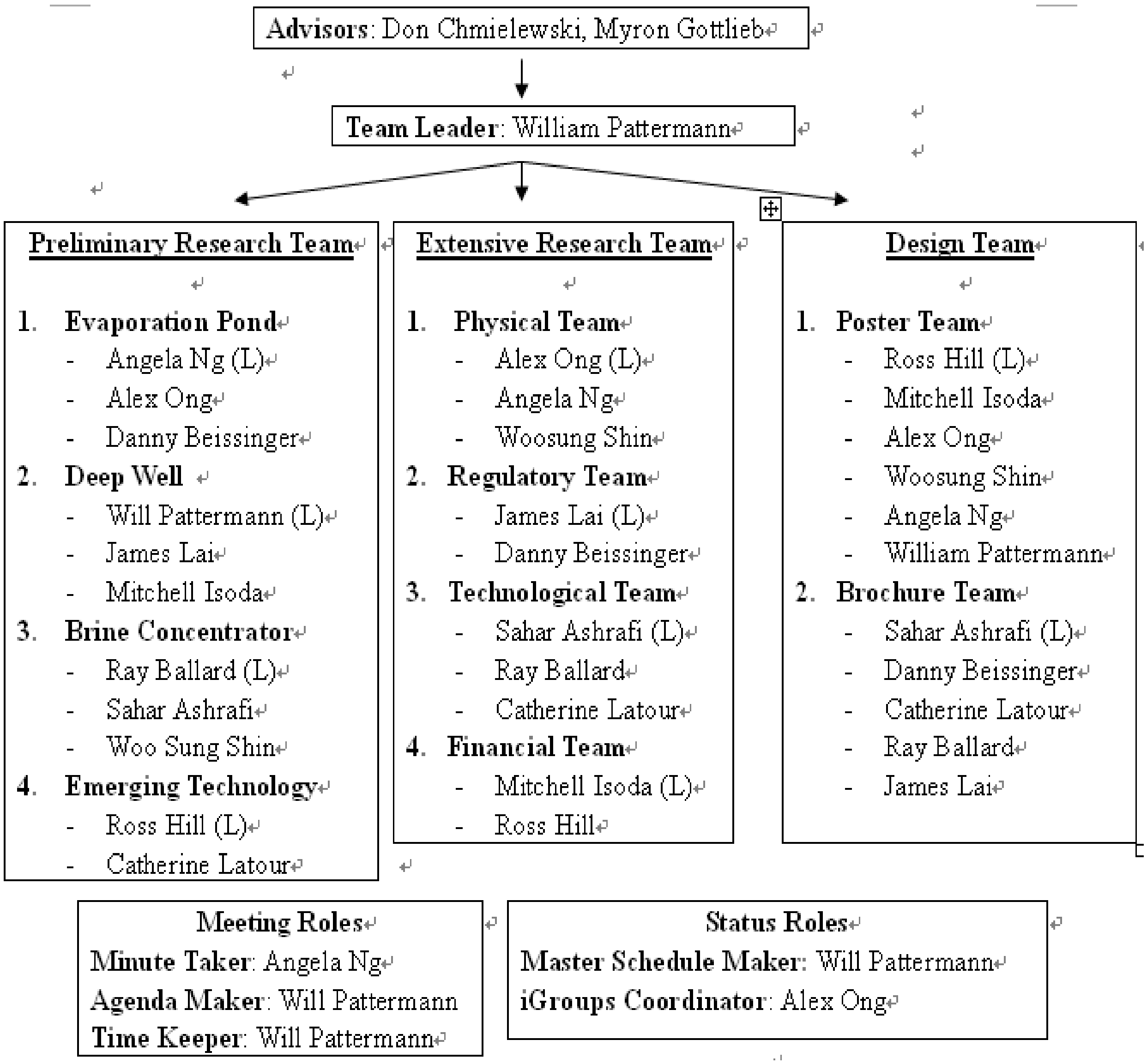
4. Methodology

Attached on the following page is the Gantt chart that was created at the beginning of the semester. With adequate foresight, it was not necessary to make major adjustments to our timeline. Our project completion date was set to be two days before IPRO day with adequate leeway given for project timelines. Although our group did come across problems that delayed the completion of certain portions of our project, we did not have to amend the timeline as a whole to account for these delays.

ID		Task Name	Duration	Start	Finish	Resource Names
1		**Project Organization**	7 days	Mon 2/2/09	Tue 2/10/09	Complete Team
2		Define the Project	1 day	Thu 1/29/09	Thu 1/29/09	
3		Determine Project Requirements	1 day	Thu 1/29/09	Thu 1/29/09	
4		Make Project Plan	6 days	Thu 1/29/09	Thu 2/5/09	
5		Team Information	6 days	Thu 1/29/09	Thu 2/5/09	Complete Team
6		Team Purpose and Objectives	6 days	Thu 1/29/09	Thu 2/5/09	Complete Team
7		Background	6 days	Thu 1/29/09	Thu 2/5/09	
8		Part A	6 days	Thu 1/29/09	Thu 2/5/09	Will
9		Part B	6 days	Thu 1/29/09	Thu 2/5/09	Alex
10		Part C	6 days	Thu 1/29/09	Thu 2/5/09	Katie
11		Part D	6 days	Thu 1/29/09	Thu 2/5/09	James
12		Part E	6 days	Thu 1/29/09	Thu 2/5/09	Woo
13		Part F	6 days	Thu 1/29/09	Thu 2/5/09	Katie
14		Part G	6 days	Thu 1/29/09	Thu 2/5/09	Anglea
15		Part H	6 days	Thu 1/29/09	Thu 2/5/09	Ross
16		Team Values Statement	1 day	Thu 1/29/09	Thu 1/29/09	Ray
17		Methodology/Brainstorm/Work Brea	4 days	Thu 1/29/09	Tue 2/3/09	Sahar
18		Expected Results	4 days	Thu 1/29/09	Tue 2/3/09	Alex/Angela
19		Project Budget	4 days	Thu 1/29/09	Tue 2/3/09	Ray
20		Schedule of Tasks and Milestone E	6 days	Thu 1/29/09	Thu 2/5/09	Will
21		Individual Team Member Assignmer	1 day	Tue 2/3/09	Tue 2/3/09	Will
22		Designation of Roles	1 day	Thu 1/29/09	Thu 1/29/09	Complete Team
23						
24						
25		**Research Team Tasks**	18 days	Tue 2/3/09	Thu 2/26/09	
26		Sub-Team Division Finalized	0 days	Tue 2/3/09	Tue 2/3/09	
27		Gather Research/Background	15 days	Thu 1/29/09	Wed 2/18/09	
28		Trip to Midwest Generation	1 day	Fri 2/13/09	Fri 2/13/09	Sahar
29		Evaporation Pond	12 days	Tue 2/3/09	Wed 2/18/09	Sub-Team Leader Angela
30		Deep Well	12 days	Tue 2/3/09	Wed 2/18/09	Sub-Team Leader Will
31		Brine Collector	12 days	Tue 2/3/09	Wed 2/18/09	Sub-Team Leader Ray
32		Emerging Technologies	12 days	Tue 2/3/09	Wed 2/18/09	Sub-Team Leader Ross
33		Analyzing & Selecting	5 days	Fri 2/20/09	Thu 2/26/09	Complete Team
34		Prepare for Midterm Report	4 days	Tue 2/24/09	Fri 2/27/09	
35		Designate Report Team	0 days	Tue 2/24/09	Tue 2/24/09	
36		Make Presentation Slides	4 days	Tue 2/24/09	Fri 2/27/09	
37		Mid-Term Review Presentation	9 days	Mon 3/2/09	Thu 3/12/09	
38						
39						
40		**Design Team Tasks**	28 days	Thu 2/26/09	Mon 4/6/09	
41		Sub-Team Division Finalized	0 days	Thu 2/26/09	Thu 2/26/09	
42		Extensive Research	15 days	Thu 2/26/09	Wed 3/18/09	Complete Team
43		Physical	11 days?	Thu 2/26/09	Thu 3/12/09	Physical Team
44		Regulatory	10 days?	Thu 3/5/09	Wed 3/18/09	Regulatory Team
45		Technological	11 days?	Thu 2/26/09	Thu 3/12/09	Technological Team
46		Financial	15 days?	Thu 2/26/09	Wed 3/18/09	Financial Team
47		Exhibit & Poster	15 days	Tue 3/17/09	Mon 4/6/09	Poster Team
48		Abstract or Brochure	15 days	Tue 3/17/09	Mon 4/6/09	Brochure Team
49						
50						
51		**IPRO Presentation Team**	17 days	Tue 4/7/09	Wed 4/29/09	Complete Team
52		Prepare for IPRO Day	17 days	Tue 4/7/09	Wed 4/29/09	
53		Presentation (IPRO Day)	1 day	Wed 4/29/09	Wed 4/29/09	
54						
55		**PROJECT COMPLETION**	0 days	Wed 4/29/09	Wed 4/29/09	



