NitroCool

Carson Hull, Hayden Jones, & Ryan Perkins
Shawnee Mission School District
Center for Academic Achievement
Engineering Development & Design

Table of Contents

Element A

Presentation of Justification of the Problem

Problem Statement:

High school and club athletes across the U.S. have faced an alarming rise in heat-related injuries and deaths, with the National Federation of State High School Associations(NFHS), National Library of Medicine(NIH), and medical professionals reporting exertional heat stroke as the leading cause of preventable death in athletics. This problem occurs during practices and competitions in hot outdoor environments where temperatures often exceed 90–100°F, most commonly on summer afternoons. It has been documented from 1982 to the present, impacting thousands of student-athletes nationwide each year.

Objective Statement:

Develop optimal cooling apparel for in-game wear by athletes, leveraging gaseous cooling to safely and effectively prevent heat-related illnesses and injuries in teenagers.

Problem Summary/Justification Statement:

Heat-related illnesses are a growing threat to student athletes as rising temperatures and longer heat waves increase risks during outdoor sports. Adolescents are especially vulnerable because their bodies adapt poorly to heat, resulting in nearly 9,000 annual cases of heat illness among U.S. high school athletes (EPA). Recent reports show 42 heat-related injuries and 18 deaths among athletes, with football and soccer being the most affected (NFHS, 2023). Research finds cooling vests provide good benefits, while pulse-point cooling and rapid treatments like ice-water immersion remain more effective (Casa et al., 2007; Ergodyne, 2024). Existing cooling technologies demonstrate the concept is feasible, but safety concerns, especially with substances such as liquid nitrogen, highlight the need for closed, secure systems (Vortec, 2025; NPR, 2021). A Google Forms survey of about 50 high school athletes in the Shawnee Mission School District found that 68% of athletes have experienced dizziness or lightheadedness, 35% have vomited, and 8% have lost consciousness. Overall, the evidence suggests an urgent need for safer and more effective cooling solutions that prioritize prevention and athlete safety.

Problem Focus:

The primary focus is on reducing body temperature, preventing heat-related injuries, and maintaining a low profile whilst active. Our best solution will need to be able to quickly reduce the body's core temperature, accounting for the level of activity and the outdoor temperature. In doing so, it must not cause any additional symptoms or issues for users, thereby reducing problems and not creating new ones. Our problem is meant for use on the bench and in active play, so it will need to be light enough to wear and still maneuver comfortably in sports, without hindering performance.

References:

Casa, D. J., Becker, S. M., Ganio, M. S., Brown, C. M., Yeargin, S. W., Roti, M. W., & Young, A. J. (2007). Thermoregulatory influence of a cooling vest on hyperthermic athletes. British Journal of Sports Medicine, 41(1), 42–46. https://doi.org/10.1136/bjsm.2006.030817

Environmental Protection Agency. (n.d.). Heat and teenage athletes. U.S. Environmental Protection Agency. https://www.epa.gov/children/heat-and-teenage-athletes

Ergodyne. (2024, January 15). Pulse points: Your hot spots for cooling relief. Ergodyne Blog. https://www.ergodyne.com/blog/pulse-points-for-cooling-relief

National Federation of State High School Associations. (2023, August 10). Heat awareness is top priority as high school sports, performing arts begin. NFHS. https://www.nfhs.org/stories/heat-awareness-top-priority-as-high-school-sports-performing-arts-begin

NPR Staff. (2021, July 23). 6 poultry workers died from a nitrogen leak. OSHA has issued $1 million in fines. NPR. https://www.npr.org/2021/07/23/1019784347/six-poultry-workers-died-from-a-nitrogen-leak-osha-has-issued-1-million-in-fines

Vortec. (2025). Body cooling vests: Personal air conditioner system. Vortec. https://www.vortec.com/vortec-cooling-vest-overview

Element B

Documentation and Analysis of Prior Solution Attempts

Introduction:

Through extensive research in Element A, it became clear that heat-related illnesses remain one of the most persistent and preventable dangers facing student athletes today. Despite years of studies, technological development, and public awareness campaigns, athletes continue to suffer from heat exhaustion and even heat stroke during practices and competitions. This ongoing problem raises the question: if so much research and innovation have already been dedicated to cooling technology, why is this issue still happening? Element B aims to explore that question by examining what solutions have already been attempted, identifying their limitations, and analyzing why previous designs have not fully solved the problem. Our goal is to understand these limitations so we can help develop a safer, more effective system to prevent heat-related injuries before they occur.

Drager Phase Change Cooling Vest

Description:
The Drager Phase Change Cooling Vest provides up to four hours of cooling relief using PCM. This material activates when body temperature rises above 23 °C. It absorbs the heat as it transitions from a solid to a liquid, cooling the skin's surface about 3-4 °C. The vest regenerates within four hours when stored below room temperature. It has a three-year service life and a washable outer fabric.

Pros:
- ➢ No power, freezing, or water necessary
- ➢ Can be worn under gear
- ➢ Reusable

Cons:
- ➢ Small temperature drop
- ➢ Long activation time

Sources:
Draeger Phase Change Cooling Vest. (2025, September 2). HazmatResource. https://hazmatresource.com/product/hazmat-suits-and-ppe/draeger-phase-change-cooling-vest

Vortec Cooling Vest

Description:
Vortec's Cooling vest was designed for those who work in hot conditions and perform strenuous physical work. The vest is made from flame-resistant fabric that meets CPAI-84, Sec. 6 Fire Standard Specifications, and can be used in environments with temperatures exceeding 100°F.

Pros:
- ➢ Easy to access temperature regulation
- ➢ Can be worn under gear
- ➢ Vest is impermeable to sweat, dirt, and other contaminants
- ➢ Easy to clean
- ➢ Vest allows a full range of motion

Cons:
- ➢ Very large and bulky
- ➢ Long activation time
- ➢ Tedious system setup

Sources:
Vortec. (2025). Welding cooling vest. Vortec. https://www.vortec.com/vortec-cooling-vest

Body Cool Xtreme Cooling Vest

Description:
Body Cool Xtreme is a brand of cooling vests for long-distance bike riders. The product is cooled using liquid cooling, which freezes the vest after being soaked in water and wrung out. It provides cooling for 1-4 hours per use and maintains a fixed temperature of 15 °C. For the first time, soak the shirt in water for 1 minute and let it dry. Then, soak the shirt again in water for 1 minute and squeeze out all the excess water so it is ready for use.

Pros:
- No power or freezing necessary
- Can be worn under gear
- Lightweight design
- Reusable

Cons:
- Cold water is necessary
- Tedious process to cool
- Designed specifically for biking

Sources:
Team Visma | Lease a Bike. (2025). Cycling cooling vest. Team Visma | Lease a Bike Shop. https://www.teamvismaleaseabike.com/shop/bike-accessories/cooling-vest-inuteq-team-visma-lease-a-bike

Water Cooling Vest

Description:
This water cooling vest works with a battery and a water pump. It pushes cold water through the pumps, effectively cooling the vest. This maintains a constant temperature throughout the duration of the battery life. It has a lightweight design with two side straps to adjust the fit.

Pros:
- ➢ Instant cooling
- ➢ Lightweight design
- ➢ Reusable

Cons:
- ➢ Power is necessary
- ➢ Cannot be worn under gear
- ➢ Dependent on battery life

Sources:
Amazon.com. (2025). Water cooling vest with battery pump. Amazon. https://www.amazon.com/dp/B0D7MX2JS6

Ominus Headband

Description:
The Ominus headband has 20 cooling pieces and includes a lightweight, ergonomic design. It was designed to enhance the body's natural cooling capacity by increasing the evaporation surface up to five times that of skin, delivering continuous relief as long as the pieces remain wet and exposed to airflow. This system requires no freezing or charging and is easily reusable.

Pros:
- ➢ No power or freezing necessary
- ➢ Lightweight design
- ➢ Reusable

Cons:
- ➢ Needs to be wet
- ➢ Fails under gear
- ➢ Airflow required

Sources:
Omius Inc. (2023). Headband with cooling pieces. Omius. https://www.omius.io /products/headband-w-20-cooling-pieces-copy

Tubing System Patent

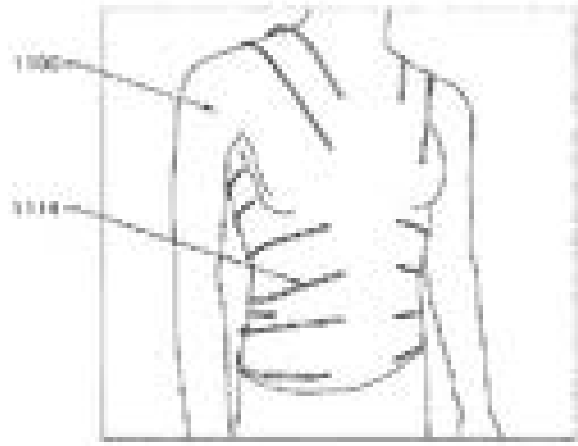


Figure 11

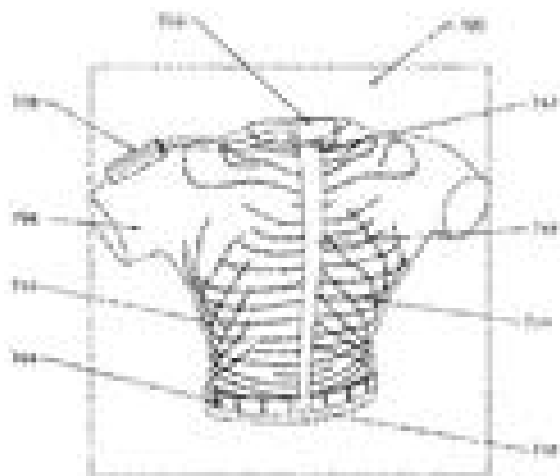


Figure 7

Description:

This design is a tubing system that wraps around the chest and cools down the body for medical purposes. The device requires two people: one wearing the piece whilst the other pumps a gas or liquid through the tubes to cool the wearer. The patent does not specify what solution is to be used in the suit, but it is intended for use in a medical setting.

Pros:

- ➢ Effective in case of an emergency
- ➢ Safely stores fluid
- ➢ Reusable

Cons:

- ➢ Needs multiple people to operate
- ➢ Limited in-game use
- ➢ Can’t be used while active

Sources:

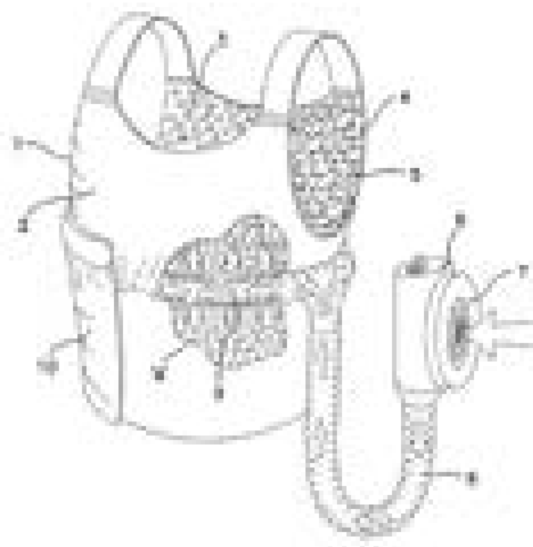
U.S. Patent No. 11,026,834 B2. (2019, February 25). Body temperature controlling system. U.S. Patent and Trademark Office. https://patents.google.com

/patent/US11026834B2/en

Cooling Garment Patent

Description:

This patent covers a personal cooling garment designed for use in high-heat or hazardous environments (e.g, firefighters, hazmat operators). It features two fabric layers forming a cavity where cool air can flow. In the cavity, raised protrusions and spacers ensure consistent airflow distribution. The design achieves 50–100+ watts of cooling over at least 3 hours, while remaining lightweight, flexible, and portable battery-powered fans. Plus, materials are highly water vapor permeable to reduce sweat build-up.



Pros:

- ➢ No water or freezing necessary
- ➢ Constant airflow
- ➢ Reusable

Cons:

- ➢ Heavy design
- ➢ Bulky
- ➢ Dependent on battery life

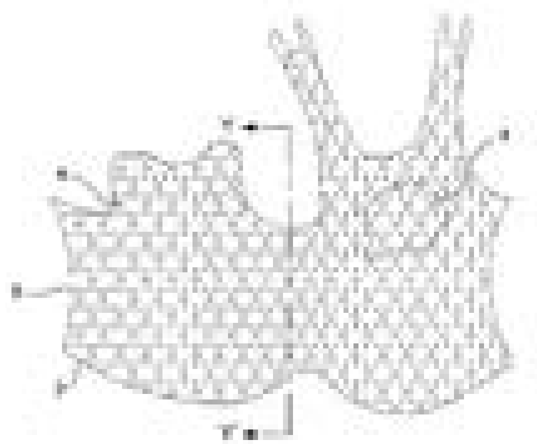


FIG. 2

Sources:

U.S. Patent No. 7,716,940 B2. (2006, February 3). Gas distribution garment having a spacer element. U.S. Patent and Trademark Office. https://patents.google.com /patent/US7716940B2/en

Nitrogen Cooling System

Description:
LN2 Liquid Cooling is a powered nitrogen cooling system that can drop down to a temperature of -190 °C. Using an MK2000, they can regulate the temperature with greater ease so that it can reach extremely high and low temperatures. Used with Instec thermal plates and chucks larger than 8 inches, the LN2-VC1L system reaches a lowest of -196°C, depending on the heat load.

