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Pure Pals: Hydro Hug

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Abstract

Reusable water bottles are popularly used, yet bacterial contamination remains a rising health concern, with studies showing bottles harboring harmful bacteria. PurePals presents HydroHug, a 3-in-1 hydro filtration system integrating UV-C sterilization, reverse osmosis (RO) filtration, and a reusable filter adaptable to various bottles. This cost-effective, sustainable alternative ensures cleaner water on the go. Engineering analysis, including fluid dynamics, thermal performance, and filtration efficiency, validates its effectiveness. Our surveys show most users value UV self-cleaning filtration, identifying active, health-conscious consumers as the primary market. HydroHug balances portability, adaptability, and ease of use while addressing durability, battery life, and filtration speed. Future work will enhance material sustainability and filtration efficiency, ensuring HydroHug meets evolving consumer needs. This project bridges a gap in personal hydration technology, offering a high-quality, accessible water purification solution for modern users.

Keywords
3-in-1 Filtration System, UV-C Sterilization, Portable & Sustainable Water Purification.

1. Introduction
Reusable water bottles, such as Hydro Bottles, are widely used for keeping drinks cold or hot and have become increasingly popular, with sales growing by over 15% annually. (Claybourn, 2022) However, bacterial contamination is a significant concern associated with these bottles. Studies have shown that 83% of reusable water bottles harbor harmful bacteria and pose health risks, especially if bottles are not cleaned thoroughly and regularly. (Sun. 2017) To address this issue, our group has developed an innovative design incorporating three critical components for decontaminating and preventing bacterial buildup. Through extensive research, we identified the most effective materials, market trends, and the most common water filtration technologies to create a product that meets the needs of modern health-conscious consumers.

1.1 Objectives
While popular and environmentally friendly, reusable hydro water bottles often lack effective, integrated self-cleaning mechanisms. Studies have found that if not regularly cleaned, bacterial levels in these bottles may contain about 40,000 times more germs than a toilet seat (in some cases) and can contain up to 20.8 million CFUs, indicating significant bacterial contamination. (Claybourn 2022) This bacteria buildup in water bottles is concerning, as these microorganisms can increase in a moist environment, mainly when the bottles are used for extended periods without cleaning. Despite this, hydro water bottles are typically overlooked in hygiene, and more built-in technology is needed to maintain cleanliness. To address this problem, our approach aims to integrate a water filtration system with advanced UV-C light technology to sterilize water and clean the bottles' interiors. Research shows that UV-C light

can inactivate over 99.9% of common pathogens such as E. coli, Salmonella, and viruses, effectively neutralizing contaminants to make the water safe for consumption. (ZME Science, 2020) This approach promotes user-friendly, low-maintenance hygiene, allowing individuals to enjoy cleaner water on the go. The growing need for clean and accessible drinking water, especially in portable and reusable format, has driven innovation in water purification technology. Existing products like the LARQ Bottle and Crazy Cap, they have implemented UV-C technology to purify and sterilize bottles. However, these solutions are often restricted to specific bottle types, limiting users who need a versatile solution compatible with different bottles or containers, particularly in environments with uncertain access to clean water.

2. Literature Review

Filtered water bottles offer an eco-friendly solution, significantly reducing reliance on single-use plastic bottles, lowering carbon footprints, and minimizing plastic waste. These bottles provide users a cost-effective way to access purified water, contributing to sustainability efforts. However, most filters are built into proprietary bottles, meaning users cannot integrate them with other personal bottles. By creating a reusable filter that fits into various bottles, we can help reduce consumer costs while making a broader impact on environmental sustainability. Lee Bradley highlights the importance of filtered water in enhancing water quality and ingestion safety, as filters trap harmful elements like protozoan cysts, bacteria, and viruses. (Bradley 2024) Our reusable filter aims to provide an effective solution for improving water quality by eliminating contaminants often found in tap or untreated water. This technology ensures access to safe drinking water wherever needed, whether for everyday use or travel, underscoring the eco-friendly benefits of filtered bottles as a reliable hydration option. Hydro bottles have gained popularity for their aesthetic appeal, functionality, and ability to keep beverages hot or cold.

