PROPOSAL FOR:

WERC ENVIRONMENTAL DESIGN CONTEST:

CONTROLLING VOC EMISSIONS FROM PRODUCED WATER RECYCLING

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ABBREVIATIONS

bbl	**B**arrel
CAPEX	**Cap**ital **Ex**penses
EnE	**En**vironmental **E**ngineering
ENG	**Eng**ineer
EPA	**E**nvironmental **P**rotection **A**gency
ESP	**E**xperimental **S**afety **P**lan
FE	**F**undamentals of **E**ngineering
GCMS	**G**as **C**hromatography-**M**ass **S**pectrometry
INT	Engineering **Int**ern
ORP	**O**xidation **R**eduction **P**otential
OPEX	**Op**erational **Ex**penses
PE	**P**rofessional **E**ngineer
PW	**P**roduced **W**ater
SENG	**S**enior **Eng**ineer
SOP	**S**tandard **O**perating **P**rocedure
SPOT	**S**alinity, **p**H, **O**RP, **T**urbidity
STEM	**S**cience, **T**echnology, **E**ngineering, and **M**ath
TEA	**T**echno-**E**conomic **A**nalysis
TECH	Lab **Tech**nician
VOCs	**V**olatile **O**rganic **C**ompounds
WERC	**W**aste-Management **E**ducation and **R**esearch **C**onsortium
UV-VIS	**U**ltra**v**iolet–**Vis**ible Spectroscopy

1.0 PROJECT UNDERSTANDING

This is a proposal for a project to create a design concept and bench-scale model for a treatment process to remove Volatile Organic Compounds (VOCs) from produced water (PW).

1.1 PROJECT PURPOSE

The goal of this project is to compete in the 32nd Waste-Management Education and Research Consortium (WERC) Environmental Design Contest at New Mexico State University. The specific task to complete for the competition is to design a treatment method and create a bench-scale model to remove VOCs from oil and gas produced water and provide clean, recycled water for reuse without releasing the VOCs into the atmosphere prior to treatment.

1.2 PROJECT BACKGROUND

The WERC environmental design competition began in 1991. At this competition, students can utilize their acquired skills to solve an engineering problem as a project engineer. This student-based activity is completed by the showcase of a bench-scale model, report, and presentation. This allows students to grow skills such as professional project participation, teamwork, and the ability to solve real-world environmental problems [1].

The WERC competition requires the submission of an Experimental Safety Plan, Preliminary Report, and Technical Report prior to the in-person aspects of the competition. The in-person portion of the competition includes a presentation and demonstration of the bench-scale model constructed by the team which is used to test the treatment process's ability to remove VOCs. The final intention of the model is for it to be able to be scaled up for use in a full-scale facility that can handle 50,000 bbl/day as a closed system. For the purposes of this project, VOCs will be represented by the presence of toluene. At the competition, testing for the presence of toluene in the treated water will be done using either Liquid Chromatography with Ultraviolet-visible spectroscopy (UV-VIS) detection for toluene or gas chromatography-mass spectrometry (GCMS). To abide by state laws, VOCs in the water are limited to 2 tons per year based on the potential to emit.

VOCs are a common pollutant found in by-product water from oil and gas operations. There are currently PW recycling processes in place, but US states are proposing to limit VOC levels in PW recycling based on the potential to emit, which does not consider the actual VOCs emitted into the atmosphere but only what is present in the aqueous phase. VOC levels in raw produced water can be anywhere from >10 ppm to >100 ppm. The PW solution to be tested is a synthetic sample of produced water based on water characteristics of PW from the Delaware shale play. The exact mixture recipe is given by the WERC Competition. The Delaware Basin, shown in Figure 1-1, where the shale play resides is a basin known for its large oil fields and is located in West Texas and southern New Mexico [2]. The most prominent PW practices involve the storage and recycling of PW for reuse in hydrofracturing.

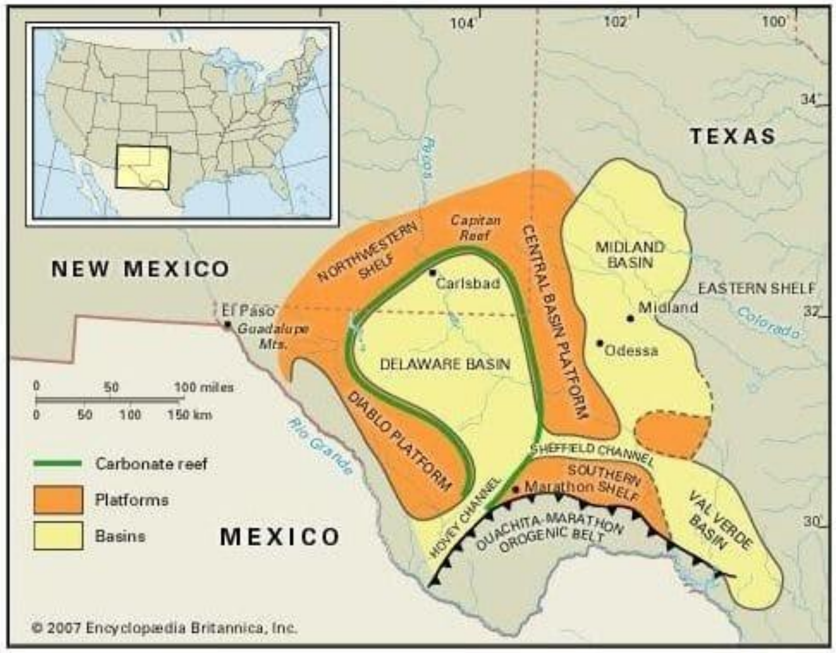


FIGURE 1-1: DELAWARE BASIN SITE MAP

1.3 TECHNICAL CONSIDERATIONS

Technical considerations include any technical analysis or design method that will be utilized in this project. Some technical aspects to consider include the following: [3]

Volatile Organic Compound Treatment Technology Analysis: A detailed analysis of several relevant technologies will need to be completed to choose the best VOC treatment method. Some technologies that may be analyzed include activated carbon, air stripping, reverse osmosis, and oxidation-reduction. These technologies and others may be conceptually analyzed and/or tested in a laboratory to determine their effectiveness. The competition specifies that the target concentration of toluene in the effluent water is 2 parts per million [3], so the goal of the treatment technology analysis will be to find technologies that have the potential to achieve this level of removal.