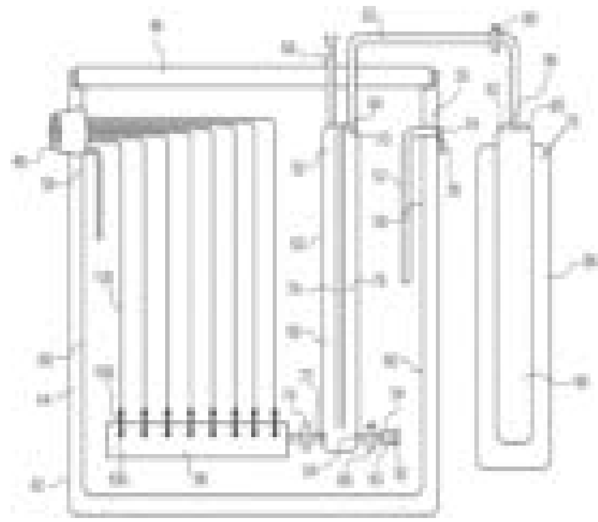
Pros:
- ➢ No power or freezing necessary
- ➢ Lightweight design
- ➢ Reusable

Cons:
- ➢ Needs to be wet
- ➢ Not portable
- ➢ Airflow required

Sources:
Instec Inc. (2025). LN2 liquid nitrogen cooling systems. Instec. https://instec.com/portal /article/index/id/48/cid/1.html

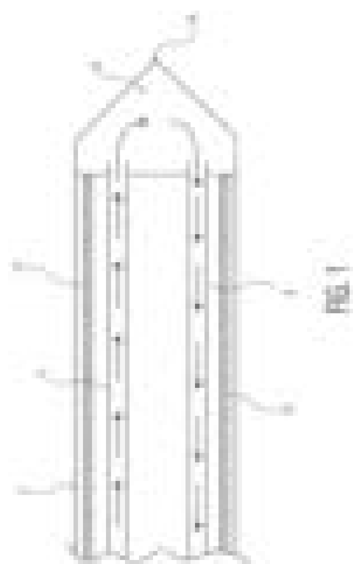
Nitrogen Tube Cooling System Patent

Description:
The patent is for a liquid nitrogen tube cooling system for cryogenics, designed for use on mechanical objects or living tissue. It's considered a form of surgical instrument to be used in scenarios that require a counteraction to high-temperature operating. The patent does not restrict others from creating their own system fastened to a clothing piece, ie, a shirt.



Pros:
- ➢ Tubing allows for precise cooling
- ➢ Regulation of temperature
- ➢ Reusable

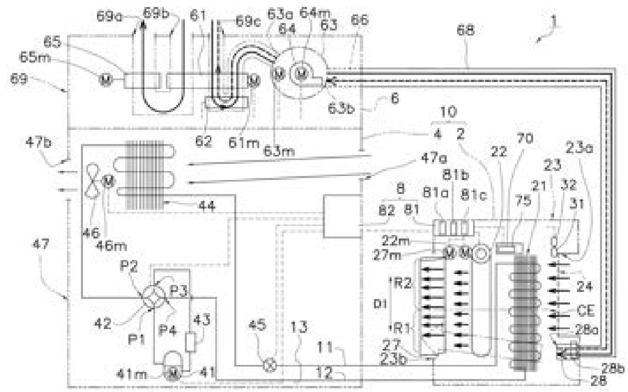
Cons:
- ➢ Heavy weight
- ➢ Expensive

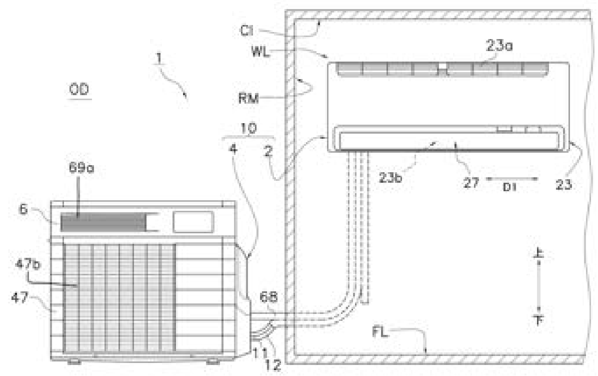


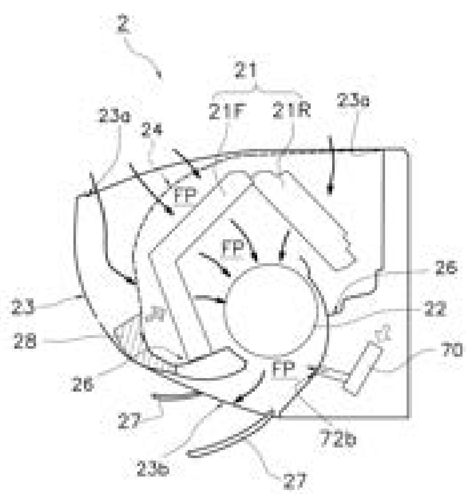
Sources:
U.S. Patent No. 11,849,989 B2. (2021, May 10). Cryogenic system and methods. U.S. Patent and Trademark Office. https://patents.google.com/patent/US11849989B2/en

Air Conditioning Unit Patent

Description:
This patent comes from Japan and is designed for the inside of an air conditioning unit. It specializes in keeping the indoor air from changing its current state. This trait is shared with other air conditioners that attempt to maintain a specific temperature set by the user. However, this is a complex system that would likely be used in a lab setting and is not intended for everyday household use. The system is much too bulky to fit in a shirt as it exists currently; however, it could be noted how they apply flow ergonomics to maintain temperature. We might consider incorporating a mesh material that promotes air flow and ventilation.







Pros:
- ➢ Highly Efficient cooling system
- ➢ Promotes air flow and analysis
- ➢ Suppresses change in the area of effect

Cons:
- ➢ Too large for personal use
- ➢ Expensive
- ➢ Very difficult to implement into a vest

Sources:
Matsumoto, S. (2021, August 6). Air-conditioning indoor unit (Patent No. JP2023024123A). Daikan Industries. https://patents.google.com/patent/JP2023024123A/en

Summary:

After analyzing a range of existing cooling vest designs, our research found that while each product offers some level of effectiveness, most are not optimized for the demands of athletic performance. Current solutions tend to be bulky, restrictive, or designed for industrial and medical use rather than high-mobility sports environments. For our stakeholders, athletes, coaches, and sports medicine professionals, these limitations highlight the need for a design that is both lightweight and highly functional during active play. Among the systems reviewed, INTEQ’s vest demonstrated strong potential due to its breathable, low-profile construction, while Vortec’s gas-based cooling method showed promise for its precise temperature control. Building on these findings, our team will explore ways to integrate similar cooling mechanisms into a more streamlined, athlete-oriented design that prioritizes comfort, performance, and safety.

Element C

Presentation and Justification of Solution Design Requirements

Introduction:

The design requirements establish the foundation for creating an innovative cooling garment that is both functional and practical for athletes and labor-intensive users. To achieve this, the apparel must deliver precise temperature regulation in the range of 40°F to 70°F while remaining lightweight, slim, and comfortable enough to be worn under other gear. Affordability, durability, and reusability are also central to the design, ensuring that the product remains accessible, long-lasting, and sustainable. Additionally, the vest must prioritize user safety by using non-toxic, skin-safe materials and maintaining reliable cooling without risk of frostbite or burns. Most importantly, the product must function as a preventative measure against the effects of heat illness. Together, these requirements form a clear framework that balances performance, comfort, and cost, guiding the development of a product capable of meeting the demands of high-performance environments.

Design Requirements

1. **Apparel must be able to reach temperatures ranging from 40°F to 70°F**
   Shirt must properly regulate the cooling function to easily and efficiently undergo temperature change in a short time period. It also needs to maintain the temperature for long durations of time to cool down the athlete wearing it.

2. **Cost Effective**
   We want customers from all classes to be able to afford our product if it is necessary, so we want to keep the price for our cooling apparel below $50 for the consumer. Additionally, use nitrogen or CO_2 capsules that are affordable to replace when the user runs out.

3. **Reusable**
   Apparel must contain a system that allows cartridges to be replaced and reused multiple times to increase value and efficiency. This will also allow us to market our product with a possible service of nitrogen or CO_2 capsule replacement in the form of a subscription, making it a viable business.

4. **Safety**
   All of the materials we use will be non-toxic and safe for the skin of any person who uses them. The cooling function must be contained enough to prevent any burns or frostbite that may occur to the user.

5. **Odor Resistant**
   Our consumers need to have a product that does not build up odor, so the product will use elastic fabric materials that avoid absorbing sweat and are odor-resistant. The outer layer should be washable without damaging any of the cooling systems, for wearers to clean it without harming their shirt.

6. **Lightweight**
   Our customers highly value weight, so it does not hinder their performance in their activity. Thus, we want our shirt to be capable of use in all scenarios, including any athletic activity and intensive labor, without greatly impacting performance. To do so, we'll create a prototype that does not exceed 3lbs.

7. **Comfort**
   Our shirt needs to be comfortable enough not to cause strain to the wearer. The materials we use will be snug fit to the body but easy enough to take off with only 1 person. Those materials will also be moisture-wicking and breathable to allow for air flow. Listed at the bottom of Element C is a comfort scale in which we need our product to achieve a 4 or higher.

8. **Non-bulky**
   The shirt should have a slim design that's capable of being worn under pads or any other possible gear the athlete or worker may need. When laid by itself, the thickness should not exceed 2 cm. Additionally, it must pass multiple maneuverability tests, including Lower coastal bending, appendage freedom, and the upper rotation test.

9. **Durable**
   Apparel should be able to withstand light cutting and absorb collision contact without damage. The tubing used will need to be resistant to hits and be low-profile to avoid debris and possible damage it could cause to the wearer when hit.

10. **Long-Lasting Cooling**
    We want our final product to have cooling benefits for at least 20 minutes before having to be replaced or removed. Meeting this requirement will have a significant impact on athletes who may have to play in heated conditions for an extended period of time.

Comfort Rating Scale (0–5 System):

1. Fit & Mobility

- ➢ 0 – Significantly restricts movement (≥25% reduction in range of motion).
- ➢ 3 – Allows near-full mobility (≤10% reduction).
- ➢ 5 – No measurable restriction compared with baseline movement.

2. Breathability & Heat Dissipation

- ➢ 0 – Traps heat and sweat; feels hot or sticky.
- ➢ 3 – Moderately breathable; occasional overheating reported.
- ➢ 5 – Highly breathable, moisture-wicking; remains cool and dry during activity.

3. Skin Feel / Irritation

- ➢ 0 – Feels rough or irritating; discomfort occurs within 10 minutes.
- ➢ 3 – Mild irritation after extended wear (>1 hour).
- ➢ 5 – Soft, smooth, and irritation-free during multi-hour use.

4. Ease of Use (Donning/Doffing)

- ➢ 0 – Requires assistance or substantial effort to put on or remove.
- ➢ 3 – Manageable independently but requires adjustments.
- ➢ 5 – Quick and intuitive; can be put on/removed in under 30 seconds.

5. Secure Fit

- ➢ 0 – Shifts, sags, or loosens during movement.
- ➢ 3 – Minor adjustments needed during activity.
- ➢ 5 – Remains secure during full athletic or labor-intensive motion.

Element D

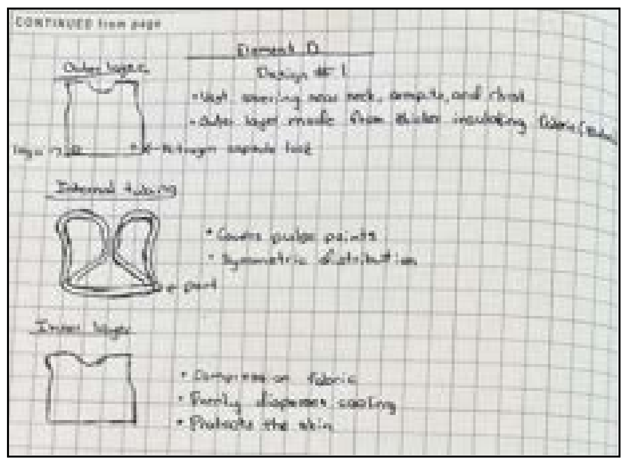
Design Concepts, Generation, Analysis, and Selections

Introduction:

When creating our design concepts, we worked to develop a wide variety of sketches that meet the objective statement. Doing this allows us to analyze the benefits of each design. All of our ideas involved a gas system integrated into the garment in order to cool down the user. Some options may be worn more loosely, while others are tightly fastened to the body. Specifically, either a mult-layer shirt or a vest system. Both of these seemed viable for the issue, so a design matrix was required to get a more subjective answer to what option would be best for testing as a prototype. Additionally, there were multiple opinions on the best positioning for the tubing throughout the apparel and where the nitrogen intake port should be located to put the least stress on the user.