According to "The History of Hydros" (Mclean, 2020), Travis Rosbach's innovation was built upon early insulation technology dating back to the 1800s. Rosbach's application of vacuum insulation and BPA-free, high-quality stainless steel has set new standards for design and durability. These advancements in bottle design inspire our filter's development by emphasizing high-quality materials and insulation features, which will be essential for creating a durable, adaptable filter for various bottles. In the study of materials of the hydro flask and material for our design, the team came across bacterial pitting corrosion. Pitting corrosion is a localized form of metal deterioration that occurs due to environmental and microbial influences. The study *Pitting corrosion of carbon steel caused by iron bacteria* (Starosvetsky, 2001) is aimed to understand the corrosion behavior of carbon steel when it is exposed to water that has been contaminated with iron-oxidizing bacteria. A particular species in the study is called Sphaerotilus. The key finding in this research indicated that iron-oxidizing bacteria contribute to the formation of rust deposits which creates conditions that promote localized pitting corrosion.

The bacteria formed layered structures on the steel surface to develop the corrosion over time and accelerate its damage. Possible prevention methods include chemical control, water control, cathodic protection, and regular cleaning and maintenance of the bottle. The articles mostly focused on the development and mechanism of pitting corrosion but did not address prevention methods extensively. This article will benefit our design in understanding the ideal material and understanding the need for our product in reducing the contamination and corrosion of the personal water bottles. The article *Failure Analysis of Additively Manufactured Polyester Test Specimens Exposed to Various Liquid Media* (Carrete 2019) investigates the effects of liquid exposure on additively manufactured polyester specimens, specifically Polylactic Acid (PLA) and Polyethylene Terephthalate Glycol (PETG). This research examines using the five common liquid media; distilled water, apple cider vinegar, Mexican Coca-Cola, 200-proof ethanol, and distilled white vinegar. It examines how these liquids affect the mechanical properties and failure characteristics of PLA and PETG over a seven-day immersion period. Through the findings, it was concluded that PLA were more sensitive to ethanol and acidic solutions while PETG were particularly affected by water absorption. The article does not specify whether the PETG filament used in the study was food-grade, which differentiates it from the food safe PETG materials the team plans for our design. These articles offered insight into the possible testing of the material in our design.

The Water Research article (Samir, 2017) stresses the importance of user compliance and maintenance in water quality outcomes, noting that regular container cleaning, ideally every four months, can improve water quality and reduce harmful contaminants. To address this, our design includes a bottle cap filter that enhances purification and filtration, ensuring a safer drinking experience. This cap is interchangeable, accommodating a range of bottle types to meet the needs of modern consumers who prioritize convenience and functionality.

2.1 Reverse Osmosis (RO) Filtration Technology

John Woodward's research on reverse osmosis (RO) systems (Woodward, 2023) underscores their efficacy in removing up to 99% contaminants. RO systems are widely used due to their high purification quality across different settings. Our project incorporates a similar system by using multiple filtration stages within a compact, UV-embedded design. This RO integration will maximize filtration efficiency and help achieve zero-waste processing by recycling water within the filter system, making it an optimal choice for portable applications.

2.2 UV Light Disinfection

Traditional cleaning methods often need to catch up in disinfection. The Antimicrobe Resist Infect Control study (Woodward, 2023) explores UV-C and pulse-xenon light, demonstrating their effectiveness in reducing pathogens. These devices target vegetative bacteria and spores, proving more efficient and requiring less time than manual cleaning. By embedding UV technology in our filter system, we aim to enhance disinfection capabilities, achieving a double filtration approach for superior water quality.

2.3 The Gap in the Research

Current research covers various aspects relevant to our project but is mainly oriented toward large-scale applications. This limits the insights available for portable or small-scale use. We aim to bridge this gap by developing a compact, versatile, and user-friendly filtration system that combines RO and UV technology, catering to the public's need for accessible, high-quality water filtration for daily use.

2.4 Scope and Constraints

Our design considers key constraints inherent to hydro bottles, including size, material, and cost. For instance, Hydro Flask bottles come in sizes ranging from 12 oz to 124 oz, and their 24 oz standard size has a diameter of 2.85 inches and a height of 12.45 inches, (HydroFlask, 2020) whereas the 32 oz wide-mouth version has a diameter of 3.55 inches and a height of 11 inches (HydroFlask, 2020). These size variations indicate that a one-size-fits-all cap is not feasible. Additionally, the stainless-steel material used in hydro bottles ensures durability but can drive up costs, affecting users' willingness to invest in additional accessories. Our filter design will strive to balance functionality, compatibility, and affordability, addressing these constraints to maximize usability.