5. Team Structure and Assignments



Above is the image of our initial team structure as created for the project plan. Some amendments were made to this structure in regard to the design team portion. Initially, as shown above, our design team was split up into two subteams. While in the extensive research phase of our project and preparing for the midterm report, our group decided that it was in our best interest to have two more sub teams in the design portion of our IPRO. One subteam would work on the final report while the other subteam would work on the final presentation for IPRO day. To create these two new sub teams, it was necessary to reassign the members of our group to different sub teams so each of the four teams would consist of members who all had different focuses throughout the project. For example, the final presentation team consisted of one person from each of the following: evaporation pond, deep well, brine concentrator and emerging technology preliminary research teams. All of these people had a different role for the extensive portion of the project research. Each final subteam consisted of a group of people who had worked on all different portions of the project thus far and therefore all had a different area of expertise for the final design team.

On the following page is a chart of all of the group members, their strengths, goals, and accomplishments for the semester.

Name:	Major/Minor	Skills & Strengths	What We Want to Gain from IPRO 302	Teams	Assignments Done
Ashrafi, Sahar	Chemical Engineering	Microsoft Office, MATLAB, Maple, HYSYS, and LabVIEW. Very organized and good at planning.	Sahar hopes to gain a deeper understanding of emissions coming from coal-fired power plants and the various options to decrease or eliminate these emissions. On an individual basis, she would like to improve her project management skills and group task delegation.	Research Team: Brine Extensive Research: Water Balance Design Team: Final Report	Completion and analysis of water balance. Compilation of final report. Extensive Brine concentration research.
Ballard, Ray	Chemical Engineering	Written/Verbal communication, C++, Maple, Matlab, Hysis, Microsoft Office.	Ray hopes to learn and utilize a great deal of chemical enginnering to study cleaner solutions for coal-fired power plants while gaining expertise in managing a team through an engineering/scientific project and presenting its results would be a great pride.	Research Team: Brine Extensive Research: Water Balance Design Team: Final Presentation	Budget Planner. Completion of water balance. Final presenter. Presentation coach. Result Analysis.
Beissinger, Daniel	Environmental Chemistry			Research Team: Evap. Extensive Research: Regulatory Design Team: Poster	Project Plan Assembler Midterm presentation. Design of IPRO Day Posters.

Hill, Ross	Mechanical Engineering	Statics, Dynamics, Materials, Thermodynamics, Technical Drawing, AutoCAD, SolidWorks, Free Hand Drawing	Ross is hoping to learn more about coal based power generation including the chemical and engineering aspects. Ross is looking forward to further developing the skills needed to work effectively in a project team as well as well as working on his time managment skills.	Research Team: Emerging Tech. Extensive Research: Financial Design Team: Final Report	Created Team Logo. Extensive research into reverse osmosis, brine concentration, crystallization. Cost analysis. Final presentation.
Isoda, Mitchell	Applied Math	Diff. Eq, complex analysis, computational mathematics, Matlab, Java, C++, Problem analysis and writing skills.	Mitchell is hoping to increse his skill in web design, time managment, and accumulation and synthesis of research data	Research Team: Deep Well Extensive Research: Financial Design Team: Final Report	Deep well research. Midterm presentation. Cost analysis. Final Report
Lai, James	Molecular Biochemistry & Biophysics	Working with power tools, AutoCAD, mathematics, biology, chemistry, physics, music, and history.	James hopes to learn more the economics behind this water project in addition to mechanical and chemical methods in solving it. He would also like to learn how to effectively use resources that have different backgrounds.	Research Team: Deep Well Extensive Research: Regulatory Design Team: Brochure	Deep well research. Brochure designer.
Latour, Catherine	Chemistry	Theoretical and applied chemistry, public speaking and technical writing,		Research Team: Emerging Tech. Extensive Research: Technological	Emerging technologies research. Midterm Report Presentation. Composition of Team Ethics statement.

Ng, Angela	Civil Engineering / Environmental Engineering	Strengths: Mathematics, English, Chemistry, Computer Skills: MathCAD, Microsoft Word, Excel, & Powerpoint, AutoCad	Angela is a very logical thinker and is hoping to increase her creativity and abstract viewing. She is open to new ideas but prefers to pick one idea and go along with it. She also wishes to learn to improve her communication skills.	Research Team: Evap. Extensive Research: Physical Team Design Team: Final Presentation	Minute Taker. Evaporation pond research and regulations. Evaporation Pond design equations. Final presentation. Final report editor. Poster editor.
Ong, Alex	Civil Engineering / Structural Engineering	Mathematics, Physics, Economics, CAEs, MMAEs, Hand Drawing, Music, Mathcad	Having chosen this iPro, Alex is looking forward to learn more about electric power generation, which is considered a new knowledge to him. To learn how to collaborate with people from different specializations and backgrounds.	Research Team: Evap. Extensive Research: Physical Team Design Team: Poster	iGroups Coordinator. Design equation team. Evaporation pond research. Poster design.
Pattermann, William	Civil & Architectural Engineering / Construction Management	Statics, Plumbing, HVAC, Thermodynamics, Circuits, Hydrology, Drafting, AutoCAD, MathCAD, SAP, Primavera	Even though this project pertains to only coal-fired power plants, Will is hoping to gain an understanding of how efficiency and productivity could be increased at all electric manufacturing plants. Will is really excited to gain team experience and is anxious to use his talents in a group setting.	Team Leader Research Team: Deep Well All aspects of project	Team Leader, Master Schedule Maker, Deep well research. Design equation research. Final presentation, and final poster.