<u>Design #1</u>

Design Summary:
The apparel in this sketch is a slim-fitting vest that implements both intake and outtake ports on the front near the waist. The tubing is symmetric on the inside and covers all pulse points around the chest. There is also an inner fabric layer that allows the cold air to disperse better around the body.



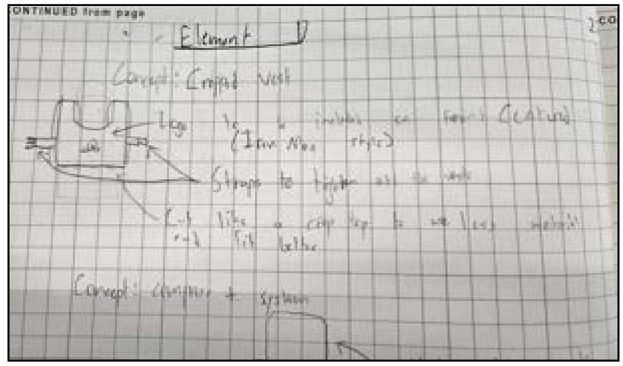
Pros: Vest has a proper opening for tubing, the tubing system ensures safe cooling without tears, and a compression-like fabric that allows for comfortable movement

Cons: Tubing will likely protrude through the fabric, and the outer layer will block mobility for the athlete

Design #2

Design Summary:

This design attempts to implement the logo and tubing in a cropped vest form that would be cut off near the abdomen. This is an attempt to make the device more universal, comfortable, and lighter to affect athletes' performance less during use.



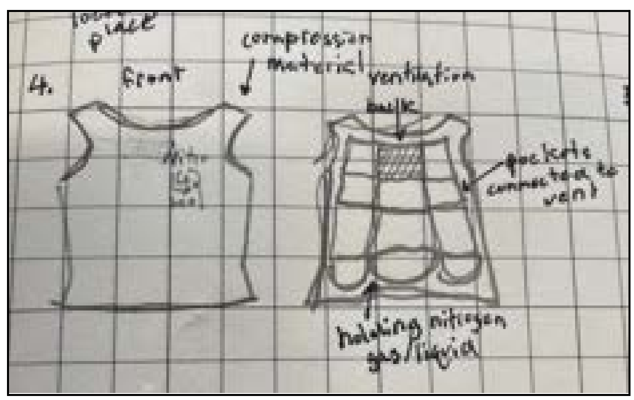
Pros: Save on materials by cutting the waist, compact and lightweight, easily adjustable to size. Easily accessible Liquid nitrogen equipment by unbuckling the straps

Cons: Design is bulkier to fit equipment inside a smaller space, potential missing areas of heat in the waist, and there is a lack of insulation

Design #3

Design Summary:

This vest concept also utilizes an inner compression layer to disperse temperature; however, all complex systems are located on the back, and it includes a holder for the CO_2 or nitrogen cartridge, as well as a ventilation layer on the top.

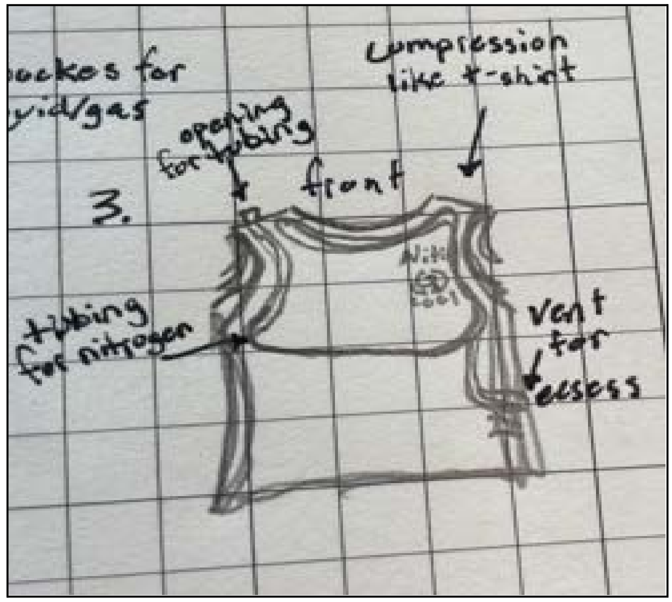


Pros: Flexible compression-like material, Ventilation system in the back using a mesh-like design, and pockets to hold cooling equipment; neoprene/ liquid nitrogen

Cons: Pockets will likely poke out of the vest, making it blocky and uncomfortable, and there is little room for putting in a cooling agent

Design #4

Design Summary:
The design here cuts the vest to allow for an even lighter design that tightly fits the tubes to your body and places vents and port access onto the sides of the compression shirt.

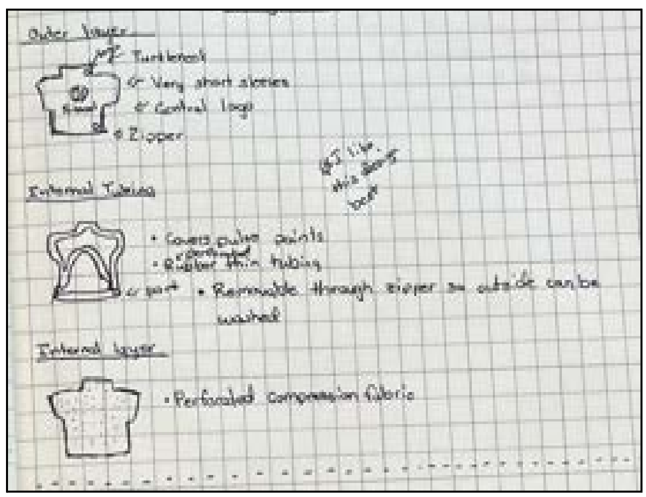


Pros: Flexible compression-like material for comfortable movement, tubing system stitched inside the material to allow for liquid cooling, and an opening for gas that is easily adjustable

Cons: Tubing will likely protrude outside of the material due to the thin fabric, and tubing will likely rip or break if impacted hard enough

Design #5

Design Summary:
Turtleneck design traps the cold air in, keeping it cooler, longer, while still having cooling properties. The tubing also covers pulse points for more effective cooling.

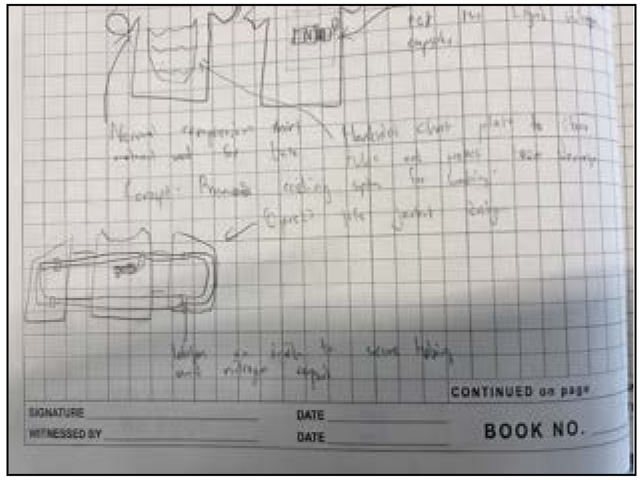


Pros: Turtleneck and short-sleeve design allows for cooling on pulse points, while allowing gear to be worn on top

Cons: Internal tubing will need insulation to protect it from damage

Design #6

Design Summary:
Life Jacket design offers an easily adjustable approach, allowing the user to quickly access all the tubing on the inside to make needed adjustments or swap out cartridges while remaining lightweight and wrapping around the body.

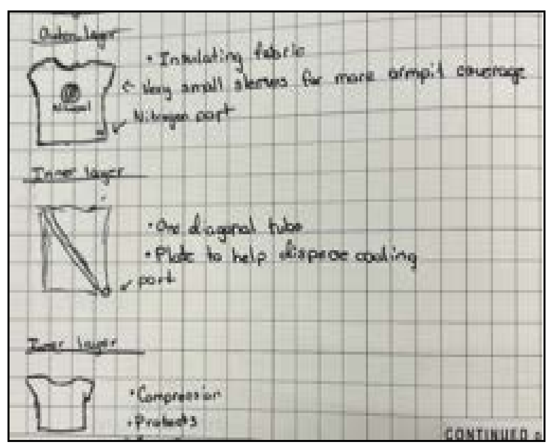


Pros: Life jacket design is universal, and the size can be adjusted to most. accessible cooling system on the inside, which can be opened, and a capsule stored on the inside for protection

Cons: Bulky design will struggle to fit under gear, may be uncomfortable for long-term use, and lacks an insulation layer to keep in cool air

Design #7

Design Summary:
This shirt has a simple tubing layout, but focuses on a cold plate to absorb the cooling from a diagonal tube to then diffuse it upon the chest of the wearer.

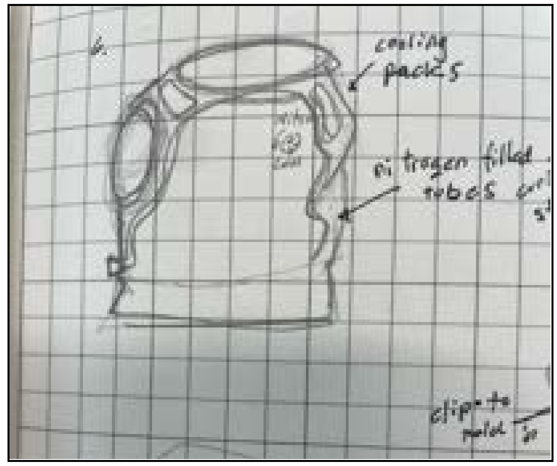


Pros: T-shirt design allows for a natural fit and cooling on the armpits, the material is insulated, trapping cooling inside the shirt

Cons: The internal plate may negatively affect comfort and mobility, and tubing may protrude through the shirt, allowing for easy rips and tears

<u>Design #8</u>

Design Summary:
Unique from other designs, this has two cooling elements, including the nitrogen tubes as well as cooling packs similar to what you would find in the freezer for an injury.



Pros: Lightweight compression material that allows for flexible/comfortable movement, a cooling system around human body heat points, and use of both liquid cooling tubing and packs.

Cons: Could be too bulky around points of tubing and packs, the opening may get in the way of sports and rip off, and tubing could break or tear

Concept Selection:

	Design #1	Design #2	Design #3	Design #4	Design #5	Design #6
Temperature	4	4	4	4	4	4
Bulkyness	5	4	4	3	5	3
Cost Effective	4	4	4	3	4	4
Odor Resistant	3	3	3	3	5	3
Lightweight	5	4	5	4	5	3
Comfortablility	4	5	4	4	5	4
Reusablility	5	5	5	5	5	4
Durablility	5	5	5	5	5	4
Safety	4	4	4	4	4	4
Long-Lasting	4	4	4	4	4	4
Total	43	42	42	39	46	37

Design Aspect	Definition
Temperature	Measures how well the design regulates the target temperature range
Bulkyness	Evaluates whether the design is slim, compact, and easy to wear
Cost Effective	Considers both production and consumer costs
Odor Resistant	Examines the design's ability to resist sweat, bacterial growth, etc...
Lightweight	Looks at the overall weight of the design
Comfortablility	Assesses the overall user experience, including softness, and breathability
Reusablility	Determines whether the design can be used multiple times
Durablility	Measures how well the design lasts long-term use without damage
Safety	Evaluates if the design poses any risks and how well it protects the user
Long-Lasting	Considers the design's ability to maintain cooling over time

Scale (1-5)
1 - Minimal
2 - Marginal
3 - Adequate
4 - Efficient
5 - Highly Efficient

Conclusion:

After evaluating six potential design concepts against ten critical aspects, including temperature regulation, bulkiness, cost effectiveness, odor resistance, weight, comfort, reusability, durability, safety, and long-lasting performance, Design #5 emerged as the strongest option, achieving the highest overall score of 46. This design consistently ranked at the top across almost all categories, particularly in comfort, reusability, durability, and lightweight performance, making it the most balanced and practical solution.

Moving forward, the concept development will focus on building upon the strengths of Design #5, ensuring that its high performance in comfort, usability, and durability remains central. At the same time, attention should be given to addressing any potential weaknesses, such as cost-effectiveness or manufacturing feasibility. This approach ensures that the final design is not only efficient and user-friendly but also sustainable and practical for long-term use.

