

Building a Robust Full-scale Design through Safety Evaluation: A WERC Case Study

Juanita Miller and Ginger Scarbrough
New Mexico State University

Undergraduate engineering capstone projects are an important workforce development tool that help institutions meet key ABET Student Outcomes that may be difficult to address in core engineering courses, particularly Outcome 2, which emphasizes societal and contextual factors such as health, safety, and environmental impacts. These outcomes can be strengthened when students build functioning prototypes of their designs. The WERC Environmental Design Contest demonstrates how capstone programs can deepen students' understanding of these factors by pairing bench-scale system development with a formal safety review.

The contest mirrors the engineering Request for Proposals (RFP) process, providing students with a near-real-world design experience while reinforcing critical thinking about full-scale project safety. By applying a structured safety process to their physical models, students develop a deeper understanding of hazard identification, mitigation, and real-world operations, leading to meaningful improvements in their full-scale designs. These findings highlight the value of integrating formal safety analysis into capstone programs to better prepare students for professional engineering practice.

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Corresponding Author: Ginger Scarbrough, gscarbro@nmsu.edu

Background

The WERC Environmental Design Contest, founded in 1991, is an annual national competition held in person in Las Cruces, NM. It brings together undergraduate engineering students, industry, and government agencies to address real-world environmental challenges. Teams design innovative solutions related to Water, Energy, Resources, and Climate (WERC), in response to Requests for Proposals (RFPs) developed by industry and agency partners.

The program was established at New Mexico State University (NMSU) in collaboration with the U.S. Department of Energy (DOE) and engineers from across the United States. Since its inception, the program has engaged 94 U.S. and 8 international undergraduate institutions, fostering engineering design skills among 1051 teams and 6510 students. In 2026, 105 students, divided among 21 teams from 9 universities, participated in the contest.

Drawing on years of experience guiding engineering students through the design process, we have identified two priorities for capstone education across all engineering disciplines: 1) providing real-world experience in a complete design process; and 2) engaging students in applying environmental, health, and safety (EHS) considerations that are essential for practicing engineers to understand.

Meeting ABET Student Outcome 2 through intentional safety design

The ABET Student Outcomes were developed to guide faculty in preparing students for professional practice by aligning student experiences with real-world career needs. As the accreditation board states on its website, “With ABET quality assurance, students, employers, and the communities we serve can be confident that a program or credential meets the standards needed to prepare graduates for a global workforce.”¹

WERC’s safety protocols provide universities with a structured mechanism for achieving ABET Student Outcomes—particularly Outcome 2: “an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.”¹ Consistent with this goal, 79% of students in WERC’s 2026 post-contest survey agreed or strongly agreed that the contest increased their understanding of the importance of health, safety, environmental, societal, and economic factors in engineering design.

WERC’s approach—applicable to a wide range of capstone programs—is to engage students in building working prototypes within a structured safety framework. As students identify and mitigate hazards in their physical models, they translate abstract principles

into concrete decisions, strengthening their ability to incorporate safety into full-scale designs and preparing them to enter the global workforce, as envisioned by ABET Outcome 2.

This multi-step approach is grounded in the safety protocols used in engineering firms, and introduces students to terms they will encounter in their careers. Through a structured sequence of activities, faculty can guide their students through:

1. Core principles of engineering safety;
2. The completion of the Experimental Safety Plan (ESP), sometimes referred to as a Safety Plan;
3. Iterative ESP feedback to address hazards that teams may have overlooked;
4. Guidelines for handling potentially hazardous materials;
5. Procedures for disposal of waste materials;
6. Formal commissioning of experiments for operation;
7. Formal decommissioning of experiments and final waste disposal after the project concludes.

Implementing the ESP process in capstone courses

We propose that all universities use a formal ESP process to guide students in developing a benchtop project. Our ESP process is based on years of history guiding students in laboratory research at NMSU² and has been refined through the WERC Contest.

WERC uses the ESP as a bridge between bench-scale demonstrations and full-scale systems, as many hazards identified during modeling are similar to those in full-scale systems. The ESP prompts students to evaluate a range of safety considerations, including chemical hazards, electrical risks, mechanical integrity, structural stability, operational limits, emergency shutdown procedures, waste management, hazard mitigation, and Safety Data Sheets (SDS). These steps promote critical thinking that evolves throughout the design process, with key concepts carried into final design reports.

Sections of the WERC ESP and their descriptions are shown in Table 1 as a guide for organizations to develop an ESP tailored to their needs.