Bench-Scale Model Design: The bench-scale model will be designed based on the selection of a treatment method for VOC removal and the necessary components for influent water storage, effluent water storage, and pipes and pumps needed to move the water through the treatment process. Materials and parts for the bench-scale model will be selected and sourced with the intention of minimizing the cost while also creating a high-quality and safe product. The model will also be created with mobility in mind since it must be transported to the competition. When the treatment method is selected, a process flow diagram will be created to show how the PW sample will flow through the system. Before construction begins, a technical drawing will need to be created of the model based on the process flow diagram to show all the dimensions and parts that will be utilized.

Bench-Scale Model Testing: The bench-scale model will be prototyped and tested in a laboratory setting. The primary contaminant that will be tested for post-treatment is toluene. However, pH, turbidity, salinity, ORP, oil, and particle size will also be tested [3]. This analysis will be completed using standardized methods.

Hydraulics Analysis: The design of the system's hydraulics will be important as the model will need to process and treat produced water. Calculations will need to be done to analyze energy, head losses, and flow rates through each part of the system. This is done to make design choices such as pump selection, sizing of pipes and tanks, and determining the optimal pipe material.

Design of conceptual facility model: The design of the full-scale facility model will be done using a flow diagram and bench-scale production drawings. The flow diagram will include all the processes and information needed to begin a construction drawing, although a construction drawing is not part of the scope of this project. To fabricate a full-scale treatment plant, the flow diagrams can be scaled up and new flow and removal rates calculated.

Techno-Economic Analysis: This analysis requires calculating the costs associated with the construction of a full-scale PW facility. This should include both upfront capital costs (CAPEX) as well as operational costs (OPEX). Ideally, this design will minimize costs while still being able to treat to the desired concentration. An analysis will be required to determine what components are needed to run a full-scale facility that is based on the conceptual model. This should include staffing considerations, consumable materials, waste disposal, industrial natural gas, and electricity consumption for a facility based on the conceptual full-scale design at a 50,000 bbl/day treatment rate.

1.4 POTENTIAL CHALLENGES

This project has the potential to encounter several problems. One of the potential issues is the progression of the COVID-19 pandemic during this project. If the spread of COVID-19 increases, it could hinder lab access, decrease the quality of communication, and cancel the in-person aspect of the WERC competition altogether. This challenge is out of the team's control, but measures can be taken to prepare for different end scenarios.

Another potential challenge is the budget for the fabrication of the bench-scale model. Limited funding is available for materials and equipment, so the design of the bench-scale model will need to take this into account. If funding for the project becomes an issue, there is the possibility of fundraising to increase the budget.

One potential problem related to lab testing is the availability of testing equipment. The environmental lab at Northern Arizona University may not have all the testing equipment needed to determine VOC levels, so the equipment might need to be acquired or another lab utilized for certain tests.

All these potential challenges will be considered beforehand so that if they are encountered during the project, their impacts can be minimized.

1.5 STAKEHOLDERS

Northern Arizona University (NAU) Engineering Department: The successful creation of a VOC treatment method and entry into the 32nd WERC Environmental Design Competition in Las Cruces, New Mexico, would reflect positively on the NAU Environmental Engineering (EnE) department.

NGL Water Solutions: Task 5 of the WERC competition has been proposed and sponsored by NGL Water Solutions. A successful project would benefit them directly and give a potential solution to their proposed problem.

Oil/gas drilling companies & produced water treatment/storage facilities in and around the Delaware Basin: A successful project would benefit oil and gas companies in and around the Delaware Basin area that use hydrofracking techniques. The recycled PW would be able to be reused for fracking without using substantial amounts of new water. This will also help to meet oil production needs and decrease the freshwater demand required for oil fracking. An ideal solution could be applied to PW holding facilities to improve cost efficiency as well as meet environmental regulations for VOCs in both water and air by limiting the potential to emit.

Delaware Basin community: This treatment method will help reduce volatile organic compounds in local water sources and the surrounding ambient air, protecting the communities in and around the Delaware Basin from prolonged exposure to elevated levels of both VOCs and ground-level ozone. Reduction of these pollutants will create positive trends in the environment by limiting harmful effects on sensitive vegetation and ecosystems. Human health-related to the lungs and general respiratory system that are being aggravated due to poor air quality should also see an improvement. Utilizing the VOC treatment method at full scale will require the employment of several workers from the neighboring vicinity. Additionally, local drilling companies will see a reduced need for freshwater if their produced water can be reused. This will reduce overall process costs in the Delaware Basin's oil and gas industries.

2.0 SCOPE OF SERVICES

The scope of services for the WERC Competition project requires the completion of nine tasks. All tasks are necessary for the successful completion of the project and describe the process needed to construct a bench-scale model and design a conceptual full-scale process to remove VOCs from PW.

2.1 TASK 1.0: COMPETITION PREPARATION

The team will prepare to compete in the 2022 WERC Design Competition and prepare future laboratory analysis procedures.

2.1.1 TASK 1.1: COMPETITION REGISTRATION

Complete online registration by December 31, 2021, to register for the competition. The pre-approval process will be completed by the client. Each team member will then apply on the WERC website.

2.1.2 TASK 1.2: OBTAIN LABORATORY ACCESS

Laboratory access will be obtained according to the requirements detailed in NAU Standard Operating Procedure (SOP) 001A. NAU Environmental Engineering (EnE) lab and/or alternate lab training will be done to gain access to the labs and equipment.

2.1.2.1 TASK 1.2.1: NAU ENE LAB RAPID REQUEST FORM

An initial rapid request form will be submitted to the NAU EnE Laboratory manager to begin the process of gaining lab access. The initial document will include general details of the project including the project objective and team members. The Rapid Request Form also includes a description of the source of funding for the project.

2.1.2.2 TASK 1.2.2: LABORATORY PLANNING DOCUMENT

A detailed experimental plan will be submitted to the NAU EnE Laboratory manager that includes specific details about the experimentation including items such as planned lab activities, types of samples to be collected, methods of analysis, hazards associated with the testing, wastes generated, equipment that will be used, and applicable safety training needed.

2.1.3 TASK 1.3: SHORT COURSE ENROLLMENT

Enrollment in Environmental Safety Plan (ESP) Short Course as well as the Techno-Economic Analysis (TEA) Short Course.

2.2 TASK 2.0: ANALYZE TREATMENT OPTIONS

The overall design for a treatment method that removes VOCs from produced water will be determined in this step.