Shin, Woo	Civil Engineering	C++, Microsoft Office, MathCad, AutoCad, Mathlab, Mathematics and Physics	Woo Sung is expecting to learn more about electric generation facilities andlearn how to cooperate with other people.	Research Team: Brine Extensive Research: Physical Team Design Team: Brochure	Brine concentration research, Design equation research. Creation of Brochure.

6. Budget

Supplies (Lab supplies, office supplies, etc.)

$75

$75 covers extraneous supplies that will certainly be needed. The IPRO poster is covered by the IPRO office, but our team believes many non-poster costs are to be expected. These include the costs of other books and articles (that have not been taken into account by our equipment needs) that may be necessary to purchase along the way, as well as business cards, copying, and other printing/development needs.

Equipment (Purchase materials and/or parts for testing or construction.)

$170

Our team found that the book "Steam: It's generation and it's uses" by Babcock and Wilcox would be instrumental in our research. The following sites are for ordering the book:

http://www.babcock.com/library/steam.html

http://www.babcock.com/library/pdf/steambook.pdf

It is an immense book on coal-fired power plants, their components, and it includes many of the utilities we need to comprehend. Also, an article by the American Society of Civil Engineers ($18+shipping) had a lot of information on the subject that we would like to purchase.

Travel/Meetings (Transportaion costs, meals, conference passes, etc.)

$250

We will be taking a trip to a Midwest Generation coal-fired power plant for a personal tour of a plant similar to the one we will be analyzing; to ask questions regarding the many processes involved in the plant and to discuss possible options for zero liquid discharge with experts at the plant. Costs for this trip include the gas mileage (for 3 vehicles) to the plant and back, as well as a meal while away from school for the trip. This should cost no more than $100 (budget below shows $96.79).

Driving directions to Crawford Station, 6.2 mi – about 9 mins (up to 20 mins in traffic)
From: 3241 S Federal St 1. Head north on S Federal St toward W 31St 0.2 mi
Chicago, IL 60616 2. Turn left at W 31st St 289 ft
3. Turn right at S La Salle St 0.3 mi
To: Crawford Station 4. Take the ramp on the left onto I-90 W/I-94 W 0.5 mi
3501 S Pulaski Rd 5. Take exit 53B for Stevenson Expy/I-55 S 0.6 mi
6. Merge onto I-55 S 4.0 mi
7. Take exit 287 for Pulaski Rd toward 4000 W 0.3 mi
8. Turn right at S Pulaski Rd 0.4 mi
Destination will be on the right

<u>Budget for Midwest Generation Power Plant Trip</u>

Driving: 6.2 miles one way, two directions, 3 vehicles = 37.2 miles total

Federal rate for 2008 is 50.5 cents per mile.

Total reimbursement for team equals 37.2 miles x 50.5 cents = $18.79

Breakfast food at $6 per person x 13 persons = $78

Total Reimbursement = $96.79

Other Meeting costs include money for occasional meals during team-building and work meetings. We will need $150 with a minimal budget of $25 per meal (for the whole team, i.e. Little Caesars). This comes out to a maximum of six team meals/meeting costs. We believe this will be a necessary component for our members when we meet on nights and weekends because of the costs associated with missing meals in the Commons, as well as the loss of time for commuters and Greeks to prepare their meals during this time. We want to have our focus on the subject of our project, and eliminate the stress of meals.

7. Code of Ethics

Overarching Standard

Our team will conduct ourselves in a professional manner to find an economically feasible solution to eliminate the waste water stream from a coal-fired power plant in Nevada.

-Honoring "The Honor System"

Cannon: As a team we shall hold honesty in the highest regard at all times. We shall report and manage all resources accurately and without bias; including but not limited to, time keeping, financial expenditures and consequential reimbursement, ethical and honest.

Pressure: The need to put forth appropriate amount of time and dedication into the IPRO-302 Team effort while balancing other practical concerns.

Pressure: In the midst of a tight schedule to accurately keep track of the use and allocation of all resources so as to prevent any misuse of funds or misrepresentation of time and/or other resources.

Risk: Lack of appropriate dedication on the part of the team as a whole or of any one individual could result in a low grade or inadequate solution (to sponsors) .

Risk: Lack of sufficient planning and accountability could lead to waste or misuse of finances.

Measure: Team members shall hold one another strictly accountable for honest, accurate and honorable behavior in these areas and seek frequent advice from our advisers and qualified professionals to ensure all such concerns are properly handled.

-Environmental Law

Cannon: When developing a solution for Zero Liquid Discharge (ZLD) we shall take into account and follow completely all laws set in place to protect the environment at the national, state and local levels. We shall not aid, abet, or prescribe any course of action which might potentially directly or indirectly violate these laws and/or cause undue harm to the environment

Pressure: Developing a feasible solution ZLD solution for a 500MW power plant in Nevada within the allotted time.

Pressure: Presenting a solution to Sargent & Lundy* that is both affordable and effectual

Risk: Insufficient research into laws and ordinances may lead to violation of these regulations and thereby incur fines or legal action.

Risk: The use and endorsement of a new and therefore untested product used to achieve zero-liquid discharge. Because of the time frame of testing, some new products may not have evidence to support claims of compliance with environmental regulations.

Measure: Specific care will be taken to adhere thoroughly and completely to all laws set in place to protect the environment. If no fines or legal actions are incurred then this measure has been successful.

-Intellectual Property

Cannon: The intellectual property of others shall be respected and recognized at all time by members of the team when formulating and reporting a solution to the problem given to us by our sponsors. Academic honesty, adherence to trademark, copyright, patent, rights reserved an all other laws, measures or policies in place to protect intellectual property. Credit shall be given to any and all sources of information used in research and deliverables.

Pressure: A marketable and strategic system to achieve ZLD must be set forth to both our sponsors and the IPRO academic panel within the 10 weeks allotted.

Pressure: The use of information that is presented from unreliable sources.

Risk: The use of falsified information in our report resulting in an inaccurate recommendation to our sponsor.

Risk: Being judged by peers, IPRO day judges, our sponsor and our advisors for the use of such information.

Measure: Multiple team members as well as other outside sources will look over the origin of all data that is to be submitted.

Measure: Team members will hold each other accountable for unlawful use of intellectual property and point out and correct any possible conflicts of interest or disrespect of intellectual property, both legally and academically. If no legal or disciplinary action is taken, then this has been successful.

-Professionalism

Cannon: As a team we will conduct ourselves in an orderly and respectful fashion at all times; we shall respect the time and efforts of all team members and outside individuals, take all matters seriously and handle all disputes and disagreements in a logical, rational and professional manner.

Pressure: The need to handle the complexity of a real world situation in a very limited amount of time.

Pressure: Working with a new group of peers consisting of many who have the same technical background.

Risk: Communication problems within the team could lead to anger, quarrellings and unprofessional behaviors

Risk: A small miss-communication might under-go a snow-ball effect if left unchecked

Measure: Team members will attend and participate in team building sessions that address these issues to ensure they are dealt with properly.

-Personal Relations

Canon: Each member will do their best to put forth their efforts and available time to support the team and its work.