3. Methods

3.1 Early-Stage Testing and Prototypes

The early stages of prototype development came in the form of using cheap materials found at the dollar store to create a quick prototype of the idea the team had in mind. Testing and prototyping using dollar store materials is an effective and cost-efficient way to refine ideas before investing in expensive materials or manufacturing. Using this cost-effective experiment ensured that the dollar store materials allowed the team to test concepts without financial risk. This also allowed the team to create multiple iterations of a prototype at a fraction of the cost of high-end materials. One of the benefits in this approach was rapid prototyping. Due to these materials being affordable and widely available, the team quickly assembled and modified prototypes without worrying about wasting expensive resources. This process encouraged the team to think creatively, as all of the team members had a different idea on how the HydrHug should look like.

Also, working with inexpensive, everyday items forces you to think outside the box and find creative solutions to design challenges. As this testing and prototyping process is still in the early stages, the risk of failure in using expensive materials should be avoided at this stage. When prototyping with costly materials, people often hesitate to experiment. Cheap materials eliminate this fear, making it easier to test, fail, and improve. The team believed that functional testing should be executed to ensure clarity in our design before final testing and production begins. Even though dollar store materials may not be the final materials, they can still help test the function, form, and feasibility of a design before moving to high-end production. Testing availability is vital for brainstorming the design and because most dollar stores have a variety of materials, like glue to small mechanical parts, allowing for easy access to essential prototyping supplies.

3.2 The Next Phase of Testing and Potential Prototypes

In conclusion to the results the team came across, by reviewing the results from the first prototype, the team identified weaknesses, durability issues, or design flaws, this information was gathered as user feedback to understand usability and performance gaps. Now that these gaps have been identified, the design of the HydroHug can now begin to be finalized to begin the process of testing with the appropriate materials that relate to the final prototype. This will be done by replacing temporary materials with ones closer to the final product and by testing different material properties. The team has made several orders for the necessary components that will be integrated into the HydroHug, so therefore ensuring all parts work together as intended is important in the next phase of the testing process. The team will also consider ergonomics and user experience refinements once the initial prototype is created. Our CAD model has allowed the team to have preciseness in our early-stage prototypes. In the next phase implementation of the simulated tests done on Fusion360 will ensure the safety features of the prototype are executed properly.

After the early stage testing the team agreed on design changes based on testing results, this will continue by testing small refinements rather than overhauling the entire design at once to ensure optimization for efficiency, cost, and ease of production. By finalizing material sourcing and production methods, the team can begin transitioning into the manufacturing process. In *Figure 1*, our solid works design for the external housing portion of the design is shown. In *Figure 2*, you can see the design of the top cap, which holds all of our electrical components to enhance the UVC-led light. In *Figure 3,* is the filter that will be going in the bottom of the product to ensure the water is being filtered. In *Figure 4*, it displays a semi- transparent design implementing food-grade PETG and food-grade silicone to help with the realism of the conceptual design. These CAD models illustrate Hydro Hugs design, combining UV-C sterilization and filtration into a portable, modular water purification 3-in- 1 filter. The system is well-integrated, with each component serving a specific role in ensuring clean, safe drinking water.

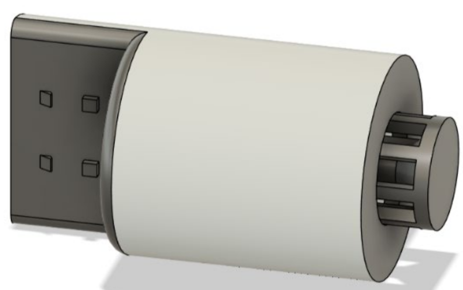

Figure 1. SolidWorks model of the UV-C Light Module Housing.

Figure 2. SolidWorks model of the cap of HydroHug.

Figure 3. SolidWorks model of filter/filter housing.

Figure 4. SolidWorks model of the conceptual design of HydroHug.