2.2.1 TASK 2.1: TREATMENT RESEARCH

Multiple existing treatment methods will be found and evaluated based on defined technical parameters.

2.2.1.1 TASK 2.1.1: LITERATURE REVIEW

Existing literature will be reviewed for VOC treatment concepts including, but not limited to, biofilters, membrane filters, and absorption/adsorption filter technologies. 10 to 15 potential treatment methods will be selected for further evaluation from the literature based on the team's engineering judgement.

2.2.1.2 TASK 2.1.2: DETERMINE CRITERIA FOR DECISION

A decision matrix will be created to define the parameters for the evaluation of the 10-15 treatment methods researched in task 2.1.1. Constraints and criteria will include both technical and practical considerations. This matrix will be used to select 3-5 potential treatment methods.

2.2.2 TASK 2.2: PRELIMINARY EXPERIMENTS

Preliminary experiments and testing will be performed on the 3-5 potential treatment methods from task 2.1.2 to inform research and selection of the single most effective treatment method. These experiments will be analyzed to determine the removal efficiency of VOCs along with treatment time to select the best treatment option.

2.2.2.1 TASK 2.2.1: CONDUCT EXPERIMENT PLANNING

Experimental procedures as well as quality assurance and control measures will be written. VOC testing will not be done according to the methods specified by WERC but by a testing method available to complete in the EnE lab. The materials needed for testing will also be obtained including PW sample ingredients and treatment process materials.

2.2.2.2 TASK 2.2.2: CONDUCT EXPERIMENTS

Preliminary experiments will be conducted for the 3-5 potential treatment methods according to the methodology determined in task 2.2.1. Toluene concentrations will be the only parameter tested at this point. A Gas Chromatography-Mass Spectrometry (GCMS) will be used to test the toluene concentrations.

2.2.2.3 TASK 2.2.3 SAMPLE ANALYSIS

The sample analysis at this stage will involve looking at the sample results from the GCMS testing for initial and final toluene concentrations. The initial and final toluene concentrations will be compared to each other to determine the removal efficiency of the process and whether or not the concentration goal of 2 parts per million specified by the competition is met. The experiment durations will also be examined to determine how long it took to achieve satisfactory toluene removal. The samples analyzed in the GCMS will also be compared to samples tested with known concentrations to assess the accuracy and reliability of the testing methods.

2.2.3 TASK 2.3: SELECTION OF BEST TREATMENT PROCESS

The best treatment technology to use in the bench-scale model will be selected based on data gathered from the literature research and preliminary tests done in task 2.2.2. The decision matrix created in task 2.1.2 will also be used to ensure the selected technology meets the defined constraints and criteria.

2.3 TASK 3.0: BENCH-SCALE MODEL DESIGN

The development and design of a bench-scale model will be completed. This will potentially include modeling treatment methods using unconventional materials.

2.3.1 TASK 3.1: PROCESS FLOW DIAGRAM

A process flow diagram will be developed to show the treatment process from the influent to the effluent of the bench-scale model prototype.

2.3.2 TASK 3.2: PARTS AND MATERIALS SELECTION AND SOURCING

Determination of which materials will be used for the fabrication of the bench-scale model and material sources will be identified. This will include materials that act as filters, material for pipes, and provisional pumps modeled by gravity. Parts and materials will be selected to ensure the model can be transported to the competition.

2.3.3 TASK 3.3: PROCESS DESIGN

A detailed process design will be drawn up to explain and clearly lay out every part of the treatment process. This design will include sizing, influent and effluent conditions, material types, as well as an identification of the waste stream generated.

2.3.4 TASK 3.4: DRAWING PRODUCTION

The final design will be drawn to scale for fabrication of a bench-scale model in AutoCAD including all materials, dimensions, flow rates, volumes, concentrations, and other design parameters.

2.4 TASK 4.0: BENCH-SCALE MODEL FABRICATION AND TESTING

The team will fabricate a functional and testable prototype to yield laboratory results and complete several iterations of testing and re-design of the prototype to produce a high-quality product.

2.4.1 TASK 4.1: FABRICATION AND TESTING

This task will involve the fabrication of the bench-scale model according to the design created in task 3.4. The parts and materials obtained in task 3.2 will be used for fabrication.

2.4.2 TASK 4.2: POST-TREATMENT SAMPLE TESTING

After the fabrication of the bench-scale model, the team will conduct laboratory testing to determine the VOC removal efficiency of the design.

2.4.2.1 TASK 4.2.1: QA/QC PROCEDURE

A general quality assurance plan will be created, then specific quality control sampling procedures will be defined to promote high-quality sample testing results.

2.4.2.2 TASK 4.2.2: VOC TESTING

Complete the (GCMS) SW846-8260 or 8021 or Liquid Chromatography with (UV-VIS) detection tests for toluene concentrations.

2.4.2.3 TASK 4.2.3: ADDITIONAL ANALYSIS

The WERC competition requires additional testing for PW characteristics outside of VOC concentration. These tests include the salinity, pH, oxidation/reduction potential, and turbidity (SPOT) tests as well as the EPA static oil sheen test and a visual test for settled solids.

2.4.3 TASK 4.3: MODEL REDESIGN

The results from previous tasks will be used to make improvements to the bench-scale model and treatment design. After the changes have been implemented, the water will be re-tested according to task 4.2. This task may be repeated for several iterations until a satisfactory model has been created.

2.5 TASK 5.0: FULL-SCALE DESIGN

A full-scale PW recycling facility will be conceptualized to complete the Techno-Economic Analysis of a full-scale project. This design will be based on the team's bench-scale model and flow process but scaled up to a size that could treat 50,000 bbl/day of PW.

2.5.1 TASK 5.1: BENCH-SCALE MODEL SCALING

The full-scale conceptual design will be based on the design choices made for the bench-scale model. A new flow process diagram will need to be created, incorporating the most key aspects of the bench-scale mode. The analysis of generated waste streams should also be considered. This is done to have a more comprehensive understanding of the operational cost of the facility.

2.5.2 TASK 5.2: HYDRAULIC ANALYSIS

The hydraulic analysis for the treatment design will consist of pipe flow systems, head loss, flow measurement devices, and all associated parameters.

2.5.2.1 TASK 5.2.1: TANK DESIGN

Tanks will be designed based on the baseline treatment flow rate and retention needs.

2.5.2.2 TASK 5.2.2: PIPE DESIGN

Piping for the treatment process will be determined by cost-effectiveness, friction factors, maintenance costs, and durability.