Pressure: Each member has external concerns and time commitments.

Risk: Work needed for the project to be completed will not get done before set deadlines.

Risk: Not working together as a cohesive team and some members end up doing more than his or her share.

Measure: Holding each member accountable for their deadlines and keeping track of any extensions.

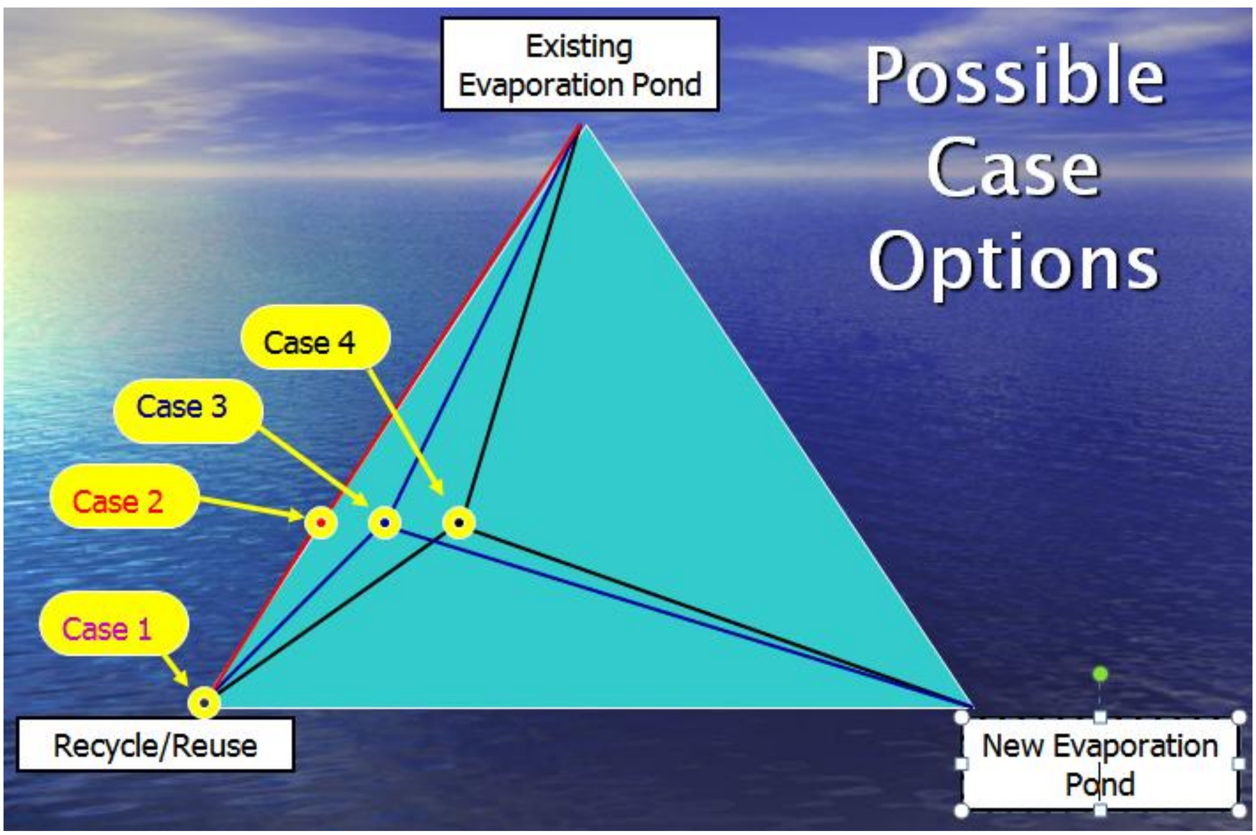
8. Results

A. Our preliminary research showed the team that we were dealing with a specific set of technologies that are viable in achieving zero liquid discharge: brine concentrator, evaporation pond, and reverse osmosis. Another option, deep well injections, was eliminated early on in the semester because our research team found that injecting waste water into these wells was prohibited by Nevada state law. The brine concentrator subgroup extensively researched the historical success and effectiveness of this unit in achieving zero liquid discharge. It is shown that, when operated correctly, the brine concentrator works with over 95% efficiency in removing waste from the liquid stream. The brine concentrator is also a unit that has been implemented worldwide with notorious success. By using this unit, the power plant can ensure that most of the water will be recovered for reuse. The brine concentrator, despite its large size, is also known for being an energy efficient unit operation compared to its counterpart of steam-driven evaporation. The largest of brine concentrators can treat water at a flow of 660 gallons per minute and smaller units can treat water for flows as low as 15 gallons per minute. The brine concentrator, however, was found to have undesirable attributes as well. Because of the nature of the unit operation, expensive alloys must be used in the construction of the brine concentrator to prevent build-up and deterioration of the construction materials. Maintenance and installation costs are also high due to the sensitivity of the brine concentrator to contamination of inflows.

Evaporation ponds are also a viable option in achieving zero liquid discharge. The technology is simple to grasp and the regulations involving evaporation ponds in Nevada are very clear. Evaporation ponds' main cost is that of the land needed to make a shallow holding for wastewater to sit and evaporate. Other costs include liners for the pond to prevent seepage into groundwater and material to keep wildlife away from the pond. The major drawback is that all the water placed in the evaporation pond is no longer usable. In Nevada, where there are regulations on the amount of water available, evaporating water is not always a viable option.

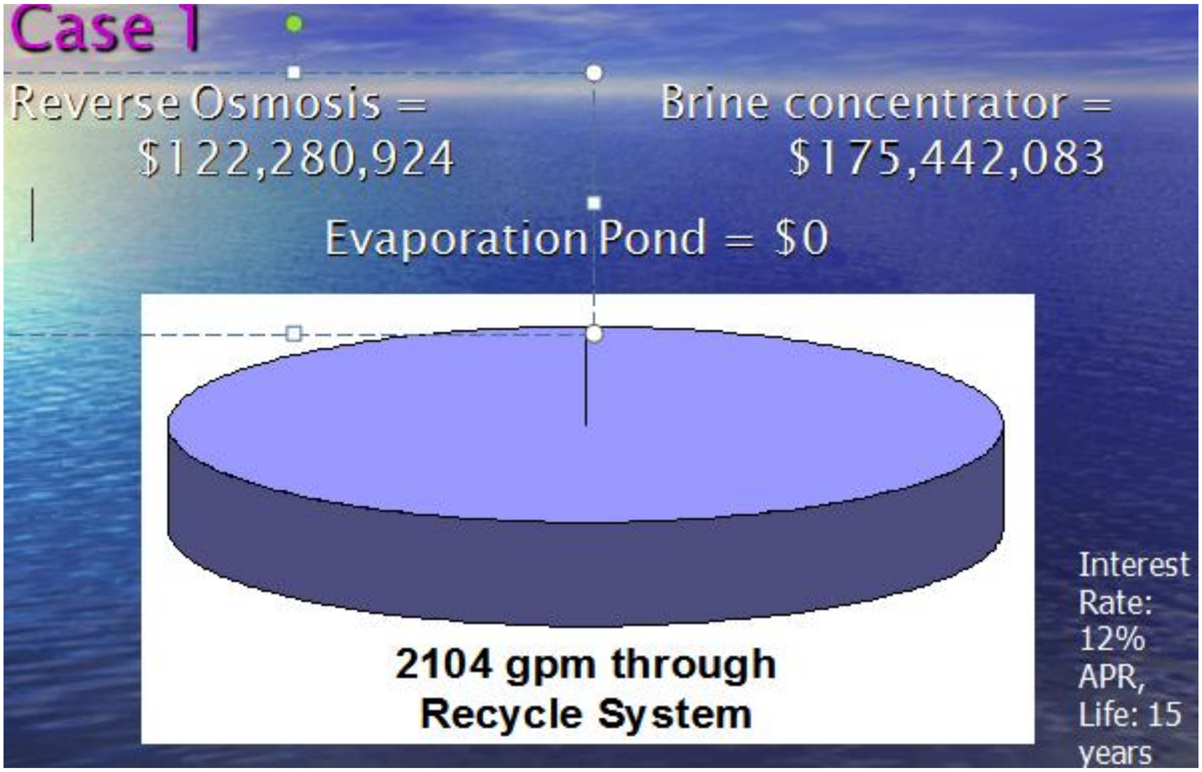
The other technology that was extensively researched was reverse osmosis. To achieve the high degree of efficiency similar to that obtained by a brine concentrator, several reverse osmosis membranes would need to be placed in series. Reverse osmosis is also a technology that is historically successful in this application. These membranes, however, are very susceptible to clogging and need to be maintained very well. Any change in the quantity or size of concentration would most likely cause a membrane to clog. Personnel would need to be employed to monitor the particle quantity and size that was being separated by the membrane and to check continually for clogged filters. If this were to happen, filters would need replacement more often, thus increasing the maintenance cost of the unit. A basic benefit, however, is the number of units that would be employed. If, for example, six reverse osmosis membranes were placed in series and one membrane clogged, this single membrane can be replaced while the other five units are still working to clean the wastewater, though at a lesser degree of efficiency.