4. Data Collection

Creating an engineering design analysis for our 3-in-1 water filter involves breaking down the key aspects of the system into distinct categories. Here's an analysis for each component:

4.1 Thermal Analysis (refer to Figure 5)

Purpose: To ensure proper heat dissipation from the UVC-LED and evaluate the thermal compatibility of materials and components. Thermal analysis plays a pivotal role in our design process by allowing us to study materials properties and how they behave under various temperature conditions. As we develop a filtration system for reusable hydro water bottles, it's essential to maintain the desired temperature, to meet consumer's preferences.

Key Considerations: UVC-LEDs generate heat, which can affect performance and surrounding materials. Aluminum or copper heat sinks should be included near the UVC-LED to dissipate heat efficiently. Silicone gaskets and housing materials must withstand operating temperatures (up to 85°C for the UVC-LED).

Analysis Results: Thermal simulations show that heat from the UVC-LED stabilizes below 50°C during operation, ensuring user safety. Materials like quartz glass (UV-transmissive and heat-resistant) and UV-stable ABS or polycarbonate (for housing) can maintain structural integrity. Ensures the product temperature meets thermal properties and standards.

4.2 Fluid Dynamics Analysis (refer to Figure 6 and Figure 7)

Purpose: The analysis of fluid dynamics is vital to ensuring that water flows smoothly through the filter system without excessive resistance or pressure drop. As well as optimizing the flow rate and ensuring even distribution through the filtration and UVC system.

Approach: Simulations performed on Fusion 360 to model water flow through the filter and UVC-LED chamber. Here pressure drops across each filtration layer are analyzed as well as the impact on flow rate.
Design Adjustments: Optimize filter porosity and UVC chamber geometry to balance flow rate and filtration performance. Use flow regulators if simulations show excessive flow or turbulence that could reduce filtration efficiency.

Analysis Results: Ensure water flow rate remains between 0.5–1.0 liters/min, balancing usability and disinfection efficiency.

4.3 Filtration Efficiency Analysis

Purpose: An analysis of Filtration Efficiency validates the effectiveness of the filter in removing contaminants from the water, such as bacteria and other impurities.

Tests to Perform: To perform this analysis, it is important to evaluate the filter media's pore size and material properties and use simulation or empirical testing to measure filtration performance. Chemical Removal Efficiency: Test activated carbon for absorption of chlorine, VOCs, and odors. Particulate Removal Efficiency: Test hollow fiber membranes for removal of particles >0.2 microns. Bacterial Removal: Confirm UVC-LED eliminates 99.99% of bacteria and viruses.

Efficiency Metrics: Combined filtration and UVC treatment should achieve EPA standards for drinking water safety. Conduct experiments using contaminated water samples to measure pre- and post-treatment quality.

4.4 Material Selection and Compatibility

Purpose: Material Selection in the design is important because choosing materials that are safe for use with drinking water, durable, and resistant to corrosion or chemical reactions.

Selected Materials: Quartz glass for UVC-LED enclosure: High UV transmission and chemical resistance. Food-grade silicone: Seals and gaskets for flexibility and durability. UV-stable plastic (e.g., PETG or polycarbonate): Lightweight and strong housing for the filter. Activated carbon and hollow fiber membranes: Effective for chemical and particulate filtration.

Compatibility Testing: Materials must be non-reactive with water and resistant to UV degradation. Ensure adhesives or bonding materials for the LED and housing do not release harmful compounds under UV exposure.

4.5 Safety and Regulatory Compliance Analysis

Purpose: To evaluate compliance with industry standards for water purification and product safety.

Safety Features: Auto shut-off for the UVC-LED when the cap is open. Leak-proof design to prevent water from damaging electrical components. UV leakage prevents quartz housing and shielding.

Standards to Meet: NSF/ANSI 55: Certification for UVC water purification systems. EPA Standards: Effective microbial removal for safe drinking water.

Regulatory Testing: Verifying that all materials were FDA-approved for contact with drinking water and that the sterilization process does not produce harmful by-products. Validating UVC-LED wavelength at 260–280 nm for germicidal efficiency and test materials for BPA-free and toxin-free certification.