Final Design Sketch:

Element E

Application of STEM Principles and Practices

Introduction:

Developing the components of our design will require investigating STEM principles, such as material science, thermodynamics, heat prevention technology, cooling engineering, and flow rate. Using information taken from articles and research papers, we will be able to find ways to apply these principles and develop a solution for our preventative cooling shirt.

STEM Principles:

Science
- ➢ Liquid nitrogen cooling
- ➢ CO_2 cooling
- ➢ Heat transfer
- ➢ Human thermoregulation
- ➢ Odor-resistant
- ➢ Thermodynamics

Technology
- ➢ Fusion 360 modeling
- ➢ Sewing

Engineering
- ➢ Release port
- ➢ Strong, thin tubing
- ➢ Ergonomics
- ➢ Stress analysis
- ➢ Hazard prevention

Math
- ➢ Dimensions for nitrogen ports
- ➢ Time for effectiveness
- ➢ Sizing for vest
- ➢ Flow Rate

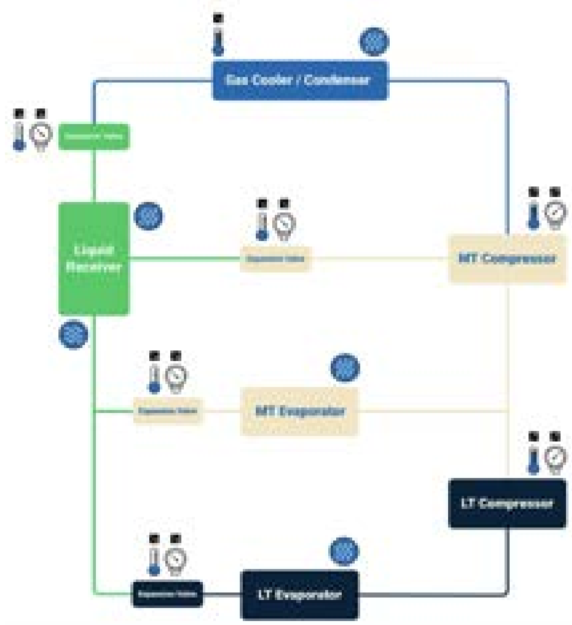
SCIENCE:

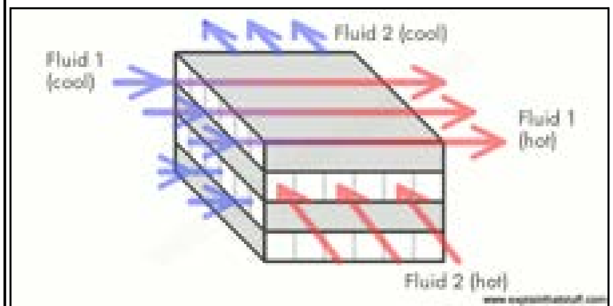
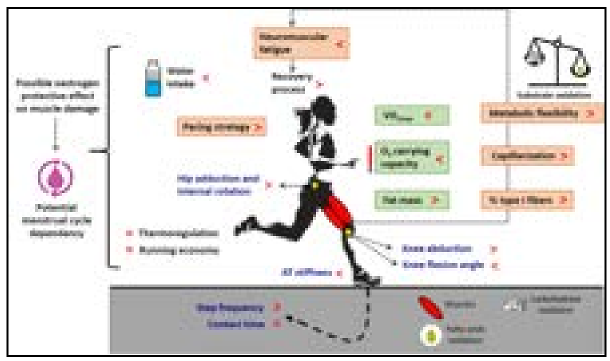
Liquid Nitrogen Cooling:

Liquid Nitrogen Cooling is a process used in many systems for refrigeration purposes. Cryotherapy is a medical treatment that uses extreme temperatures to repair broken or abnormal tissues. (Clinic) The method of Cryotherapy reduces acute pain/inflammation in the body while enhancing blood circulation to promote the repair of human tissue. Even so, the process has not been validated for large-scale applications due to the limited research on cryotherapy. This process will help us develop ways to properly store and use nitrogen in the design of our shirt without harming the user.

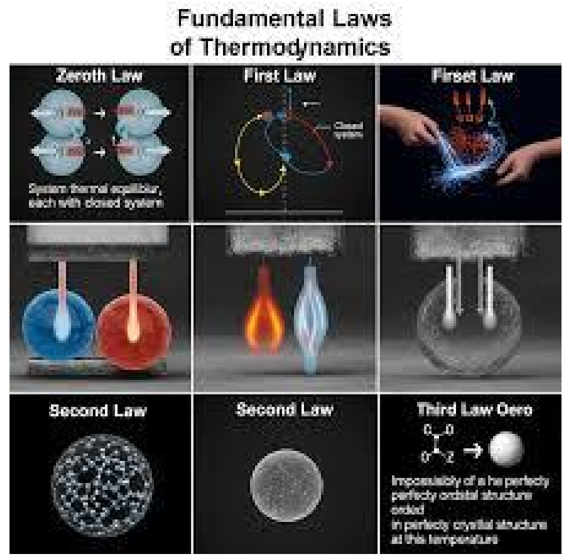
CO_2 Cooling:

It is important to explore alternative cooling processes to ensure the most effective cooling. CO_2 can be easily accessed in canisters as it is used for common items such as bike tires. In the last few years, it has been used in other cooling applications, including refrigeration systems such as the one displayed on the right. The effects of climate change make this technology a major environmental innovation. “Unlike traditional refrigeration systems that rely on harmful refrigerants, transcritical CO_2 systems utilize carbon dioxide, a natural and environmentally friendly substance.” (Frigo) CO2 may be just as effective, if not more than nitrogen, in our situation, but without additional sources, we will have to run our own testing.



<table>
<tr>
<td>Heat Transfer Principles:
We are focusing on these principles because they will help determine how our product can properly cool a person without harming or overcooling them. Past studies have shown that the most important factor in material heat transfer is the thickness of the material used for the product. While other studies show that air permeability is also an important factor, there still needs to be a pocket layer between two layers, which accounts for 60% to 80% of the insulation. This information gives us a focus on the material structure of our product and the layering of different materials to ensure effective cooling.</td>
<td>
</td>
</tr>
<tr>
<td>Human Thermoregulation:
Thermoregulation is the maintenance of a person's core body temperature by balancing heat generation with heat loss. A healthy individual typically has a temperature between 37 ± 0.5°C (98.6 ± 0.9°F). This range is necessary for the human body’s metabolic system to function properly. Researching human thermoregulation will help us identify the optimal temperatures and body areas that are the most effective in cooling someone down.</td>
<td></td>
</tr>
<tr>
<td>Odor Resistance:
Odor-resistant clothing is a crucial feature of our product as it's used by athletes who often sweat heavily while playing their sport. Anti-odor technology captures and blocks odor-causing bacteria that come from the human body. The main solution other clothing brands use is moisture-wicking apparel that contains polyester, which doesn’t absorb as much water as cotton. In our design, we will use polyester shirts to help reduce odor buildup.</td>
<td></td>
</tr>
</table>

Thermodynamics:
Thermodynamics is a branch of science that deals with heat and temperature in relation to transfers of energy, matter, and radiation. This is typically applied to mechanical heat engines. However, we may incorporate thermodynamic principles in our vest to cool down an overheated person. Additionally, Thermodynamics concerns entropy, which is crucial in our designs and prototypes.

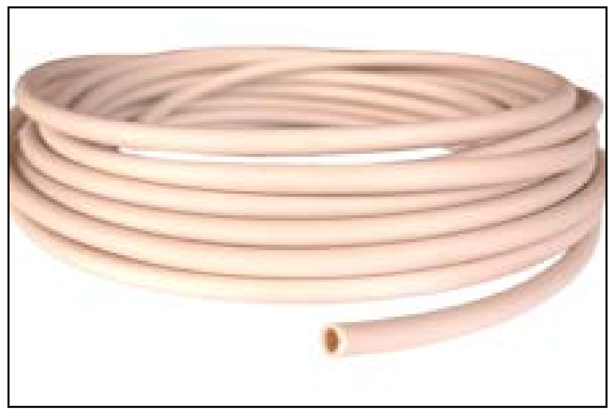


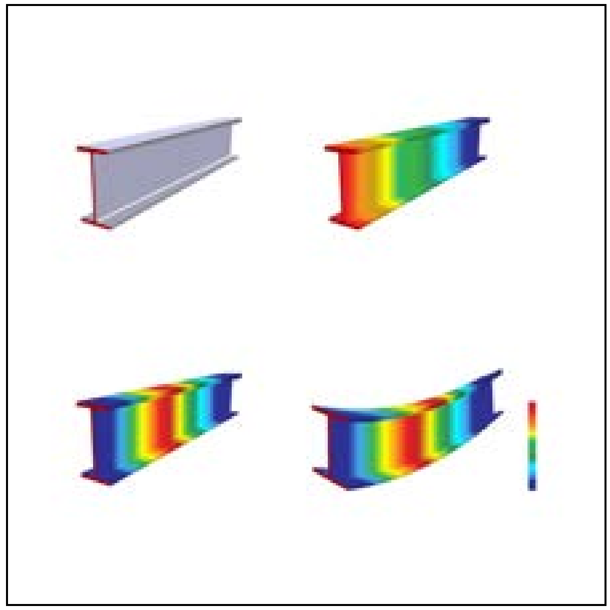
TECHNOLOGY:

Fusion 360 Modeling:
Fusion 360 is an online CAD software, commonly used to generate design concepts and model parts. It provides many tools that help create 3D renditions of the product or item someone wants to make. Fusion will help us get a sense of how our design would function or appear to the person using our product. It will also help us design a realistic product that will properly fit our consumers.

Sewing:
Sewing is a craft in which thread is used to connect pieces of fabric. It is the basis for how patches are implemented on products and how pieces of clothing are stitched. We will use a sewing machine to attach the tubing to the shirts using fabric strips and sew the inner and outer shirts together.

ENGINEERING:

Nitrogen Release Port: A release port for nitrogen or CO_2 is a crucial feature for our product, enabling us to properly insert the nitrogen or CO_2 into the product without complication. The port will need to be similar to a tire gauge port, allowing no gas to enter or exit the tubing system. The piece will also need to be in a comfortable spot on the vest so that it does not get in the way or damage the shirt.	
Strong, Thin tubing: Durable and chemical-resistant tubing is needed for our product due to the high intensity of sports and the chemical properties of nitrogen and CO_2. TPV tubing is a ubiquitous material used in labs due to its flexible rubber-like properties and its resistance to harder plastics. TPE, Copper, and PVE tubing are applicable to our product design, having similar properties to TPV while also being more cost-effective and efficient for our needs.	
Ergonomics: Determining the ergonomics of the interaction between the human body and nitrogen or CO_2 will allow us to set safe levels of cooling for the human body. Nitrogen and CO_2 have severe risks if mishandled due to their unique properties; they can rapidly burn human skin and expand 695 times their original mass. This could cause severe respiratory problems, related to fainting or blacking out, if inhaled.	

Stress Analysis: It's vital to know how much physical stress our product can withstand. Acquiring this information will allow us to design the shirt using the correct materials properly. The compression material chosen for our shirt is very durable due to its woven structure. Still, the tubing will need to be insulated because it could break under high pressure from direct collisions between football players or other big impacts.	
Hazard Prevention: When handling a product containing compressed nitrogen or CO_2, it is important to be aware that if an accident happens, it could cause severe injuries. For this reason, we will need to fortify the tubing to ensure the gas is the only chemical that gets inside the tubing. Using a stronger outer layer material will also be necessary for the user's safety.	

MATHEMATICS:

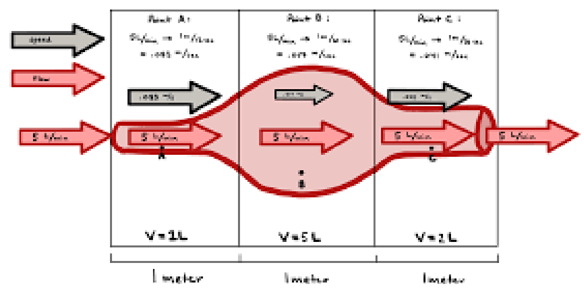
Dimensions for Nitrogen Ports: To ensure a steady, consistent flow without gas loss, the dimensions of the gas ports must be precise. The dimensions will need to be thoroughly considered and applied in our prototype. Our tubing has an inner diameter of ⅛ in. The nozzle of our purge tool should be equal to or marginally less than the measurement to ensure functionality and seal.	
Time of Effectiveness: Since our product is a preventative solution for heat illness, it is important to determine how long the vest can be worn effectively. The shirt also needs to be cool the body within 5 minutes to adhere to the standard water break time. At some point, when the vest temperature has risen significantly, the nitrogen or CO_2 will need to be refilled. The timing window for cooling is based on other conditions, which could help set regulations for the product to meet KHSAA standards.	