Using the data obtained for land cost, flow rate, and efficiency of a system, design equations were obtained to evaluate all technologies on the same level. Once these design equations were finalized, our project team came up with four possible cases - on the parameters of the design equations - to evaluate.

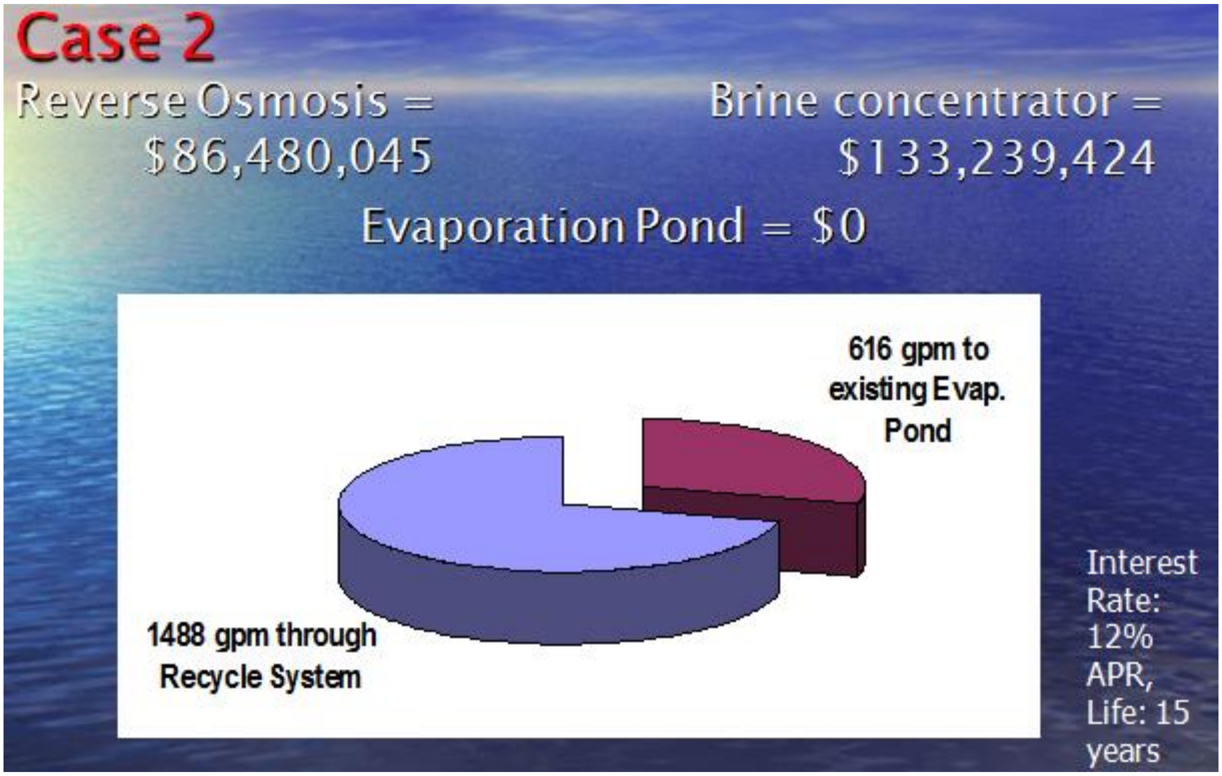


Cases

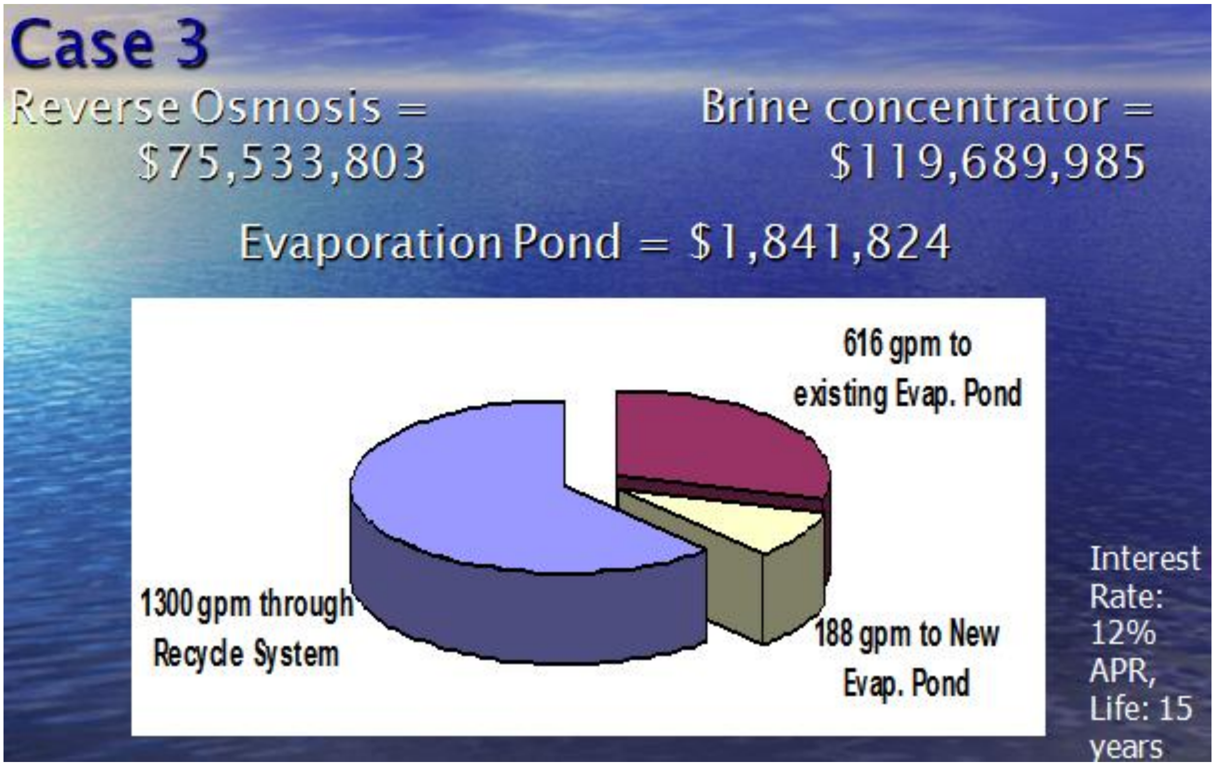
The first case involved the use of reverse osmosis and a brine concentration unit. In this case, all 2104 gallons per minute in the waste stream would be purified and recycled back into the plant.