TABLE 1. EXPERIMENTAL SAFETY PLAN OUTLINE

Experimental Safety Plan	
Sections	Description
Experimental Scope	Explain the experiment concept, including all equipment and chemicals to be used

Process Flow or System Diagram	Illustrate the experiment using a block diagram or flow chart
Normal Operations, Startup and Shutdown Procedures	Provide step-wise procedures for the work performed. Indicate if any equipment will run after hours. Provide procedures for both startup and shutdown. Propose mitigations for any high hazards
Emergency Shutdown Procedures	Define a shutdown procedure in the event of an emergency
Waste Management Procedures	Describe waste generated, leftover feedstock, and recommended management methods.
Hazard Identification and Mitigation	Complete the Hazard Assessment Checklist and recommend mitigations
Safety Data Sheets	Provide SDS documents for each chemical and material, including common household & craft products

Each year, WERC engages up to 32 teams, led by 15-20 faculty advisors from across the U.S. and Canada. Undergraduate teams select from among six open-ended design challenges (the “Tasks”). WERC guides the safety process through the use of the ESP and the project deliverables. Not only does the safety officer review the ESPs prior to the onsite event, but the judges also evaluate the team’s approach to managing and mitigating the potential hazards of their bench- and full-scale designs.

Dr. John Pardue, an LSU faculty advisor who has brought teams to the contest for over 20 years, has found that most students participating in WERC have never before been required to consider safety issues for a full-scale, real-world situation. This is supported by the 2026 post-contest survey, which found that 76% of students agreed or strongly agreed that, as a result of the design contest, their knowledge and understanding of how to develop and follow an ESP had improved.

Case study: 2026 contest entries and the ESP process

Here we present an example of a 2026 task in which two teams—Brigham Young University (BYU) and Louisiana State University (LSU)—competed. This case study demonstrates how the safety analysis process informed and refined each team’s concept as they progressed from a bench-scale model to a full-scale final design.

Teams were challenged to design an innovative enhanced-evaporation process for managing produced water (PW) in oil-producing regions such as the Permian Basin, where large volumes of PW are generated alongside oil extraction. The goal was to cost-effectively maximize evaporation, reduce reliance on costly disposal methods, and design a system, both at full- and bench-scale, capable of evaporating PW at the rate of 500,000 bbl/day (21 million gallons/day) while maintaining a reserve of 1 MM bbl of PW, in the event of unexpected operational shutdowns.³

At the competition, WERC provided teams with lab-created PW. The recipe (Table 2) contained constituents representative of PW in the Delaware Shale oil field.

TABLE 2. SYNTHETIC PRODUCED WATER CONSTITUENTS

Constituent	Amount per liter of Aqueous Solution
Sea Salt	120 g
True Syn 200 1 (oil phase)	200 mg
Fine Arizona 1 est Dust	50 mg
Sodium bentonite drilling clay	50 mg
Tap water	Add to create 1 liter of solution

Table 3 outlines the task's deliverables. We will focus on Item #8, the safety aspects of handling the raw PW.

TABLE 3. ENHANCED EVAPORATION PROJECT DELIVERABLES

Item	Deliverable Description
1	Review the literature; develop an innovative design using synthetic PW chemistry (Table 2). Consider either continuous or batch treatments.
2	Develop an enhanced evaporation design that manages Permian Basin PW at a flow rate of 500,000 bbl/day and stores 1 MM bbl for fracking operations.
3	Include a Process Flow Diagram (PFD). Include all mass and energy balances.
4	Extrapolate full-scale evaporation rates from the bench-scale prototype. Compare with a 500,000 bbl/day flow rate.
5	Report the residence time needed for the evaporation of a given volume of PW. Discuss how variations in input flow rates will affect the system's performance.
6	Identify and address the fate of any waste products: salt drift, solids disposal, etc.

7	Present a Techno-Economic Analysis for the full-scale system.
8	Address safety aspects of handling the raw produced water, volatiles, and any final products. Safety issues for the full-scale design and the bench-scale demonstration should be addressed in both the written report and the Experimental Safety Plan (ESP).

Each of the two teams took a very different approach to enhanced evaporation, but many of their safety concerns were similar due to the constituents in PW and their hazards to people and the environment.

The BYU team pumped PW across aluminum and fiberglass mesh sheets to increase the evaporative surface area, recognizing that evaporation is diffusion-limited and depends on the available surface area (Fig. 1).