Sizing for Vest:
The shirt is designed for athletes, so their fitting needs have to be considered. We need to find what size and proportions are going to be optimal and fit our consumers. For example, we want to make a proportionally large version designed for linemen in football. As stated previously, these are the athletes most affected by EHS. The size should aim to be compressed to the wearer, hence the choice of an elastic material. From Anthropometric data, we gain the dimensions needed for our sizing ratios.

Definition of parameter	*Value of the 5th %ile (mm)*	*Value of the 95th %ile (mm)*
Shoulder width (biacromial)	310	430
Hip width (seated)		440
Length of anterior grip	615	
s of abdomen and backside when seated	190	
Thickness of thigh	125	185
ength from backside to knees		687
Length of feet		285
Arm diameter (fixed value)	121	121

Data source: ScienceDirect

Flow Rate:
Flow rate calculations could help control the system's temperature. Compressed nitrogen and CO_2's low temperature comes from a quick pressure change. Slowing down or speeding up the flow rate will change how quickly the pressure in the cartridge changes, allowing for temperature control. We know from Bernoulli's equation that the higher the flow rate, the cooler the gas will be. We want a system that helps control and measure the internal temperature of the tubes.



Resources:

Bursey, M. M., Galer, M., Oh, R. C., & Weathers, B. K. (2019). Successful management of severe exertional heat stroke with endovascular cooling after failure of standard cooling measures. *The Journal of Emergency Medicine, 57*(2), e53–e56. https://doi.org/10.1016/j.jemermed.2019.03.025

Cleveland Clinic. (2020). *Cryotherapy: Uses, procedure, risks & benefits.* Cleveland Clinic. https://my.clevelandclinic.org/health/treatments/21099-cryotherapy

Douma, M. J., Aves, T., Allan, K. S., Bendall, J. C., Berry, D. C., Chang, W.-T., Epstein, J., Hood, N., Singletary, E. M., Zideman, D., Lin, S., Borra, V., Carlson, J. N., Cassan, P., Charlton, N. P., Markenson, D. S., Meyran, D., Sakamoto, T., Swain, J. M., & Woodin, J. A. (n.d.). First aid cooling techniques for heat stroke and exertional hyperthermia: A systematic review and meta-analysis. *Resuscitation*.

Frigo, SCM. (2024, January 11). *CO_2 refrigeration system: How it works.* SCM Frigo. https://www.scmfrigo.com/en/blog/co2-refrigeration-system-how-it-works/

KHSAA. (2025). *Exertional heat illness.* Kansas State High School Activities Association. https://www.kshsaa.org/public/pdf/ActSpecificConsiderations.pdf

Kerr, Z. Y., Casa, D. J., Marshall, S. W., & Comstock, R. D. (n.d.). Epidemiology of exertional heat illness among U.S. high school athletes.

Niven, D. J., Gaudet, J. E., Laupland, K. B., Mrklas, K. J., Roberts, D. J., & Stelfox, H. T. (n.d.). Accuracy of peripheral thermometers for estimating temperature: A systematic review and meta-analysis. *Annals of Internal Medicine*

Element F

Consideration of Design Viability

Introduction:

A major part of creating our design to the best of our ability is identifying the cost and vendor to buy the items we need. Our product is not a high-cost design, so we will be able to modify the prototype and identify problems and solutions without exceeding our budget. We also need to know pricing so our group can use the most affordable and high-quality materials that we can use in our product. This product will likely be sold in the $60-$80 price range, which gives a $50 cost budget per unit. The design should meet our design requirements and remain effective, all while staying under budget.

Assembly or Project Progression:

User Influence/Professional Input:

After discussing our ideas and progress with professionals, they provided us with some helpful feedback regarding our goals for the prototype, including questions on our design process, such as the duration of the device's effectiveness for the user. Dr. Kevin Stalsberg recommended that we develop a method to regulate temperature (e.g., through circulation or venting) to prevent heat buildup. He also noted that the vest needs to cool athletes without hindering performance if worn during play. Additionally, it must adhere to established safety and equipment policies from organizations like NFHS. Spencer Lifferth noted that we should consider the thermal mass of our materials that surround the tubing in hopes that they might carry the temperature of the cooling gas in the tubing as well to increase the duration. He also said that a gauge connected to a valve could help control the flow rate of the system, letting us control the temperature of the gas entering the shirt. Kent Glasier made it clear that we should be definitive in whether our device was for an emergency application or for preventative cooling.

Ayden Raza told us to look into thin copper tubing similar to what you might find in plumbing or refrigeration, as it can withstand extreme temperatures and transfer heat well. He also stated that we should look to stretch our fluid testing from just nitrogen, like CO_2, comparing how it affects efficiency with TPV tubing as opposed to other materials. Josh Hollway evaluated our circumstances and told us to prioritize an easy method of recharging the cartridges to continue cooling when the shirt heats up. We also need to study the flow path to ensure the tubing covers the most important parts of the body to cool. Agreeing with previous professionals, he also recommended a way to control the flow rate through the valve to control the temperature change in the shirt from the same cartridge. Michael Maguire gave us some of our best insight, with the recommendation to drop nitrogen and switch to CO_2 entirely. With all this in mind, we continued to adjust our prototype, making changes where necessary to create an optimal result with stakeholders in mind.

Suggested Materials:

- ➢ Short-sleeve compression shirt
- ➢ Long sleeve compression shirt
- ➢ TPV Tubing
- ➢ Liquid Nitrogen
- ➢ Sewing equipment
- ➢ Aluminum
- ➢ Copper tubing
- ➢ Compressed nitrogen

Bill of Sale:

Item Purchased:	**Cost:**	**Shipping:**	**Vendor:**	**Deducted from budget of $50**
Short-Sleeve Compression T-shirt	$3.87	Free	Alibaba	$46.13
Long-Sleeve Compression T-shirt	$1.90	Free	Alibaba	$44.23
Thread	$1.00	Free	Amazon	$43.23
Purge tool	$9.98	Free	Amazon	$33.25
Co2 canisters	$16.00	Free	Amazon	$17.25
TPV Tubing	$17.10	10.69	Ebay	$0.15

Failure Mode and Effect Analysis:

Function	Potential Failure Mode	Potential Effect of the Failure	Potential Cause of Failure
Tubing	Breaks or tears during use	Cold nitrogen gas could leak, causing harm to the user, and it must be replaced completely afterward.	Hard contact
Tubing	Could restrict movement	If the tubing is not malleable or gets brittle when cold, it could restrict the athlete's movement, hindering performance.	The cold gas could make the PVT tubing brittle due to its cold temperature.
Shirt material	Only retains effective temperature for a short period of time	The shirt material may trap heat, causing the user to heat up, rather than to cool down.	The insulator layer has holes or doesn't have high enough thermal conductivity
Gas Port	The port could not be air-tight	If the port is not properly sealed after gas is inserted, the nitrogen gas will leak, and the vest will not be cold.	Turf or grass may obstruct the seal, causing gas to leak.
Release port	Tubing break	If the gas release port gets clogged or does not function properly, the pressure from the gas could rupture the tubing, rendering the vest ineffective.	If turf or grass gets caught inside the port, it could prevent gas from escaping.
Cooling	Ineffective tubing or Tubing break	The tubing may insulate the cold gas too much, making the interior of the vest not feel cold, and instead trapping body heat.	The tubing may have a high thermal conductivity rating, or it could be too thick.
Cooling	Too cold	The nitrogen gas may get too cold, potentially making the vest unwearable or causing the user burns or frostbite.	Gaseous nitrogen can drop to around -90 °C, which could easily burn or give frostbite to the consumer if not insulated properly.

Summary of Analysis:

The analysis highlights several critical risks in the design that must be addressed for safety and effectiveness. The tubing presents the most significant concerns, as breaks, tears, or brittleness from extreme cold could cause nitrogen leaks, user injury, or restricted movement. Similarly, improper tubing material or thickness could insulate the cooling effect, making the vest ineffective. The shirt's insulating layer may also fail if it has poor thermal conductivity, leading to overheating rather than cooling. Gas ports and release ports pose additional risks if not sealed or maintained properly, as leaks or clogs could cause pressure buildup or ineffective cooling. Finally, the potential for nitrogen to become dangerously cold underscores the importance of proper regulation and insulation to prevent frostbite or burns. Overall, while the design addresses a real need, these failure modes show that material choice, airtight sealing, pressure regulation, and safety layering are essential to ensure both user safety and reliable cooling performance.

Conclusion:

In summary, our product offers a valuable and innovative remedy to heat exhaustion, specifically in sporting or labor applications. Its potential depends strictly on our choice of material, proper construction, and safety measures. The helpful input of combined professionals allowed us to evaluate such parameters, including constraints. The low-cost and effective design results in a budget-friendly solution. This price point can be achieved, but requires careful budgeting so we can maintain the proper cost. The main risks, i.e., tubing failure, gas overcooling, and insulation failure, highlight the need for the use of durable, flexible tubing, managing the flow of nitrogen, and allowing garment material to allow effective thermal transfer without loss of comfort or safety. Prioritizing these potential modes of failure at an early stage of prototyping will be critical in making a reliable, high-performance, and marketable product in a timely manner.

Element G

Construction of a Testable Prototype

Materials List:

- ➢ 16g Compressed CO_2 Cartridge
- ➢ Long-sleeve Compression Shirt
- ➢ Short-sleeve Compression Shirt
- ➢ TPV tubing
- ➢ Elastic Thread
- ➢ CO_2 Purge tool
- ➢ Port & Fittings
- ➢ Vinyl Logo

Tools List:

- ➢ Sewing machine
- ➢ Thermometer
- ➢ Shirt Press
- ➢ Fabric Scissors
- ➢ Cricut

Sub-Systems:

- ➢ Outer layer
- ➢ Inner layer
- ➢ Port
- ➢ Tubing

Procedure:

Prep Shirts

1. Wash and dry the inner and outer shirts

Plan Tubing Layout

1. Lay the inner shirt flat and sketch the tubing path with chalk
2. Mark where the gas port will be
3. Target pulse points of the human body and map tubing accordingly around those areas, ie, armpits, neck, waist, etc…

Attach Tubing to inner shirt

1. Pin tubing with fabric pins along the chalked path on the inner shirt.
2. Use wide zig-zag stitches or elastic loops of

fabric to hold tubing in place.
3. Reinforce high-stress areas of the tubing with extra fabric strips or stitching

Create gas port exit

1. Cut a small reinforced hole at the marked spot on the inner shirt's side seam
2. secure the gas port to the tubing systems and Confirm it has an air-tight seal
3. Sew in a reinforcement patch and insert the gas port fitting. Secure tightly with stitching

Combine Shirts

1. Turn the outer shirt inside out
2. Slide the inner shirt inside the outer shirt, aligning seams and necklines
3. Carefully pin layers together around the hem, collar, and sleeves
4. Sew the two shirts together along the edges so they act as one garment.
5. Turn the garment's outer layer to the outside
6. Print out the desired logo and heat press it onto the outer layer of the shirt
7. Once all constraints have been met, align the tubing to your desired fit and attach and release gas canister once ready for use.

Element H

Prototype Testing and Data Collection Plan

Specifications Tested:

1. Temperature Regulation
2. Cost Effectiveness
3. Reusability
4. Safety
5. Odor Resistance
6. Weight
7. Comfortability
8. Mobility
9. Durability
10. Lasting Cooling Effect

Below are the team's 10 specific tests that will be conducted to see if the Nitrocool vest meets our essential criteria for market use.

Purpose: Verifies that the garment can reach and maintain an internal temperature between 40°F and 70°F.

Purpose: Ensures the garment production cost is affordable and competitive.

Purpose: Verifies the garment can be used repeatedly without degradation.

Purpose: Verifies the garment is safe from leaks, burns, and other hazards.

Purpose: Ensures the garment resists odor buildup after extended wear.

Purpose: Ensures the garment is lightweight and easy to wear.

Purpose: Determines if the garment can be considered comfortable for users to wear for an extended period of time.

Purpose: Ensures the garment does not restrict movement.

Purpose: Confirms the garment withstands wear and tear.

Purpose:
Verifies the garment maintains cooling for extended use.

Parts List:

Part	Cost Per Part	Parts used in prototype	Total Cost
TPV Tubing	$10.26	1	$17.10
Long-Sleeve Compression T-shirt	$9.99	1	$9.99
Short-Sleeve Compression T-shirt	$9.99	1	$9.99
Elastic Thread	$1.00	1	$9.99
18g CO_2 Cartridge	$0.80	20	$16.00
CO_2 purge tool	$9.99	1	$9.99
Total:	$42.03	6	$73.06

Stakeholder Opinion:

Test #1, #10:
Michael McGuire helped us through these testing documents by suggesting better ways of holding the tubing in place, using bike clamps and tape. He also suggested using CO_2 gas instead of nitrogen gas, which greatly improved the cooling effect and duration of the product. Both of these suggestions were needed to improve our testing efficiency and our product as a whole.