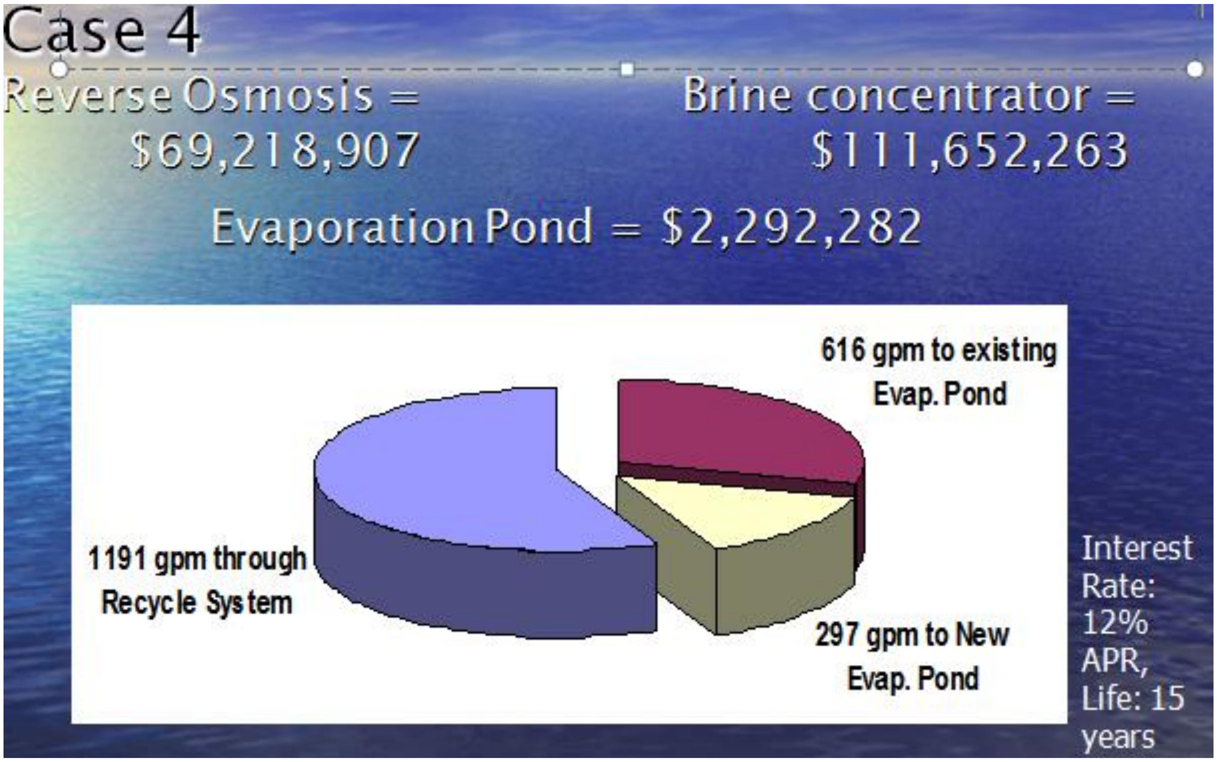
The second case requires the use of the existing evaporation pond at the power plant in addition to the use of reverse osmosis and a brine concentration unit. The excess of 1488 gallons per minute that is unable to fit in the existing evaporation pond would be purified for reuse within the plant.



The third case involves the minimum amount of recycling 1191 gallons per minute to meet the inflow needs of the power plant and the creation of an additional evaporation pond to hold the additional waste water.