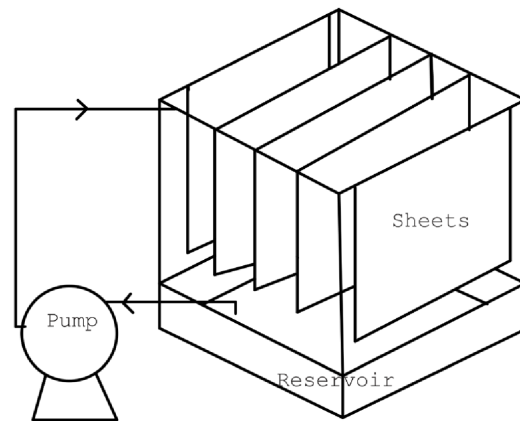


Fig. 1. BYU's enhanced evaporation design concept.

The LSU team added surfactant to the PW and aerated the mixture under heat lamps, noting that a full-scale system would require more and larger pumps and compressors, along with a robust heat source to provide energy for evaporation (Fig. 2).

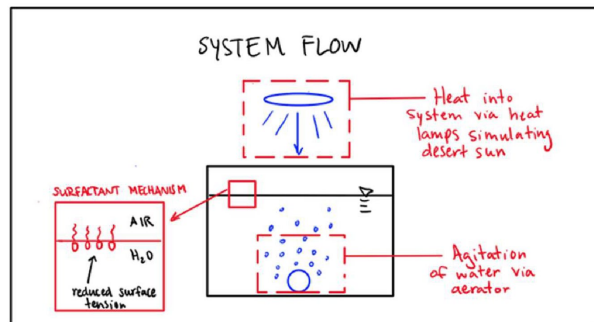


Fig. 2. LSU's enhanced evaporation design concept.

Teams' safety assessments

In their ESPs, both teams noted the following bench-scale hazards.

- Model testing would need to run for multiple hours and would stretch into an unattended overnight operation.
- Electrical equipment near the large volumes of test solution could create a hazard. To mitigate this risk, they required secondary containment to capture leaks or line breaks.

BYU's team reported these additional hazards:

- The PW solution is corrosive and requires special handling.
- The bench-scale model assembly requires sharp tools.

LSU's student team reported these additional hazards:

- Pinch and caught-between hazards from the prototype platform. They proposed mitigation through careful apparatus placement.
- A high center of gravity hazard, to be mitigated by applying weights to keep the platform upright.

Full-Scale design hazards

Each team submitted its full-scale design 4 weeks after WERC's safety officer reviewed their ESP. In their full-scale design, both teams summarized relevant OSHA, EPA, and other state and federal regulations and explained how each applied to their specific designs.

Between the submission of the ESP and their final full-scale designs, both teams demonstrated a deeper understanding of hazard and mitigation strategies, addressing issues they had overlooked in the ESP phase and introducing significant design improvements.

For example, the BYU team extended the ESP framework to develop an Emergency Action Plan (EAP) for real-world operation, expanding their scope beyond the task requirements. They outlined plant emergency protocols, including chain of responsibility, communication procedures, evacuation plans, and emergency shutdown procedures. They outlined staff training and drills and developed a HazCom training program, covering hazard identification and labeling.

Similarly, LSU used information from the ESP to develop safe handling procedures for residual brine to reduce worker exposure and hazards. These included secondary containment, leak mitigation, cleanup procedures, and personal protective equipment for workers. During their hazard evaluation, they identified that atomized brine poses a risk to people and the environment. To mitigate the hazard, in their full-scale design, they proposed using low-intensity aeration to prevent mist formation. Their updated design addressed

ways to reduce worker exposure to slippery surfaces and corrosive water.

Conclusions and recommendations

Although this was likely the students' first experience addressing safety in a full-scale design, both teams demonstrated strong critical thinking aligned with ABET Student Outcomes. The ESP process prompted more thorough design analysis and led teams to exceed the task requirements by proposing detailed risk mitigation and operational protocols in their full-scale designs. Their consideration of impacts on the facility, its workers, and the general public reflects a deepened understanding of the critical role safety plays in facility operations.

These outcomes are not isolated. WERC's 2026 post-contest survey results showed that 76% agreed or strongly agreed they felt better prepared to address safety issues in full-scale engineering designs after completing the WERC safety process. This reflects measurable gains in students' ability across the broader cohort to address safety in full-scale engineering designs.

The survey results cited in this paper also reveal opportunities to strengthen student learning by ensuring that all team members engage more fully in the ESP process. Although WERC required every student to complete a 30-minute asynchronous course on preparing an ESP, active participation in developing each team's ESP varied, as teams often divided project responsibilities among members.

To increase engagement, future work will include interactive ESP reviews between WERC staff and all team members. These meetings will reinforce the importance of safety planning and its direct connection to the construction and operation of each team's design. Involving all team members in these discussions is expected to deepen engagement and further strengthen safety-related learning outcomes.

These findings highlight the value of structured safety integration in supporting ABET Student Outcomes and better preparing students for engineering practice.

References

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