Test, #7, #8, #10:
After completing most of our tests, we needed an outside opinion on the versatility of our product. So we decided to get Dr. Stalsberg's opinion as he wore the product, which he was able to move in properly and stated that its comfort was nice, and didn't limit him in any way. We then inserted the CO_2 canister into the shirt and turned the purge tool on so the gas would flow through the tubing system. He stated that the cooling was very effective and almost a large rush of cool air that gave him more energy, almost like an adrenaline rush. The cooling then lasted for the duration of our conversation with him and longer after, around 30 minutes. The feedback he gave was very positive and didn't suggest any further steps besides maybe running more tubing through the shirt. Overall, this information validated our tests and gave us more information on the state of our product and what we need to accomplish moving forward.

Element I

Testing, Data Collection, and Analysis

Test #1: Temperature Regulation Test

Purpose:
Verify that the garment can reach and maintain an internal temperature between 40°F and 70°F.

Materials on hand:
- ☑ NitroCool prototype
- ☑ Nitrogen Cartridge
- ☑ Digital thermometer
- ☑ Insulated test box
- ☑ Data logger
- ☑ Timer

Initial conditions:
- ☑ Garment at room temperature (~70°F)
- ☑ Sensor secured near the chest area

Pass/Fail Criteria:
The test will be considered a success if the garment reaches and maintains 55°F ± 10°F after nitrogen gas is introduced within 5 minutes.

Safety precautions:

Hazard	Controls
1. Temperature extremes	1a. Handle the garment only after stabilization
2. Pressure release tear	2a. Run the tubing on its own before wearing it while in use
3. Product heats once nitrogen depletes	3. Use a constant flow of Nitrogen

Procedure:
- ☑ 1. Ensure that all initial conditions are met.
- ☑ 2. Ensure that all safety precautions are satisfactory.
- ☑ 3. Place the garment in the test chamber
- ☑ 4. Release nitrogen gas into the system when the vest is a room temperature
- ☑ 5. Record the time and temperature
- ☑ 6. Compare to the criteria

Trial	1	2	3	4	5	6
AVG Temp.	50.4°F	61.1°F	58.6°F	54.2°F	50.1°F	49.2°F

Results:
Avg Temperature: 53.9 °F after 5 ~~minutes~~ seconds Pass ✓ Fail ____

Signatures

Carson Hull	Carson Hull	Date 11/17/25
Hayden Jones	Hayden Jones	Date 11/17/25
Ryan Perkins	[signature]	Date 11/17/25

Approval
Teacher signature [signature] Date 11/17/25

Test #2: Cost Effectiveness

Purpose:
Ensure garment production cost is affordable and competitive

Materials on hand:
- ☑ Bill of materials
- ☑ Calculator

Initial conditions:
- ☑ Completed bill of materials

Pass/Fail Criteria:
The test will be considered a success if the total production cost is less than $100/unit

Safety precautions:

Hazard	Controls
N/A	

Procedure:
- ☑ 1. Ensure that all initial conditions are met.
- ☑ 2. Ensure that all safety precautions are satisfactory.
- ☑ 3. Collect component costs
- ☑ 4. Compare with the target

Cost Matrix:

Materials for Nitrogen Shirt	Outer Shirt Layer	Inner Shirt Layer	TPV Tubing	$/Nitrogen Cannister	Purge Tool	Thread	Total
Pricing	$7.99	$9.49	$15.99	$3.60	$9.80	$1.00	**$47.87**

Materials for CO_2 shirt	Outer Shirt Layer	Inner Shirt Layer	TPV Tubing	$/$CO_2$ Cannister	Purge Tool	Thread	**Total**
Pricing	$7.99	$9.49	15.99	$0.85	$9.80	$1.00	**$45.12**

Results:
Total Production Cost/unit for Nitrogen: $__$47.87__ Pass _X__ Fail ____

Total Production Cost/unit for CO_2: $__$45.12__ Pass _X__ Fail ____

Signatures
- Carson Hull — Carson Hull — Date 11/19/25
- Hayden Jones — [signature] — Date 11/19/25
- Ryan Perkins — [signature] — Date 11/19/25

Approval
Teacher signature [signature] Date 11-19-25

Test #3: Reuse Cycle Test

Purpose:
Verify the garment can be used repeatedly without degradation.

Materials on hand:
- ☑ Prototype
- ☑ Timer
- ☑ Test Chamber
- ☑ Nitrogen Cartridges

Initial conditions:
- ☑ Functioning Garment

Pass/Fail Criteria:
The test will be considered a success if the garment does not experience any leaks or damage after 5 nitrogen charges.

Safety precautions:

Hazard	Controls
1. A leak causing damage to the fabric or users skin	1a. Test will be run without a person wearing it and check for leaks before each use
2. Unnoticed damages to the prototype could harm a user or material outside of the tubing	2a. Inspects at the end of test for any subtle differences in comparison to the beginning

Procedure:
- ☑ 1. Ensure that all initial conditions are met.
- ☑ 2. Ensure that all safety precautions are satisfactory.
- ☑ 3. Release the nitrogen cartridge into the shirt
- ☑ 4. Wait 30 min
- ☑ 5. Inspect and note leaks or damage
- ☑ 6. Repeat 4 more times

Results:

	Cycle #1	Cycle #2	Cycle #3	Cycle #4	Cycle #5
Notes on Damage	No damage	No damage	no damage	no damage	no damage
Pass/Fail?	Pass	Pass	Pass	Pass	Pass

Notes:

Overall: Passes 5 Fails __

Signatures

Carson Hull	Carson Hull	Date 11/17/25
Hayden Jones	Hayden Jones	Date 11/17/25
Ryan Perkins	[illegible]	Date 11/17/25

Approval
Teacher signature [illegible] Date 11/17/25

Test #4: Hazard Inspection Test

Purpose:
Verify the garment is safe from leaks, burns, and electrical hazards after significant use

Materials on hand:
- ☑ Prototype
- ☑ Spray Bottle
- ☑ Nitrogen Cartridge
- ☑ PPE

Initial conditions:
- ☑ Garment assembled and operational

Pass/Fail Criteria:
The test will be considered a success if the shirt has no leaks and maintains a temperature above 32°F and below 100°F for 5 minutes.

Safety precautions:

Hazard	Controls
1. The nitrogen gas could leak	1a. Team members will wear appropriate PPE.
2. Burn skin from contact with freezing surface	2a. Test will be conducted in a well ventilated area

Procedure:
- ☑ 1. Ensure that all initial conditions are met.
- ☑ 2. Ensure that all safety precautions are satisfactory.
- ☑ 3. Release nitrogen into the shirt
- ☑ 4. Wait 5 minutes
- ☑ 5. Check for the leaks
- ☑ 6. Check for temperature

Results:
Cycle 1:

# of leaks 0
Temperature 69 °F Pass ✓ Fail ____

Cycle 2:

# of leaks 0
Temperature 68.1 °F Pass ✓ Fail ____

Cycle 3:

# of leaks 0
Temperature 60.1 °F Pass ✓ Fail ____

Signatures
Carson Hull Carson Hull Date 11/17/25
Hayden Jones Hayden Jones Date 11/17/25
Ryan Perkins [signature] Date 11/17/25

Approval
Teacher signature [signature] Date 11/17/25

Test #5: Odor Resistance Test

Purpose:
Ensure the garment resists odor buildup after extended wear

Materials on hand:

- ☑ Prototype
- ☑ Testers
- ☑ Odor Rating Survey

Initial conditions:

- ☑ Garment worn after exercise

Pass/Fail Criteria:
The test will be considered a success if the average odor rating ≥7/10 (minimal odor).

- Test after being warned throughout strenuous activity
- Judges will be professionals in this field and our team, to determine its odor strength

Safety precautions:

Hazard	Controls
1. Apparatus could fall off the table and hit the team member on the head.	1a. Team member will wear appropriate head covering such as a hat or helmet.
2. Team member could slip on the floor.	2a. Test will be conducted on a carpeted floor.

Procedure:

- ☑ 1. Ensure that all initial conditions are met.
- ☑ 2. Ensure that all safety precautions are satisfactory.
- ☑ 3. Testers will rate the odor resistance of the garment through a survey
- ☑ 4. Record the ratings in the space provided.

Results:

	Tester #1	Tester #2	Tester #3
Rating	10/10	7/10	5/10

Average Rating: 7.3/10 Pass ✓ Fail ____

Signatures

Carson Hull [signature] Date 11/19/25
Hayden Jones [signature] Date 11/19/'25
Ryan Perkins [signature] Date 11/19/25

Approval

Teacher signature [signature] Date 11-19-25

Test #6: Weight Test

Purpose:
Ensure the garment is lightweight and easy to wear

Materials on hand:

- [x] Prototype
- [x] Digital Scale

Initial conditions:

- [x] Fully assembled prototype

Pass/Fail Criteria:
The test will be considered a success if the garment is less than 5 lbs.

Safety precautions:

Hazard	Controls
•Vest may fall off scale and injure our feet	•Teammate must wear proper footwear to protect from injury
•Vest may damage the scale with nitrogen	•Ensure the vest is not in use during testing

Procedure:

- [x] 1. Ensure that all initial conditions are met.
- [x] 2. Ensure that all safety precautions are satisfactory.
- [x] 3. Place the garment on the scale
- [x] 4. Record the weight
- [x] 5. Repeat and create 2-3 prototype weight ratios

Results:
Weight 1.162 lbs. Pass ✓ Fail ____

Signatures
Carson Hull ____ Date 11/18/25
Hayden Jones ____ Date 11/18/25
Ryan Perkins ____ Date 11/18/25

Approval
Teacher signature ____ Date 11/18/25

Test #7: Comfortability

Purpose:
Determine if the apparatus can be considered comfortable for users to wear for an extended period of time.

Materials on hand:

- ☑ Prototype
- ☑ Testers
- ☑ Survey

Initial conditions:

- ☑ Garment is fully assembled

Pass/Fail Criteria:
The test will be considered a success if the average comfortable rating $\geq$7/10 (Very comfortable).

Safety precautions:

Hazard	Controls
1. Apparatus could fall off the table and hit the team member on the head.	1a. Team member will wear appropriate head covering such as a hat or helmet.
2. Team member could slip on the floor.	2a. Test will be conducted on a carpeted floor.

Procedure:

- ☑ 1. Ensure that all initial conditions are met.
- ☑ 2. Ensure that all safety precautions are satisfactory.
- ☑ 3. Testers will wear the garment
- ☑ 4. Testers rate the garment's comfort on the survey
- ☑ 5. Record the ratings in the space provided

Results:

	Tester #1 - sports med	Tester #2 - medical science	Tester #3 - student athletes
Rating	8/10	8/10	7/10

Average Rating: 7.6/10 Pass ✓ Fail ____

Signatures

Carson Hull ______ Date 11/19/25
Hayden Jones ______ Date 11/19/25
Ryan Perkins ______ Date 11/19/25

Approval
Teacher signature ______ Date 11-19-25

Test #8: Mobility Test

Purpose:
Ensures the garment does not restrict movement.

Materials on hand:
- ☑ Prototype
- ☑ Measuring tape

Initial conditions:
- ☑ Garment fully assembled

Pass/Fail Criteria:
The test will be considered a success if the wearer can perform mobility tasks such as bending, sitting, walking, and raising arms comfortably.

Safety precautions:

Hazard	Controls
1. Apparatus could fall off the table and hit the team member on the head.	1a. Team members will wear appropriate head covering such as a hat or helmet.
2. Team members could slip on the floor.	2a. The test will be conducted on a carpeted floor.

Procedure:
- ☑ 1. Ensure that all initial conditions are met.
- ☑ 2. Ensure that all safety precautions are satisfactory.
- ☑ 3. Have each tester complete one of the movements
- ☑ 4. Each tester will rate the mobility and comfort of the shirt during the movement
- ☑ 5. Record the rating in the space provided.
- ☑ 6. Repeat for each movement

Results:

	Tester #1	Tester #2	Tester #3
Lower Coastal bending test	Pass	Pass	Pass
Upper Rotation test	Pass	Pass	Pass
Appendage freedom	Pass	pass	Pass

Pass: 9 Fail: 0

Notes:
One tester experienced minimal discomfort in lower coastal bending test but it did hinder mobility.

Signatures

Carson Hull Carson Hull Date 11/18/25
Hayden Jones Hayden J Date 11/18/25
Ryan Perkins Ryan Date 11/18/25

Approval

Teacher signature ______ Date 11/18/25

Test #9: Durability

Purpose:
Confirm the garment withstands wear and tear.