2.5.2.3 TASK 5.2.3: PUMP SELECTION

Pumps for the treatment process will be selected based on the energy needs, head loss, and flow rate of the system. Since this project is not based on a specific location, elevation heads will take assumed values.

2.6 TASK 6.0: TECHNO-ECONOMIC ANALYSIS

The cost and feasibility for implementation of the PW treatment process will be analyzed.

2.6.1 TASK 6.1: SHORT COURSE ATTENDANCE

As mentioned in task 1.3, the team will have enrolled in two short courses. Attending and completing these short courses will provide valuable information in the completion of both the environmental safety report as well as the techno-economic analysis report.

2.6.2 TASK 6.2: ECONOMIC ANALYSIS

This task will determine the costs of construction and operation for the implementation of the full-scale conceptual treatment process.

2.6.2.1 TASK 6.2.1: CONSTRUCTION COST

Costs will be determined for construction of the large-scale PW treatment plant.

2.6.2.2 TASK 6.2.2: OPERATION COST

Operation costs for operating the full-scale treatment plant over time will be determined. This includes the cost of labor, maintenance, and the replacement of equipment.

2.6.2.3 TASK 6.2.3: LIFECYCLE COST

The most cost-effective way to own, operate, maintain, and dispose of captured products for the full-scale treatment plant will be determined.

2.6.3 TASK 6.3: TECHNO ANALYSIS

The technical performance of the treatment process is analyzed.

2.6.3.1 TASK 6.3.1: REMOVAL EFFICIENCY

The design will be analyzed for removal efficiency based on the bench-scale model to determine the practicality of application and usability of water post-treatment.

2.6.3.2 TASK 6.3.2: PROCESS REQUIREMENTS AND INVESTMENT

Should the conceptual PW plant be considered for construction at a specific location, the information needed for possible implementation among existing infrastructure at that location will be assessed.

2.7 TASK 7.0: IMPACTS ANALYSIS

The impacts of building and operating a plant to treat VOCs in a full-scale treatment process attached to an oil production facility will be assessed.

2.7.1 TASK 7.1: ECONOMIC IMPACTS

Assuming complete implementation of a full-scale PW recycling facility, an analysis of how the local economy might be affected will be carried out. This analysis should cover local wages, gas prices, electricity rates, water rates, food prices, and anything else that may be affected by a PW recycling facility. This analysis will also include how employment opportunities may be created in the area by the construction and operation of the facility.

2.7.2 TASK 7.2: ENVIRONMENTAL IMPACTS

This analysis will consider how the project will affect the environment, including overall environmental quality, plant and animal life, and local ecosystems.

2.7.3 TASK 7.3: SOCIAL IMPACTS

The analysis of social impacts will be completed to consider the positive and negative impacts on the health and wellness of people that may have been affected by VOC emissions in the area. This analysis will consider recreation, employment opportunities, and overall contribution to the surrounding community.

2.8 TASK 8.0: DELIVERABLES

All submittals to the competition as well as CENE 486 are listed here. CENE 486 requires submittals displaying progress in making the final report, presentation, and website.

2.8.1 TASK 8.1: COMPETITION DELIVERABLES

The WERC competition has its own set of deliverables that must be completed. A list of each required deliverable as requested by the WERC competition will be provided below.

2.8.1.1 TASK 8.1.1: EXPERIMENTAL SAFETY PLAN

This is a required deliverable for the competition and is the first document that is due. This item is meant to address the safety aspects of handling raw produced water and volatile chemicals. The safety issues that are associated with both a full-scale design as well as the bench-scale model should be addressed in this safety plan.

2.8.1.2 TASK 8.1.2: PRELIMINARY REPORT

The preliminary report is due before the final technical report. This preliminary report should describe the proposed solution to the problem statement so that the team can receive early feedback on the initial plans. this will help produce both a better technical report as well as a better bench-scale demonstration.

2.8.1.3 TASK 8.1.3: TECHNICAL REPORT

The technical report should provide an overview of the whole project. The report must fully outline the problem and propose a detailed solution including all aspects of both a full-scale model as well as the bench-scale model. The report should address items mentioned in the competition problem statement, design considerations, evaluation criteria, and the 2022 WERC team manual.

2.8.1.4 TASK 8.1.4: PRESENTATION AND COMPETITION

All teams that attend the competition are required to do a presentation on their treatment solution. A well-thought-out and concise presentation should be prepared with slides. In addition to this formal presentation, a demonstration of the team’s bench-scale model will be conducted at the competition. The design should be able to handle up to 5-gallons of the synthetic solution provided by the competition and demonstrate that the design can be scaled up to a 50,000 bbl/day full-scale PW recycling facility and reduce the toluene concentration to the desired level. During the demonstration, the team will need to have a poster board presentation that elaborates on the design of the bench-scale model as well as the full-scale concept.

2.8.2 TASK 8.2: 30% SUBMITTAL

The 30% submittal contains the 30% Design Report and 30% Presentation as well as a prototype bench-scale model in the beginning stages of lab testing. Tasks 1 and 2 will be complete. Task 3 will be in progress, specifically task 3.4 drawing production.

2.8.3 TASK 8.3: 60% SUBMITTAL

The 60% submittal contains the 60% Design Report and 60% Presentation with corrections from the 30% submittal. The final bench-scale model will be made, and lab testing will be complete. Tasks 3, 4, and 5 will be complete.

2.8.4 TASK 8.4: 90% SUBMITTAL

The 90% submittal contains the 90% Design Report, a draft website with corrections from the 60% submittal and a draft final presentation. At this point, the competition will be completed and logged accordingly. All tasks and subtasks will be complete by this point.

2.8.5 TASK 8.5: 100% SUBMITTAL

The final submissions of CENE 486 include a final report, presentation, and a website. The entirety of the team's project will be displayed in all 3 of these submissions.

2.9 TASK 9.0: PROJECT MANAGEMENT

Project management ensures that the project is executed correctly, on time, and within budget. To these ends, we will conduct relevant project meetings, resource management, and other activities.

2.9.1 TASK 9.1: MEETINGS

A binder will be kept documenting every team meeting, client meeting, grading instructor meeting, and technical advisor meeting. This will detail the important points of discussion as well as the plan of action for upcoming tasks and deliverables.

2.9.2 TASK 9.2: SCHEDULE MANAGEMENT

For both class deliverables and competition deadlines, it will be necessary to keep careful track of what tasks need to be in progress or completed at all times for both requirements.