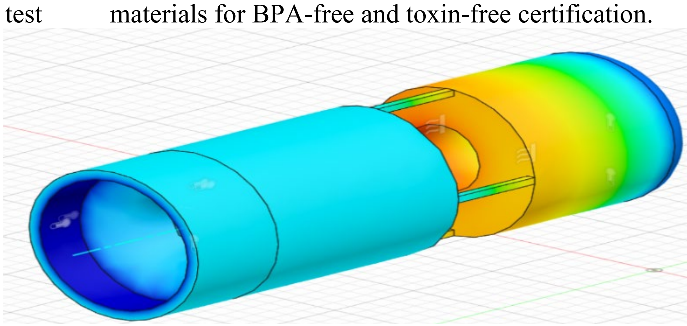

Figure 5. Thermal Analysis of the HydroHug via Fusion360.

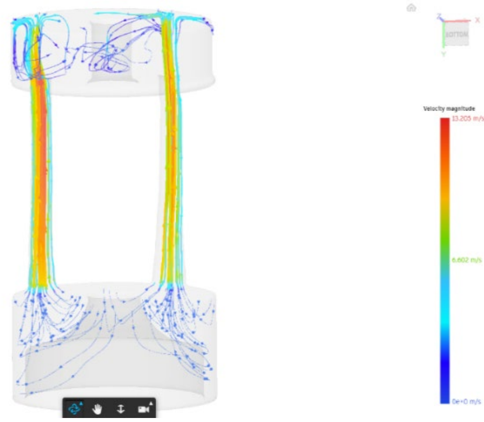

Figure 6 . Fluid Analysis throughout the HydroHug via Fusion360.

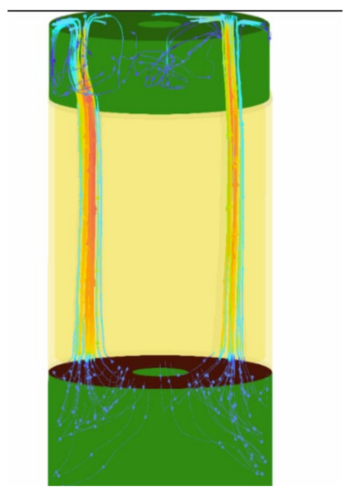

Figure 7 - Fluid Analysis within the HydroHug via Fusion360.

5. Results and Discussion

The integration of UV-C light filtration is common in other existing designs. Unlike competitors such as the LARQ Bottle and CrazyCap, which rely solely on UV-C sterilization, the HydroHug combines UV-C light with a multi-stage filtration system. This dual approach eliminates bacteria while also removing particulate matter, heavy metals, and odors, providing comprehensive purification. Compatibility Across Multiple Bottles Many high-end self-cleaning bottles, like LARQ, have built-in purification systems that only work with their proprietary bottles. The HydroHug is designed as a universal attachment, making it adaptable to different reusable bottles. The silicone grip ensures a secure fit across various bottle shapes and sizes. Enhanced Safety Features Incorporates auto shut-off mechanisms for the UV-C light to prevent overuse and potential harmful exposure. Use food-grade, BPA-free materials to ensure safety and compliance with health standards. Cost Efficiency & Sustainability Unlike proprietary designs requiring costly replacements, HydroHug offers replaceable filter cartridges, making it more affordable over time. Designed with recyclable and sustainable materials, contributing to eco-friendly practices. Improved User Experience Features a faster filtration process, maintaining optimal flow rates while ensuring effective sterilization. The modular design allows users to easily clean and replace components, unlike fixed systems. By combining advanced purification, universal adaptability, and enhanced safety, HydroHug presents a more effective, versatile, and user-friendly solution than existing self-cleaning water bottles.

6. Conclusion

Our 3-in-1 hydro filtration design prioritizes and emphasizes the importance of broader impacts by focusing on industry, society, and global sustainability efforts. HydroHug recognizes industries are moving towards a more sustainable future, and it's our commitment to drive these innovations of value to broader change. Health and safety are our number one priority, enhancing secure and reliable eco-friendly products for individuals to use. Our team understands the importance of embedding safety features to build trust and encourage users to use the product as effectively and efficiently as possible. Quality considerations are significant by providing user expectations and performance reliability over our product's intended lifespan. We are committed to using testing procedures that remove all contaminants, clean the bottle, and ensure safe drinking water without exposing the UV-C LED for long periods of time. Our design prioritizes user-friendly features with ease of maintenance, assembly, and durability. By shifting to a more sustainable future, we want to adopt sustainable packaging by reducing our carbon footprint and promoting good green practices. Furthermore, societal impacts are being implemented by encouraging individuals to make more environmentally conscious decisions. Our team is advocating for individuals to reduce plastic waste by implementing the use of reusable water bottles into their everyday lives.