Materials on hand:
- ☑ Prototype
- ☑ Tester

Initial conditions:
- ☑ Prototype

Pass/Fail Criteria:
The test will be considered a success if the garment has no tears, leaks, or other failures after durability testing.
- Using student athletes in their sports, workouts/weight lifting, and simulations put on the product through puncture and tear testing

Safety precautions:

Hazard	Controls
1. Apparatus could fall off the table and hit the team member on the head.	1a. Team members will wear appropriate head covering such as a hat or helmet.
2. Team members could slip on the floor.	2a. The test will be conducted on a carpeted floor.

Procedure:
- ☑ 1. Ensure that all initial conditions are met.
- ☑ 2. Ensure that all safety precautions are satisfactory.
- ☑ 3. Tester will stretch and be pulled on weak points
- ☑ 4. Tester will be poked and prodded to create wear
- ☑ 5. Record any tears or leaks

Results:
# of tears or leaks: 0 Pass ✓ Fail ____

Notes on Failures:

Stretch Test
Shirt 1: No comprimes, the compression fabric held up.
-
~~Shirt 2:~~
-

Tear Test
Shirt 1: No cuts or rips in the fabric or tubing.
-
~~Shirt 2:~~
-

Signatures
Carson Hull Carson Hull Date 11/18/25
Hayden Jones [signature] Date 11/18/25
Ryan Perkins [signature] Date 11/18/25

Approval
Teacher signature [signature] Date 11/18/25

Test #10: Cooling Duration Test

Purpose:
Verify the garment maintains cooling for extended use

Materials on hand:

- ☑ Prototype
- ☑ Thermometer
- ☑ Timer
- ☑ Nitrogen Cartridges
- ☑ CO_2 Cartridges
- ☑ Test Chamber

Initial conditions:

- ☑ Room temperature prototype

Pass/Fail Criteria:
The test will be considered a success if the apparatus maintains an average temperature below 55°F ±10°F over a 30-minute time period.

Safety precautions:

Hazard	Controls
1. Apparatus could fall off the table and hit the team member on the head.	1a. Team member will wear appropriate head covering such as a hat or helmet.
2. Team member could slip on the floor.	2a. Test will be conducted on a carpeted floor.

Procedure:

- ☑ 1. Ensure that all initial conditions are met.
- ☑ 2. Ensure that all safety precautions are satisfactory.
- ☑ 3. Release Nitrogen into the shirt
- ☑ 4. Take the temperature at 0 minutes, 10 minutes, 20 minutes, and 30 minutes
- ☑ 5. Record the value in the space provided.
- ☑ 6. Repeat for each weight category.
- ☑ 7. Repeat all the steps, but use CO_2 instead of Nitrogen.

Results:

Average temperature over 30 minutes(Nitrogen) 70.1 °F. Pass ____ Fail X

Weight of User: 100lb-165lb

Time	0 minutes	10 minutes	20 minutes	30 minutes
Temperature	68.1 °F	70.2 °F	71.0 °F	71.2 °F

Weight of User: 166lb- 225lb

Time	0 minutes	10 minutes	20 minutes	30 minutes
Temperature	67.8 °F	70.0 °F	70.9 °F	71.1 °F

Weight of User: 226ln - 285lb+

Time	0 minutes	10 minutes	20 minutes	30 minutes
Temperature	68.2 °F	70.4 °F	71.2 °F	71.5 °F

Average temperature over 30 minutes(CO_2) 63.2 °F. Pass ✓ Fail ____

Weight of User: 100lb-165lb

Time	0 minutes	10 minutes	20 minutes	30 minutes
Temperature	54.0 °F	61.2 °F	64.5 °F	70.0 °F

Weight of User: 166lb- 225lb

Time	0 minutes	10 minutes	20 minutes	30 minutes
Temperature	53.5 °F	62.0 °F	67.3 °F	69.4 °F

Weight of User: 226ln - 285lb+

Time	0 minutes	10 minutes	20 minutes	30 minutes
Temperature	54.1 °F	64.3 °F	68.8 °F	69.8 °F

Signatures

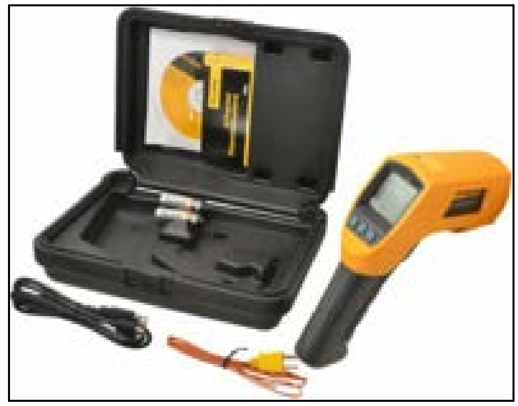
Carson Hull — Carson Hull — Date 11/19/25
Hayden Jones — [signature] — Date 11/19/25
Ryan Perkins — [signature] — Date 11/19/25

Approval

Teacher signature Stacy Higgins Date 11-19-25

Testing Analysis:

Test #1, Temperature Test:



- ➢ The temperature test was a success after switching to CO_2 gas. We were able to complete testing for this criterion by measuring the temperature, using a laser thermometer, which we then recorded data over the course of 6 trials. The temperature consistently stayed in the low 50ºF, resulting in the test being considered a pass.

Test #2, Cost-Effectiveness Test:

- ➢ Our goal for this test was to have the product's unit cost less than $50/unit. We were able to achieve this goal. To meet this criteria, we stayed away from large gas canisters, bought cheaper purge tool options, and ordered from McMasterCarr for the tubing. Since we were able to maintain a steady budget and stay within margins below our original budget, both prototypes are considered a pass.

Test #3, Reusability Test:

- ➢ For testing reusability, we activated the cooling system and measured the damage done to the product after the 30-minute cooling window was over. We did this test over the course of 6 trials, with the results showing no signs of damage over the 3-hour period. The main things our team was looking for were punctures and breaks in the tubing system from areas of greater leakage near the endpoints. Since there were no cracks, kinks, or punctures within the tubing, it passed.

Test #4, Hazard Inspection Test:

- For this test, we looked for any hazards, such as burns or leaks, that would occur after constant use of the product. Using 3 trials, we activated the cooling system and then recorded any hazards after immediate use of the product. From our testing, we found zero hazardous spots, so the shirt is safe internally and will not produce any harm to the wearer. Due to these results, this test was a success as a whole.

Test #5, Odor Resistant Test:

- For this test, we had one of our team members run for a certain distance until they began to sweat. After they ran, we let the shirt sit for around 30 minutes, and we were able to smell the shirt to check for any serious odour. After checking ourselves, we asked several people if they smelled any pungent odour from the apparatus. All individuals, including our team, did not notice any unpleasant smell from the product. These results show that this test was a pass.

Test #6, Weight Test:

- We need to ensure that the vest is lightweight so that it doesn't limit any athlete's capability in their sport. After weighing the product on a scale, the weight resulted in 1.162lb. This is considered lightweight for our product due to it staying under 3-5lb, and will not limit the functionality of the athlete. This procedure was not weighed with the canister because the canister is detachable and will only be in for a short period of time. The test passed the constraints made for the product.

Test #7, Comfortability Test:

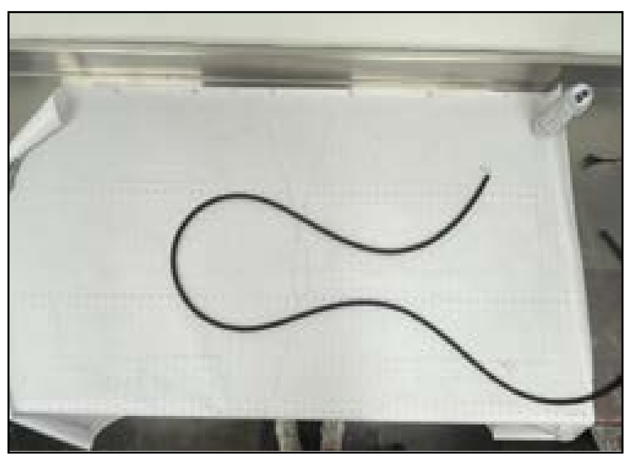
➢ For this test, we had multiple people wear the apparatus, including Hayden Jones, Carson Hull, Ryan Perkins, and Dr. Kevin Stalsberg. After each person wore the cooling vest, we asked them a series of questions relating to the comfort while wearing the product, such as whether there were any uncomfortable poking from the tubing or if the material of the shirt was comfortable in most positions. All participants stated that it felt relatively snug and was not a bother to wear. With an average score of 7.5/10 on a scale of comfort, this test was passed.

Test #8, Mobility Test:

➢ For testing mobility, we had our team each try a basic army stretching mobility test while wearing the vest. The tasks included workouts like jumping jacks, push-ups, shoulder stretches, and walks/jogs. Each team member was able to complete each task without feeling any discomfort from the shirt. This ensures that when athletes wear the product, it will not limit their athletic ability and performance in their sport. The testing results pass our constraints made for this test.

Test #9, Durability Test:

➢ Testing durability had to be carried out by poking and prodding the tubing and shirt with sharp objects, and using hammers to create blunt force attacks on the shirt. After we completed testing, there were zero punctures, kinks, cracks, or rips in both the shirt and tubing for the vest. This result validates the durability of our product and ensures that the athlete will not damage the vest when using it throughout their sport. This test passed its durability constraints.



Test #10, Cooling Duration:

- ➢ The cooling duration was one of our most important constraints when it came to creating our product, which we needed to keep a somewhat consistent cooling effect over the course of 20-30 minutes. We did both tests with the nitrogen and CO_2 gases to determine which one would stay cool for a longer period while also being cost-effective. The CO_2 performed much better than the nitrogen gas and was a cheaper option. The shirt was able to stay below 70ºF after being used 30 minutes prior, which was consistent throughout the 3 trials. These results show that are cooling system is a success, and it will perform for the athletes wearing the vest. The test passed due to the results of staying at a constant cool temperature.

Testing Summary:

Our group was able to pass all testing criteria for our product and excel in categories relating to temperature flow, due to the change from nitrogen to CO_2 gas. Thankfully, most tests were easy to emulate and could be judged accordingly using the tools at the CAA to our disposal. It was hard to test the odor resistance and comfort since we did not have an exact variable to meet when testing, but by using our experience with shirts similar to our product, we were able to compare the shirt properly and pass the tests. Almost every test was done using an outside individual, not from our group, to eliminate any bias we might have toward our product, with several people being enthusiastic about the effectiveness of our product. We also got feedback from Dr. Stalsberg, who has been our leading mentor and interviewee throughout the design and construction process of our product. His reaction to our complete tests was very positive, and surprised by the effectiveness of the cooling throughout the tubing system.

Element J

Documentation of External Evaluation

Dr. Kevin Stalsberg:
Sports Medical Instructor
CAA

September 18, 2025
Kevin Stalsberg gave some helpful questions for us to include in our design process, such as the time duration for our device to be viable for the user. Additionally, finding a way to regulate the temperature, whether it be circulation through a vent or another method. Without circulation, the apparel will heat up quicker as the warm air is trapped inside. The apparel should be able to cool down the athlete without hindering their performance. Remaining within these constraints would greatly benefit the viability of our product and make it marketable to people over previous solutions.

September 25, 2025
Our second interview with Dr. Stalsberg brought up many constraints and questions in our product. One question asked was about how the tubing would cool the person down in a short amount of time and if the tubing would properly regulate heat throughout the body. To answer that, we will need to find the chemical resistance of the tubing's temperature compared to the temperature that radiates from the tubing once it reaches the desired temperature. We were also asked about the target for our product and maybe expanding our audience to the amount in the general population that are more susceptible in high heat settings. This would allow our product to reach more individuals on the market and solve more issues relating to heat illness.

October 9, 2025
Our interview with Dr. Stalsberg was very brief and was mainly a summary of where our product has gone since the last time we spoke with him. We updated him on our sewing, which we were able to get fully completed, and cut to fit proportions for the final product. At this point, we also had the nitrogen tubing system fully mapped out and functional with the Nitrogen canisters that we used at the time, instead of CO_2. After giving our briefing on the product, Dr. Stalsberg emphasized that the nitrogen might not be the right choice for the product due to its low heat resistance, which forces it to heat back up fairly quickly.

November 11, 2025
Dr. Stalsburg allowed us to present our product prototype to his class and gain a better understanding of how others felt about our product. We explained our reasoning behind our design process and why we believed that our cooling shirt was a needed fix towards solving heat-related injuries in college athletes. After going through our pitch, we were asked a plethora of questions relating to the functionality of our product and its heat-conductive properties. One question that was asked many times was the danger of the cold nitrogen gas potentially touching human skin. We informed them that the nitrogen gas is much less harmful than liquid nitrogen,

and the chance of someone getting an injury from the gas itself is very low, considering that the gas is warmer than the liquid form of nitrogen. Overall, we got plenty of needed information and responses from the pitch with Stalsberg, which we were able to use to help us with our testing process.