2.9.3 TASK 9.3: RESOURCE MANAGEMENT

The team must be aware of pricing and materials for the bench-scale model to stay within the budget that the university has provided. In addition, the team must manage time wisely to stay on schedule. The project will require lab hours, construction time, and design work, so the time spent on these activities will be tracked along with expenses. This will ideally keep the project within the staffing and resources budget.

2.10 EXCLUSIONS

The following items will not be implemented in the project.

The team will not be responsible for the drawings or construction of a full-scale PW plant. While a conceptual design for a full-scale treatment plant will be created and considered for the purposes of the techno-economic analysis, construction drawings will not be created, construction plans will not be made, and a plant will not be constructed under any circumstances.

The bench-scale model for produced water treatment will be used to treat mixtures containing toluene as the primary volatile organic compound present. This is the target of the designed treatment method. Therefore, anything other than toluene including oil and solids will not be actively treated.

The focus of this project and competition is the treatment of volatile organic compounds. Therefore, the design efforts and budget will be applied towards the bench-scale model, not other structures or buildings that could be related to VOC treatment processes at a larger scale.

While the WERC competition will have teams create PW samples similar in composition to that of the Delaware Basin, no specific location has been or will be determined for the implementation of the bench-scale model or full-scale plant design.

3.0 SCHEDULE

The purpose of the schedule is to ensure the team stays on track and moves along at the pace necessary to meet deadlines and confirm all tasks are completed. The Gantt chart schedule is in Appendix A.

3.1 OVERVIEW

The total duration of this project will be 134 days based on a 5-day work week with the project start date on 10/25/21 and the final date on 4/28/22. The start date is earlier than the beginning of the spring 2022 semester because the project requires preparation in advance to ensure enough time for multiple iterations of testing and redesign.

3.2 MAJOR TASKS AND DELIVERABLES

The competition will take place on April 10-13 so completion of major tasks must be completed prior to the normal CENE 486 capstone class dates. Major tasks include obtaining laboratory access, deciding on the bench-scale model design, fabricating the bench-scale model, and designing the conceptual full-scale model. This is because they will take the most time and are critical to the completion and continuation of the project. While these tasks will require a substantial amount of time from the team, they will only be a part of the major deliverables that are due to both the competition as well CENE 486. Some of the major deliverables that the team will need to complete on time prior to the competition are the technical report and the completed bench-scale model. These tasks will be due before the end of the spring semester and will encompass most of the team's technical work. Other major deliverables that the team needs to complete are the benchmark submittals for CENE 486 as well as the final 100% report and presentation.

3.3 CRITICAL PATH

A Gantt chart with the complete list and display of project tasks, durations, and predecessors can be found in Appendix A. The critical path of the project can be found in the figure, highlighted in red. The critical path shows the path necessary follow to ensure the team does not fall behind on deadlines and can complete the project. The critical path is based on the dependencies of the tasks. This path has been automatically chosen based on the team’s major tasks and deliverables. The team plans to keep up with the schedule by completing each major task and deliverable on time and not falling behind on due dates. This will apply even to the tasks that have been manually assigned due dates by the team, unlike the major deliverables that have hard due dates that are required by the competition and school. In addition to this, some tasks will have lag times built-in (such as weekends and holidays) that will allow the team to do additional work and get caught up if needed.

4.0 STAFFING PLAN

4.1 STAFF POSITIONS

Senior Engineer (SENG): The senior engineer manages the team and its budget in addition to overseeing the project work and deliverables. This position manages the project and reviews technical work. It requires a career full of previous experience to ensure that the team is producing professional quality work. Qualifications include

- 5 or more years of engineering experience
- Licensed PE
- Bachelor’s degree in STEM or engineering related field (higher degrees preferred)

Engineer (ENG): The engineering position requires a lot of technical knowledge as well as previous experience in the field. This position performs much of the more involved technical design work that requires previous experience. Qualifications include

- 2-3 years of engineering experience
- Bachelor’s degree in a STEM or engineering related field
- Completed FE
- Proficient in any relevant software/programs (e.g., AutoCAD and Excel)

Lab Technician (TECH): This position is responsible for many of the experiments and testing that is required by the team. This position should have a lot of previous experience running experiments as well as be familiar with standard lab procedures and methods. Qualifications include:

- 1-3 years of engineering laboratory experience
- GED or associate degree required, bachelor’s degree in STEM-related field preferred
- Fundamental knowledge of lab equipment and experimental methods

Engineering Intern (INT): This position requires the least amount of previous experience as the work done by this team member is not very technically involved. Qualifications include:

- GED or associate degree required, pursuing bachelor’s degree in engineering related field
- Some technical knowledge or proficiency with office application/software
- Willingness to learn and have good verbal and written communication skills

4.2 STAFFING SUMMARY

The senior-level engineer will have the least number of hours at 68 hours (about 9 days) because their role in this project is to review and make suggestions for improvement throughout the process. The engineering role will have approximately 268 hours (about 6 and a half weeks) of work for a project completion because most of the heavy design work and overall idea for the project will come from the engineer. The intern, who works below the engineer, will have many hours devoted to this project as well because their tasks will involve doing many of the technical tasks directed by the engineer. The lab technician will be working about 304 hours because a lot of time in this project is spent in the lab building and testing the bench-scale model prototypes. Table 4-1 below shows a summary of the work hours for each position and each major task. For a full list of all tasks and subtasks as well as the work hours for each one, see Appendix B.

TABLE 4-1: TASK STAFFING HOURS

Task Name	SENG (hours)	ENG (hours)	TECH (hours)	INT (hours)	Task Total Hours
Task 1: Competition Preparation	2	0	40	17	59
Task 2: Analyze Treatment Options	6	60	76	48	190
Task 3: Bench-Scale Model Design	8	40	12	48	108
Task 4: Bench-Scale Model Fabrication and Testing	6	40	152	60	258
Task 5: Full-Scale Design	4	44	0	32	80
Task 6: Techno-Economic Analysis	6	20	0	26	52
Task 7: Impacts Analysis	6	12	0	0	18
Task 8: Deliverables	18	16	12	24	70
Task 9: Project Management	12	36	12	36	96
Total Hours	68	268	304	291	931

Table 4-2 below shows a summary of the total hours each position is expected to spend on the project. This data is pulled from table 4-1.