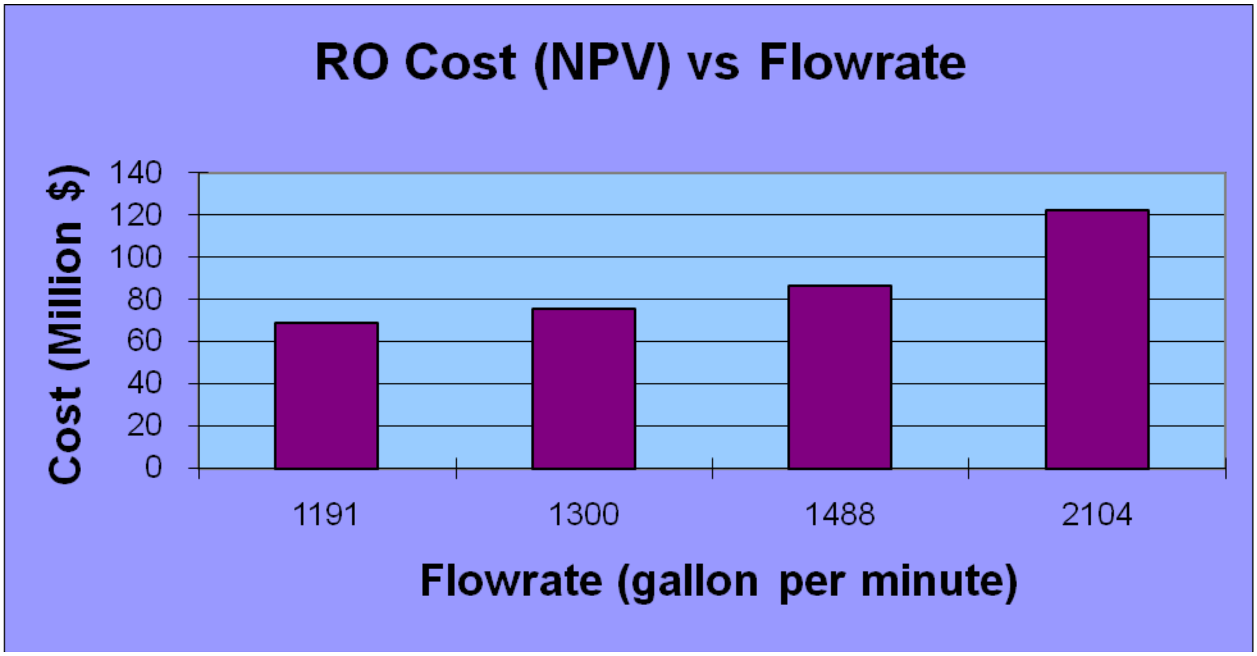


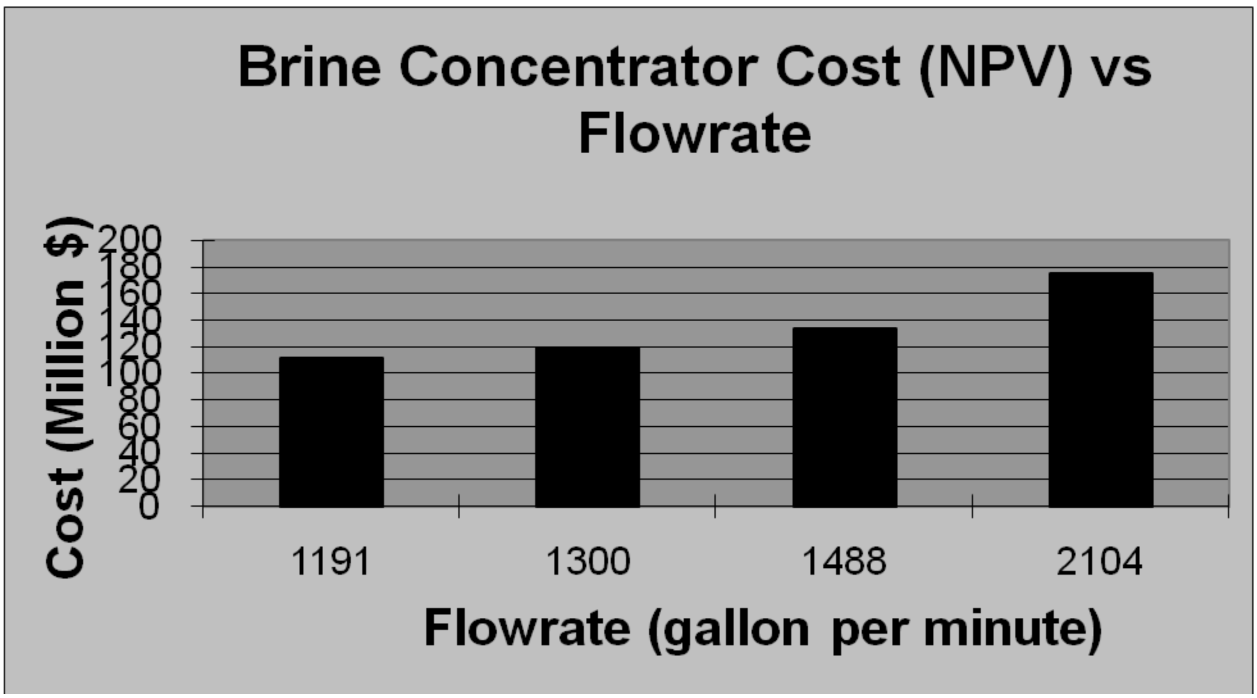
The final case is an arbitrary one. This case involves 1300 gallons per minute being recycled and the rest being placed into an additional evaporation pond. This value for the amount of water recycled was chosen as an intermediate value between the extreme of recycling all the waste water and recycling the bare minimum amount of water necessary for the power plant to function.

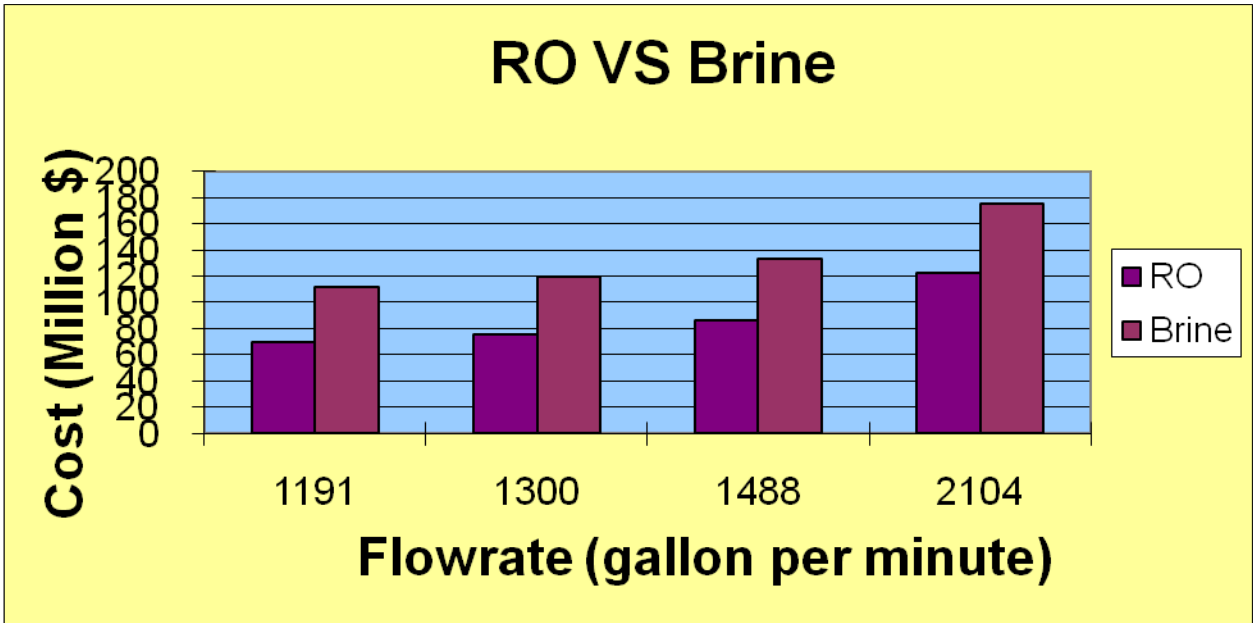


The evaluation of these cases was done on the basis of cost effectiveness and need for additional water. It was decided that, based on the cost of each unit and the amount of water being recovered, the final case presented was the best option for the power plant in our IPRO.

Evaluation of cases based on cost:


RO Cost (NPV) vs Flowrate
Cost (Million $)
140
120
100
80
60
40
20
0
1191
1300
1488
2104
Flowrate (gallon per minute)


Brine Concentrator Cost (NPV) vs Flowrate
Cost (Million $)
200
180
160
140
120
100
80
60
40
20
0
1191
1300
1488
2104
Flowrate (gallon per minute)



B. The project team found several different ways of achieving zero liquid discharge for a coal-fired power plant located in Nevada. Each member of the team had the option of learning in-depth about a specific technology used to achieve zero liquid discharge and relay this knowledge to the other group members. The project team was able to come up with a cohesive solution to a complex problem given to us by our sponsor. The different scenarios were the achievement for the objective given by Sargent & Lundy. Our team believes that we had a number of abstract achievements unrelated to the research of our problem but still contributed to the success of the semester. As a whole, the group felt more prepared to take on large-scale undefined problems such as the one encountered through this IPRO. The group agrees that a major achievement was the development and understanding of leadership and teamwork skills as well as the importance of ethics as a guide to project management.