The shift in behavior can be motivating and inspiring to prioritize a more sustainable future around different areas around the world. In regions where clean water is limited, our innovative design holds a valuable purpose by improving water quality and health choices. We are contributing to a more dependable solution for safe drinking water for the overall well-being of underserved regions. Additionally, HydroHug recognizes the crucial support needed in disaster relief scenarios, where clean water can often be hard to find. Our product can ensure individuals in affected areas have access to safe hydration through relief organization communities or emergency first responders distributing our product during the recovery period. This can help support the resilience of communities after facing disaster relief. Environmental aspects are significant because they impact the sustainability of our planet and will benefit society at large. Recognizing the importance of environmental aspects, Hydro Hug is committed to integrating eco-friendly materials, reducing waste, and decreasing our carbon footprint. Utilizing the use of recycled products ensures longevity and durability by minimizing Muda and being 100% recyclable. This approach encourages other companies to adopt sustainable practices for a positive environmental aspect. HydroHug's 3-in-1 filtration design has a comprehensive commitment to ensuring positive change in broader impacts by advocating for new standards of eco-friendly practices. Through integrating sustainable materials, we are inspiring a movement towards a healthier, safer, and sustainable planet.

Acknowledgements

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Biographies

Sepideh Abolghasem is an associate professor in the Department of Manufacturing Systems Engineering and Management at California State University at Northridge. Prior to this appointment, she was an associate professor in the Department of Industrial Engineering at the University of Los Andes, Bogotá, Colombia. She earned her B.Sc. Degree in Industrial Engineering from Sharif University of Technology, Tehran, Iran and her M.Sc. and Ph.D. degrees in Industrial Engineering from University of Pittsburgh. Her main research interests span the integration of the disciplines of Operations Research and Materials Science. Much of her work has been focused on machining the manufacturing process where she tries to improve the understanding of the interrelationships among the process parameters and the microstructure of the materials. Recently, she has been working on the application of machine learning techniques combined with simulation for material properties prediction.

Miguel Angel Amaya is a graduating student from California State University, Northridge, earning a degree in Engineering Management. Throughout their academic journey, they have developed expertise in project management, process optimization, and leadership within technical environments. With a passion for innovation and efficiency, they aspire to apply their skills in industries such as manufacturing, technology, or consulting.

Sirirat 'Lilly' Chonboonwatana, is a graduating senior in Engineering Management at California State University, Northridge. They possess strong proficiency in software tools such as SOLIDWORKS, Arena, AutoCAD, and @RISK. Lilly is eager to pursue a career in supply chain logistics, where they can apply their skills and knowledge to drive operational efficiency and innovation.

Amani Evans, an Engineering Management Technology major at California State University, Northridge. Amani has a strong interest in sustainability and technology and loves to combine her knowledge and skills with making impactful solutions. This project reflects Amani's passion for clean technology, hands-on design, and social impact.

Rhani Kahn, a first-generation college student from Inglewood, CA, is an Engineering Management Technology major at California State University, Northridge. With experience in construction and engineering through roles at Fluor Engineering and JMH Engineering & Construction, she specializes in piping materials, project management, and industrial design. Rhani's technical skills extend to AutoCAD, Six Sigma, and isometric drawings, while her creative side thrives in graphic design, marketing, and content creation. Passionate about both innovation and artistry, she blends analytical problem-solving with a love for astronomy, art, and design. As a leader in CSUN's student housing and engineering mentorship programs, she excels in teamwork, mentorship, and event coordination. Driven by a vision for the future of technology and infrastructure, Rhani continues to build, design, and explore, while always seeking new ways to merge creativity with engineering.

Destiny Garcia Palomares is a dedicated student in the College of Manufacturing Systems Engineering and Management with an interest in innovations and modern engineering practices, and project management. Destiny has excelled in her academic pursuits, and her engagement in rigorous courses. Beyond her studies, Destiny participates in collaborative projects and is known for her organization in projects and forward-thinking mindset. Her ambition and dedication position her as a strong future engineer.