TABLE 4-2: STAFFING HOURS SUMMARY

Staffing Hours Summary	
Position	**Hours**
Senior Engineer	68
Engineer	268
Lab Technician	304
Engineering Intern	291
Total Hours	**931**

5.0 COST OF ENGINEERING SERVICES

The total cost for PurePro Purification Co. engineering services for this project is $61,259 as shown in table 5-1. Based on the labor hours in table 4-2 above and standard salaries which include overhead and benefits, the costs of personnel are shown in table 5-1, section 1.0. The total cost for travel is also included in section 2.0 of table 5-1 and has been determined based on standard NAU travel costs given per mile [4]. Additionally, the lab space rental, lab testing and bench-scale model construction supplies, and cost of testing are included in sections 3.0, 4.0, and 5.0 respectively. Most of the testing can be completed in the NAU EnE lab, but several quality assurance tests will be conducted by a contracted third-party lab to verify results as shown in part 5.0 of the table.

TABLE 5-1: COST OF SERVICES

Cost of Engineering Services				
Personnel	***Classification***	***Hours***	***Rate ($/hr)***	***Cost ($)***
	Senior Engineer	68	$ 180	$ 12,240
	Engineer	268	$ 80	$ 21,440
	Lab Technician	304	$ 50	$ 15,200
	Engineering Intern	291	$ 25	$ 7,275
1.0 Personnel Cost				**$ 56,155**
2.0 Travel			***Cost Per ($)***	***Cost ($)***
Transportation	1 Van 4-Day Trip		$65/day	$ 260
Mileage	868 mi Roundtrip		$0.38/mile	$ 330
Hotel	3 Rooms 3 Nights		$100/night	$ 900
Per Diem	5 People 4 Days		$19/day	$ 380
Travel Cost				**$ 1,870**
3.0 Lab Facilities				
	ENE Lab 10 Days		$100/day	$ 1,000
Lab Cost				**$ 1,000**
4.0 Supplies				
	See Itemized Supplies List			$ 1,984
Supplies Cost				**$ 1,984**
5.0 Subcontract				
	Analytical, 5 samples		$50/sample	$ 250
Subcontract Cost				**$ 250**
Total Cost				***$ 61,259***

Table 5-2 below shows a breakdown of the specific costs of materials in section 4.0 of table 5-1. Since the bench-scale model has not been designed yet a specific breakdown of these materials is unavailable, but the goal is to keep these costs under $1600.

TABLE 5-2: ITEMIZED SUPPLIES LIST

Item	Quantity	Cost
Sea Salt (Sprout's)	240 g	$10
DI Water	1500 mL	$30
TrueSyn 200 I	184 mg	$150
Toulene	100 mg	$45
Fine-grade AZ Test Dust	100 mg	$80
Sodium Bentonite	100 mg	$70
Bench-scale construction materials		$1,600
Total Cost		**$1,985**

6.0 REFERENCES

[1] *The 32nd Environmental Design Contest –The Ultimate Engineering Capstone Event*, New Mexico State University, 2021.

[2] J. Parshall, *All 'Going Right' With Delaware Play*, Journal of Petroleum Technology, 2018.

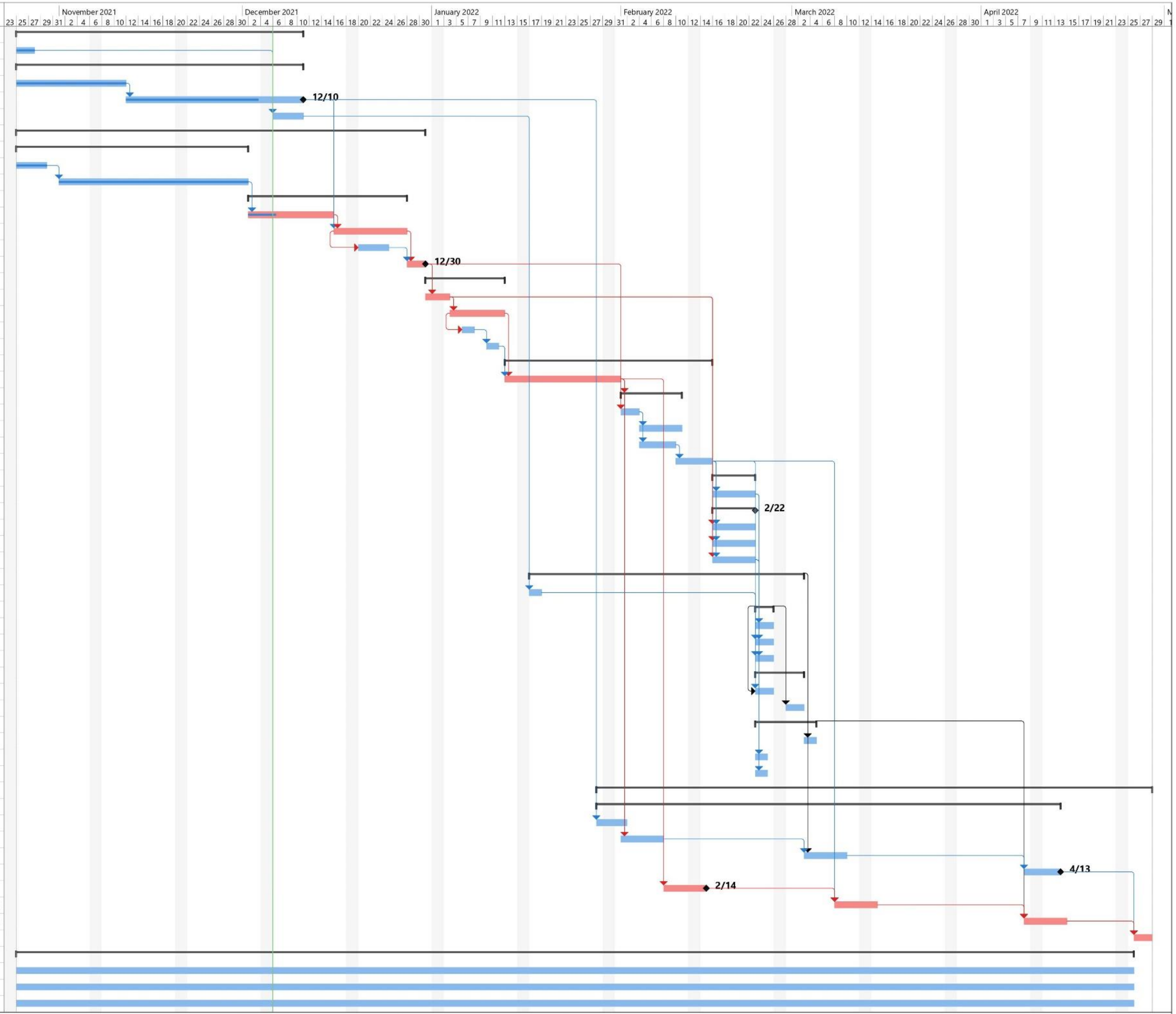
[3] L. NGL Water Solutions and Jade Dragon, *Task 5. Controlling VOC Emissions from Produced Water Recycling*, New Mexico: NGL Water Solutions, 2021.