C. At the inception of the semester, our team came up with five tangible objectives for the semester. These five objectives were preliminary research, performing a water balance, coming up with technical options, evaluating these options, and creating deliverables for the project. Fortunately, all of our objectives were met. Our initial timeline was created with sufficient “down-time” which allowed our group to stay on schedule as unexpected problems arose that delayed the work on our timeline. With a good team work-ethic and collaboration with other team members, all objectives were completed in a timely manner.

D. One ethical dilemma we faced through the duration of our IPRO was honesty when contacting vendors about specific information. As a group, we felt it dishonest to disguise our intentions for seeking information from specific vendors about their products. We also knew that some companies would be less inclined to help us knowing that we would obviously not be purchasing or actually implementing one of their products.

Also, throughout the semester, the team was split into subgroups. Sometimes an instance arose where a group came upon information that they deemed irrelevant but would have been helpful to another group working on a similar task. This communication issue, while not purposeful, can cause discontent among group members and reduce team work ethic overall.

9. Obstacles

The main obstacle throughout the project was deciding how to delegate work. Before this could be done, we had to make sure that everyone understood the problem and what a solution to that problem would look like. This meant we needed knowledge not only of how each technology dealt with wastewater, but also information about where a coal-fired power plant used water and where the wastewater produced. Essentially, the first half of the semester was devoted to research that would develop the background we needed in order to properly create a solution. Although this was entirely expected due to the scope of the given problem, it was still somewhat discouraging that we could not start developing a solution until after the midterm presentation.

To handle the amount of background research needed, we divided our group into technology specific sub-teams, analyzing each of the options proposed to us by Sargent and Lundy, as well as seeking out other technologies for treating wastewater. When investigating how to best implement a zero-liquid-discharge system, we again split up into sub-teams to analyze the different aspects of the problem. This was a necessary step to reduce the complexity of the problem that each team had to deal with, and the division of the research allowed each team member to contribute based on their major and interests. Still, separating our teams produced problems of its own. Each team had to set its own goals and evaluate its own progress, which made it difficult to judge whether enough progress was being made. While the project was structured so that everyone was equally able to contribute - without proper communication - it would be impossible to make sure that people actually were contributing. While the groups were mostly able to work independently, when one group's work depended on the results from another, not only was there time spent waiting for the results, but also time spent trying to understand the other group's work.

Again, many of these problems were inevitable given the complexity of the problem, but the problems could have been reduced. There were sub-team leaders for each group to monitor everyone’s progress, and everyone was encouraged to log their work hours on iGroups. The team leaders were also expected to set timelines for their groups and to help communicate between teams. Overall, there was a decent level of cooperation between groups, but also inefficiency due to their separation.

When we were doing background research on each of the technologies at the start of the semester, we intended to give presentations in class on how each technology worked and their pros and cons, to make sure that everyone understood our options. However, the deep well group came across information that suggested that Nevada law would prohibit use of deep wells for eliminating waste water. This presented a question of how to prioritize our research. Focusing on the regulation behind deep wells would be complicated, and if it turned out that they were not prohibited, that would delay our research into their actual use, meaning that the other groups would have to wait longer to understand this aspect of the problem. On the other hand, if they were prohibited, it would be a waste of time to research them in depth. Upon further research we established that Nevada law eliminated deep wells as an option, but this illustrates how subgroups must be willing to reevaluate their own goals to make sure they line up with the entire team’s goals.

We had quite a few problems understating the problem, but one particular incident occurred when we began in-depth research on implementing our solution. The technological team noticed that, in the water balance given to us, more water was being evaporated from the coal power plant than the plant was allowed to take in, which would make a proper solution impossible. Luckily, our sponsor was available for questions and willing to work with us. As it turned out, one of the numbers on the balance was a yearly max while the others were yearly averages. Communication with the sponsor was vital in making sure that we were solving the intended problem. The water balance that was provided to us by Sargent & Lundy was incomplete in some areas. Our initial work with the water balance showed that the numbers did not balance. Upon communicating this finding to our sponsor, we learned that two different sets of averages were used in calculating the water balance. There were also miscellaneous streams that were not in use. Because researching these functions was beyond the scope of our IPRO, we made a decision to neglect these streams in our final calculations. One specific problem that occupied much of the end of the semester was evaluating the costs of a HERO system. High Efficiency Reverse Osmosis, as its name suggests, is a refinement of previously existing reverse osmosis technology. While traditional Reverse Osmosis, RO, can recover 40 to 60 percent of the water from a waste stream, it was claimed that HERO could reach efficiencies up to 95%, while remaining cheaper than traditional RO. This would seem to make it a perfect fit for our problem. However, since HERO is a relatively new technology, less than a decade old, we had trouble finding sources that would give detailed design equations or other information that would help us evaluate the price of using it in the system. The information we did find was not consistent with our other research, giving an unusually low price estimate. Since we could not find information we considered reliable, we were not able to recommend HERO; therefore, we designed our system using traditional RO. We gave the best recommendation we could with given established information, but this meant that newer technologies were left unevaluated.

10. Recommendations

The best way to understand a complex field such as elimination of power plant waste in a short time is to split into focused research groups, but each group must have clearly established goals, and must have a leader willing to evaluate the group's progress, including a timeline with milestones and expected results. Although this will almost certainly change, continually evaluating your goals helps to give you perspective on your progress. There must also be continuous communication between groups, and vital topics must be presented to the entire team.

For well established processes such as reverse osmosis, our best source of information for implementation details and costs were books that had sections that emphasized design equations, such as *Perry's Chemical Engineers' Handbook.*   Since our project was solely research based, we did not have a good way to evaluate more recent technologies. Having a line of communication with someone in the power generation or wastewater elimination industry would definitely be beneficial.

11. References

Perry's Chemical Engineers' Handbook. 8th Edition.

Babcock, J. and C. Wilcox. *Steam: Its Generation and Uses. 4th Edition*

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12. Resources

Our team of 11 students of various disciplines successfully completed this project by putting in more than 400 hours of work outside of scheduled class time. To do this, we had to ensure a cohesive work environment. We spent part of our budget on team-building sessions. Often during these sessions the group became more open to their fellow peers and their ideas. These events were crucial in providing the basis of a good team structure to ensure that project work was done effectively and efficiently. Also, part of our budget was spent travelling to a local coal-fired power plant, Midwest Generation's Crawford Station. Here, the members in attendance got a first-hand look at the scope of our IPRO and were able to get a better grasp on the objective. Finally, the last portion of our budget was used on presentation research materials. Our group bought a copy of *Steam: Its Generation and Uses* by Babcock and Wilcox to assist in our project. These books and articles were crucial when finding design equations and analyzing the efficiency and effectiveness of the systems we chose.

13. Acknowledgements

The IPRO team would like to acknowledge all of our fellow peers who were a part o IPRO 302. We would also like to acknowledge Sunish Shah from Midwest Generation for setting up the tour of the power plant at Crawford Station. The class advisors of this project, Dr. Myron Gottlieb and Professor Don Chmielewski also played a crucial role in the success of our IPRO and deserve to be acknowledged. Finally, our liaison from our sponsor, Diane Martini from Sargent & Lundy provided crucial support when our team encountered setbacks as discussed in the report. We would also like to thank the IPRO office for processing our group's reimbursements from our team's expenditures and guiding us along the journey of this project.