[4] Northern Arizona University, "Vehicle Rental," 2021. [Online]. Available: https://in.nau.edu/university-transit-services/fleet-services/vehicle-rental/. [Accessed 9 November 2021].

APPENDICES

APPENDIX A: GANTT CHART

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Task 1: Competition Preparation**	**35 days**	**Mon 10/25/2**	**Fri 12/10/21**	
2	Task 1.1: Competition Registration	3 days	Mon 10/25/2	Wed 10/27/2	
3	**Task 1.2: Obtain Laboratory Access**	**35 days**	**Mon 10/25/2**	**Fri 12/10/21**	
4	Task 1.2.1: NAU EnE Lab Rapid Request Form	14 days	Mon 10/25/2	Thu 11/11/2	
5	Task 1.2.2: Laboratory Planning Document	21 days	Fri 11/12/21	Fri 12/10/21	4
6	Task 1.3: Short Course Enrollment	5 days	Mon 12/6/21	Fri 12/10/21	2FS+27 days
7	**Task 2: Analyze Treatment Options**	**49 days**	**Mon 10/25/2**	**Thu 12/30/2**	
8	**Task 2.1: Treatment Research**	**28 days**	**Mon 10/25/2**	**Wed 12/1/21**	
9	Task 2.1.1: Literature Review	5 days	Mon 10/25/2	Fri 10/29/21	
10	Task 2.1.2: Determine Criteria for Decision	23 days	Mon 11/1/21	Wed 12/1/21	9
11	**Task 2.2: Preliminary Experiments**	**18 days**	**Thu 12/2/21**	**Mon 12/27/2**	
12	Task 2.2.1: Conduct Experiment Planning	10 days	Thu 12/2/21	Wed 12/15/2	10
13	Task 2.2.2: Conduct Experiments	8 days	Thu 12/16/2	Mon 12/27/2	12,5
14	Task 2.2.3: Sample Analysis	5 days	Mon 12/20/2	Fri 12/24/21	13SS+2 days
15	Task 2.3: Selection of Best Treatment Process	3 days	Tue 12/28/2	Thu 12/30/2	14,13
16	**Task 3: Bench Scale Model Design**	**9 days**	**Fri 12/31/21**	**Wed 1/12/2**	
17	Task 3.1: Process Flow Diagram	2 days	Fri 12/31/21	Mon 1/3/22	15
18	Task 3.2: Parts and Materials Selection and Sourcing	7 days	Tue 1/4/22	Wed 1/12/22	17
19	Task 3.3: Process Design	2 days	Thu 1/6/22	Fri 1/7/22	18SS+2 days
20	Task 3.4: Drawing Production	2 days	Mon 1/10/22	Tue 1/11/22	19
21	**Task 4: Bench-Scale Model Fabrication and Testing**	**24 days**	**Thu 1/13/22**	**Tue 2/15/22**	
22	Task 4.1: Fabrication and Testing	13 days	Thu 1/13/22	Mon 1/31/22	20,18
23	**Task 4.2: Post-Treatment Sample Testing**	**8 days**	**Tue 2/1/22**	**Thu 2/10/22**	**22**
24	Task 4.2.1: QA/QC Procedure	3 days	Tue 2/1/22	Thu 2/3/22	15
25	Task 4.2.2: VOC Testing	5 days	Fri 2/4/22	Thu 2/10/22	24
26	Task 4.2.3: Additional Analysis	4 days	Fri 2/4/22	Wed 2/9/22	24
27	Task 4.3: Model Redesign	4 days	Thu 2/10/22	Tue 2/15/22	26
28	**Task 5: Full-Scale Design**	**5 days**	**Wed 2/16/2**	**Tue 2/22/22**	
29	Task 5.1: Bench-Scale Model Scaling	5 days	Wed 2/16/22	Tue 2/22/22	27
30	**Task 5.2: Hydraulic Analysis**	**5 days**	**Wed 2/16/2**	**Tue 2/22/22**	
31	Task 5.2.1: Tank Design	5 days	Wed 2/16/22	Tue 2/22/22	17,27
32	Task 5.2.2: Pipe Design	5 days	Wed 2/16/22	Tue 2/22/22	17,27
33	Task 5.2.3: Pump Selection	5 days	Wed 2/16/22	Tue 2/22/22	17,27
34	**Task 6: Techno-Economic Analysis**	**33 days**	**Mon 1/17/2**	**Wed 3/2/22**	
35	Task 6.1: Short Course Attendance	2 days	Mon 1/17/22	Tue 1/18/22	6FS+25 days
36	**Task 6.2: Economic Analysis**	**3 days**	**Wed 2/23/2**	**Fri 2/25/22**	
37	Task 6.2.1: Construction Cost	3 days	Wed 2/23/22	Fri 2/25/22	33
38	Task 6.2.2: Operation Cost	3 days	Wed 2/23/22	Fri 2/25/22	33,35
39	Task 6.2.3: Lifecycle Cost	3 days	Wed 2/23/22	Fri 2/25/22	33,35
40	**Task 6.3: Techno Analysis**	**6 days**	**Wed 2/23/2**	**Wed 3/2/22**	
41	Task 6.3.1: Removal Efficiency	3 days	Wed 2/23/22	Fri 2/25/22	36SS,27
42	Task 6.3.2: Process Requirements and Investment	3 days	Mon 2/28/22	Wed 3/2/22	36
43	**Task 7: Impacts Analysis**	**8 days**	**Wed 2/23/2**	**Fri 3/4/22**	
44	Task 7.1: Economic Impacts	2 days	Thu 3/3/22	Fri 3/4/22	34
45	Task 7.2: Environmental Impacts	2 days	Wed 2/23/22	Thu 2/24/22	29
46	Task 7.3: Societal Impacts	2 days	Wed 2/23/22	Thu 2/24/22	29
47	**Task 8: Deliverables**	**65 days**	**Fri 1/28/22**	**Thu 4/28/22**	
48	**Task 8.1: Competition Deliverables**	**54 days**	**Fri 1/28/22**	**Wed 4/13/2**	
49	Task 8.1.1: Experimental Safety Plan	3 days	Fri 1/28/22	Tue 2/1/22	5FS+34 days
50	Task 8.1.2: Preliminary Report	5 days	Tue 2/1/22	Mon 2/7/22	22
51	Task 8.1.3: Technical Report	5 days	Thu 3/3/22	Wed 3/9/22	50,34
52	Task 8.1.4: Presentation and Competition	4 days	Fri 4/8/22	Wed 4/13/22	51FS+21 days
53	Task 8.2: 30% Submittal	5 days	Tue 2/8/22	Mon 2/14/22	22FS+5 days
54	Task 8.3: 60% Submittal	5 days	Tue 3/8/22	Mon 3/14/22	27,53FS+15 days
55	Task 8.4: 90% Submittal	5 days	Fri 4/8/22	Thu 4/14/22	43,54FS+18 days
56	Task 8.5: 100% Submittal	3 days	Tue 4/26/22	Thu 4/28/22	55FS+7 days,52
57	**Task 9: Project Management**	**131 days**	**Mon 10/25/2**	**Mon 4/25/2**	
58	Task 9.1: Meetings	131 days	Mon 10/25/2	Mon 4/25/22	
59	Task 9.2: Schedule Management	131 days	Mon 10/25/2	Mon 4/25/22	
60	Task 9.3: Resource Management	131 days	Mon 10/25/2	Mon 4/25/22	



Project: WERC Gantt Chart NEW
Date: Mon 12/6/21

Task	▬	Summary	┏━┓	Inactive Milestone	◇	Duration-only	▬	Start-only	[	External Milestone	◆	Critical Split	┈
Split	┈	Project Summary	┏━┓	Inactive Summary	┏━┓	Manual Summary Rollup	▬	Finish-only	]	Deadline	⇩	Progress	▬
Milestone	◆	Inactive Task	▭	Manual Task	▬	Manual Summary	┏━┓	External Tasks	▬	Critical	▬	Manual Progress	▬

APPENDIX B: STAFFING AND WORK HOURS

Task Name	SENG (hours)	ENG (hours)	TECH (hours)	INT (hours)	Task Total Hours
Task 1.0: Competition Preparation	2	0	40	17	**59**
Task 1.1 Competition Registration	0	0	0	1	
Task 1.2 Obtain Laboratory Access	2	0	40	8	
Task 1.2.1 NAU EnE Lab Rapid Request Form	0	0	0	8	
Task 1.2.2 Laboratory Planning Document	0	0	40	0	
Task 1.3 Short Course Enrollment	0	0	0	8	
Task 2: Analyze Treatment Options	6	60	76	48	**190**
Task 2.1 Treatment Research	0	40	0	48	
Task 2.1.1 Literature Review	0	0	0	40	
Task 2.1.2 Determine Criteria for Decision	0	40	0	8	
Task 2.2 Preliminary Experiments	2	12	70	0	
Task 2.2.1 Conduct Experiment Planning	0	4	20	0	
Task 2.2.2 Conduct Experiments	0	4	30	0	
Task 2.2.3 Sample Analysis	0	4	20	0	
Task 2.3 Selection of Best Treatment Process	4	8	6	0	
Task 3: Bench-Scale Model Design	8	40	12	48	**108**
Task 3.1 Process Flow Diagram	2	4	0	24	
Task 3.2 Parts and Materials Selection and Sourcing	2	12	12	0	
Task 3.3 Process Design	2	12	0	12	
Task 3.4 Drawing Production	2	12	0	12	
Task 4: Bench-Scale Model Fabrication and Testing	6	40	152	60	**258**
Task 4.1 Fabrication and Testing	2	0	60	60	
Task 4.2 Post-Treatment Sample Tests	2	0	92	0	
Task 4.2.1 QA/QC Procedure	0	0	12	0	
Task 4.2.2 VOC Testing	0	0	40	0	
Task 4.2.3 Additional Analysis	0	0	40	0	
Task 4.3 Model Redesign	2	40	0	0	
Task 5: Full-Scale Design	4	44	0	32	**80**
Task 5.1 Bench-Scale Model Scaling	2	8	0	32	
Task 5.2 Hydraulic Analysis	2	36	0	0	
Task 5.2.1 Tank Selection	0	12	0	0	
Task 5.2.2 Pipe Selection	0	12	0	0	
Task 5.2.3 Pump Selection	0	12	0	0	
Task 6: Techno-Economic Analysis	6	20	0	26	**52**
Task 6.1: Short Course Attendance	0	2	0	2	

Task Name (continued)	**SENG (hours)**	**ENG (hours)**	**TECH (hours)**	**INT (hours)**	**Task Total Hours**
Task 6.2: Economic Analysis	2	6	0	24	
Task 6.2.1 Construction Cost	0	2	0	8	
Task 6.2.2 Operation Cost	0	2	0	8	
Task 6.2.3 Lifecycle Cost	0	2	0	8	
Task 6.3: Techno Analysis	4	12	0	0	
Task 6.3.1 Removal Efficiency	0	8	0	0	
Task 6.3.2 Process Requirements and Investment	4	4	0	0	
Task 7: Impacts Analysis	6	12	0	0	**18**
Task 7.1: Economic Impacts	2	4	0	0	
Task 7.2: Environmental Impacts	2	4	0	0	
Task 7.3: Societal Impacts	2	4	0	0	
Task 8: Deliverables	18	16	12	24	**70**
Task 8.1 Competition Deliverables	2	0	12	0	
Task 8.1.1 Experimental Safety Plan	2	2	0	3	
Task 8.1.2 Preliminary Report	2	2	0	3	
Task 8.1.3 Technical Report	2	2	0	3	
Task 8.1.4 Presentation and Competition	2	2	0	3	
Task 8.2 30% Submittal	2	2	0	3	
Task 8.3 60% Submittal	2	2	0	3	
Task 8.4 90% Submittal	2	2	0	3	
Task 8.5 100% Submittal	2	2	0	3	
Task 9: Project Management	12	36	12	36	**96**
Task 9.1: Meetings	12	12	12	12	
Task 9.2: Schedule Management	0	12	0	12	
Task 9.3: Resource Management	0	12	0	12	
Subtotal Hours	68	268	304	291	
Total Hours	931				