December 17, 2025
Dr. Stalsberg met with our team to share his feedback on the final product and discuss his vision for its future. He expressed a strong interest in the product and believes it has significant market potential, provided it is supported by credible data. He has reached out to the University of Kansas and Kansas State University to inquire about laboratory capabilities and the feasibility of conducting official performance testing on the shirt. He also recommended that we conduct an in-depth review of the research and testing methods used by similar products so we can replicate those procedures and make accurate comparisons. If the data proves favorable, he believes we should move forward with the patent process and begin marketing the product to organizations such as the NFL, colleges, high schools, as well as individual consumers.

Kent Glasier:
Shawnee Mission School District Head Athletic Director
CAA

September 11, 2025
Kent Glaser explained that most safety and equipment policies for heat management in athletics are established through KSHAA and the NFHS. He noted that most heat illness products currently available are intended for emergency use and typically rely on ice to function. Glaser emphasized the importance of temperature gauges and pointed out that equipment such as pads and helmets restricts airflow, increasing the risk of overheating. He recommended implementing more effective preventative measures rather than relying solely on emergency responses. Glaser also highlighted that football linemen are among the most susceptible athletes to heat-related issues and mentioned that cooling vests are often kept in ambulances for quick access during games or practices.

November 13, 2025
We met with Kent Glaser a second time after we finalized our shirt design and obtained the copper tubing. The main topic of this interview was whether we should use copper tubing or TPV tubing for our product. Mr. Glaser recommended the TPV tubing since the copper tubing would ultimately be very immobile and affect the athlete's comfort and mobility. Even so, Mr. Claser stated that he doesn’t know the exact heat transfer properties of both the copper and TPV tubing, but he knew that there would be no point in the vest if it did not allow for proper

movement. Overall, this interview helped us finalize the tubing we will be using for our product, and gave us an “athletic advisor” look into how the tubing’s flexibility would affect athletes.

Ayden Raza:
Mechanical Design Engineer
Hoefer Welker

September 23, 2025
During the interview with Mr. Raza, major questions were raised relating to the concerns of how the tubing will effectively hold and regulate the temperature of the gas. One solution that was brought to our attention was using a very thin copper tubing that could withstand extreme temperatures more than any other metal, and it can regulate temperatures very well for extreme cases. The concern with metals would be the comfort for the athlete while wearing the vest, since the strength of the copper material would restrain or affect the movement of the athlete. So we were advised to put more research into finding the pressure and heat transfer properties of TPV tubing (our group's original idea), so that we can identify if using the tubing or even liquid nitrogen would be the best option

December 10, 2025
Mr. Raza provided feedback and asked several follow-up questions after our presentation. He noted that our slideshow was well-organized and contained strong, relevant information. He then asked whether we had conducted any testing comparable to the collision forces experienced in football to evaluate the shirt’s durability. We confirmed that we had performed such tests, and he recommended that we include those results, as well as any additional durability testing, in future presentations.

Josh Holloway:
Systems Engineer
Tesseract Ventures

September 24, 2025
Josh focused on improving the control of gas flow and system efficiency. He recommended developing tubing ports capable of adjusting the flow rate and designing a gas release system or port to make the most out of each charge. Josh also highlighted the need to plan for refilling or recharging the nitrogen efficiently and to consider how the flow paths within the tubing can affect overall cooling performance.

Spencer Lifferth:
Mechanical Engineer
Burns & McDonnell

September 26, 2025
Spencer emphasized considering the thermal mass of materials surrounding the tubing, as this will influence how long the gas remains cool. He suggested calculating this by finding each material's specific heat capacity. Additionally, he recommended measuring the thermal conductivity of the tubing itself. He also proposed using a phase change material, such as ice melting to water, to help maintain lower temperatures for a longer duration.

November 14, 2025
In our second interview with Spencer, we mainly updated him on our product and asked if there was any way we could make the cooling effect stronger and longer-lasting. He recommended two ideas to us; one being to ditch the tubing system entirely and have the gas flow through the vest freely. The main problem with this solution is that the nitrogen already has a short time span of cooling, so the cooling time would be cut even shorter without a tubing system. The other idea he brought up was pressurizing the tubing system using the canister, keeping it shut, and then relieving the pressure to shock cool the vest. Overall, he gave us solutions that will help us finalize the cooling process of our product.

Italo Bett:
Electrical Engineer
IEEE KC Chair

November 10, 2025
During our interview with Italo Bett, he highlighted that one of the most unique and valuable aspects of our design was its efficiency and ability to provide quick cooling, allowing athletes to recover and return to activity almost immediately. He emphasized that this feature could be a major advantage in protecting athletes' health and preventing heat-related issues. Additionally, he challenged us to consider whether the tubing system in our design was truly necessary, encouraging us to explore alternative methods that could achieve the same cooling effect with potentially less complexity and improved comfort.

Michael McGuire:
Electrical Engineer
Honeywell

November 14, 2025
During our interview with Michael McGuire, we discussed how our product was going to properly function if the nitrogen heats up too quickly and can't cool the athlete down. He brought up many helpful solutions to our problems, such as pressurising the vest on a sideline using a large air compressor, using a rotation of two vests during sports events, and just putting the nitrogen straight into the vest without a tubing system. But all of these solutions were not able to meet all the constraints we made for this product, so he recommended we switch our product's coolant entirely. Bringing up CO_2 gas instead of nitrogen was the switch we needed to have the cooling last longer and cost less money to manufacture. The interview was one of the most successful ones we had, due to the conversion from nitrogen to CO_2, and now our product can reach much lower temperatures and last longer, completing our tests with predicted results.

Jack Temko:
Mechanical Engineering Student
University of Kansas

December 10, 2025
After presenting our slideshow and final prototype, Mr. Temko provided feedback and asked several follow-up questions. He expressed enthusiasm for the project and responded positively to our presentation. He recommended that we engage with larger, nationwide organizations, such as the NIH or the NFL, to obtain detailed information on applicable regulations and to confirm that our prototype is legally permitted for use during games. He also raised a question regarding our temperature testing methodology, specifically asking where the laser was positioned during measurements, and emphasized the importance of measuring multiple locations along the tubing.

Conclusion

The feedback we received from our professional interviews greatly shaped the direction of our NitroCool design. Dr. Kevin Stalsberg emphasized the importance of maintaining consistent cooling over time without restricting athletic performance, which led us to incorporate a circulation system and define measurable time goals for effectiveness. He also encouraged us to study chemical resistance and heat transfer properties of the tubing while considering broader markets beyond athletes. Kent Glaser's feedback highlighted the need for preventative cooling solutions and lightweight, breathable materials to counter the airflow restrictions of pads and helmets. From our engineering consultants, Ayden Raza's advice prompted us to research both copper and TPV tubing for temperature and pressure performance, Josh Holloway guided us to add adjustable flow controls and a recharge system for better gas efficiency, and Spencer Lifferth's insights on thermal mass and phase-change materials helped us extend cooling duration.

Altogether, their feedback refined our design from a basic cooling idea into a practical, efficient, and marketable system. But one of the most important interviews that helped us was with Michael McGuire, where he brought up the use of CO_2 in place of nitrogen. This breakthrough improved our product overall, allowing for longer-lasting cooling and greater cost-effectiveness. As a whole, these professionals gave us multiple advancements in our design process and allowed us to create the most ope timal cooling vest, meeting our constraints.

Element K

Project Design Process and Summary

Define the Problem:

For NitroCool, we sought to create a cooling function that, when in use, could be worn to reduce the body temperature of the user and give a relieving sensation to someone who has overheated. The design was an attempt to add a form of prevention for those suffering symptoms of heat-related illness.

The justifications for our problem stemmed from first-hand experiences from our team in sports, conducted research among the Shawnee Mission School District, online Health studies, and the passing of a student at Shawnee Mission Northwest High School relating to heat illness. We wanted to fill a gap in the market because of the lack of prevention devices with an abundance of emergency protocols. Why allow student athletes to get to a point of emergency when it could be prevented with a cooling shirt? We also value the discomfort of athletes and want them to be confident on the field by reducing heat-related symptoms.

Generate Concepts:

Our first idea, where NitroCool comes from, was the application of liquid nitrogen to relieve the human body from heat illness, due to its cooling properties demonstrated in complex systems such as biological sample storage. All of the sketches we created for our device would allow for a tubing system to wind around the body, allowing a fluid to run through safely. The expectation was for the fluid’s heat transfer to get from the tube to the body and the surrounding shirt material. We later realized the limitations of liquid nitrogen use for a commercial purpose and opted for CO_2 gas instead. The questions that remained unanswered were the tube material and the tubing path for maximum efficiency inside the shirt.

Pick a Solution:

Our solution came from a series of trial and error. For the tubing, we had two large criteria in mind: Durability and heat transfer. We needed something that could withstand hits in a sport such as football, but still yield a long-lasting cool temperature for the athlete. We created a list of the best tubing options and cut down until we got down to two options. The copper boasted the best results for cooling; however, it was susceptible to wear and tear and was very uncomfortable for the user. TPV tubing allows for easy flexibility, doesn't get in the way, and still manages to allow a change in temperature. Additionally, our inner layer of the shirt was originally long-sleeved, but we ended up cutting it down to get rid of unnecessary fabric. We then had to decide whether compressed nitrogen or CO_2 gas would be most optimal for heat transfer throughout the system. We ran several tests and trials using both types of gas and found that the CO_2 gas was not only cooler and longer-lasting, but also around 5x more cost-effective than the nitrogen gas. So, for our final decision, we decided to opt for CO_2 for our system's coolant.

Construct a Prototype:

We started the creation of our prototype by making a decal with a Cricut and then heat-pressing it onto our outer shirt. After, we drew the tubing path on the inner shirt using chalk. We then stitched fabric strips along the piping layout on the inner shirt and attached the outer layer to the inner layer by sewing the seams of the sleeves and neck. Once we had the prototype fully assembled, we started running tests, but we noticed a huge setback in the effectiveness of nitrogen gas. After taking input from professionals into mind, we changed to CO_2 cartridges, which yielded much better results. A drawback for stitching was the amount of time it took, due to none of our team being familiar with sewing or stitching. Ideally, we may have wanted to produce a second shirt to run tests with. However, our two-layer system, along with the layout, gave us a very comfortable prototype that satisfied testing. Our tubing also suffered when we plugged the end, as compressing gas inside the tube without a release would increase the temperature. We created small holes along the tube's body that release the gas inside the shirt, giving more circulation to the wearer and decreasing the temperature of the system. Once the tubing was properly fixed in place, we added a purge tool that could connect and screw in nitrogen canisters, allowing gas to flow through the tubing. We used electrical tape to help keep the purge tool in place when connected to the tube, and we 3D printed a cap for the other end of the tubing to help regulate the amount of gas that leaks out of the system. Lastly, we used glue and electrical tape to attach the cap to the end of the tubing, ensuring no big leaks.

Element L

Project Design Recommendations

Cooling shirt recommendations:

1. Shirt design should be double-layered, while using more elastic material for the outer and inner layers
   - ➢ Shirts with high contents of spandex, polyester, and nylon would be optimal due to their tight compression fit, breathability, and allowance for mobility.
   - ➢ Using an elastic or cotton thread will allow for long-lasting sewing in place and will create less damage to the stitching over long periods of time.
   - ➢ Creating a system of patches that hold the tubing system in place, outside of the inner layer. Recommended use of strict fabric materials that counteract the rubber material of the TPV tubing
   - ➢ Installing a zipper at the bottom of the shirt is preferred, which would make both tube changing and washing the product much easier and reliable. A zipper system will also allow for small modifications if needed without having to remove stitching within the shirt.
2. Install a tubing system that can transfer heat properly, and connects to both the perge tool and a plug to keep gas in.
   - ➢ Tubing must be durable to withstand harsh impacts from people and objects, while also properly transferring the coolant of use, so the heat transfer is noticeable and acts as a system of cooling for the recipient wearing the product.
   - ➢ Tubing should also be flexible to maintain comfort and proper mobility for the athlete. If the tubing is too stiff, it will restrict movement for the athlete and likely be prone to permanent denting into the tubing, which would prevent the flow of CO_2 throughout the product.
   - ➢ Tubing should be easy to fit around the port with minimal additions to the port attachment. We recommend using a high-force withstanding tape, like electrical tape, that will withstand high pressure from the CO_2 canisters
     - i. Correct tubing: TPV, TPE, and Plastic/Rubber materials
     - i. Incorrect Tubing: Stay away from any hard materials such as copper, aluminium, dense metals, and chemically weak tubing
   - ➢ Add small holes to the tubing in an assorted pattern using a small poking and prodding tool, like a small pair of scissors, a knife, or a compass tip. These holes will act as a decompressor for the tubing system and allow for greater flow throughout the person's body of CO_2. Without the holes in the tubing, pressure would be to great in the tubing system and not only heat up, but risk breaks and punctures in the tubing.

3. Canisters and the purge tool should be able to properly flow gas through the tubing system.
    - ➢ Originally, we tried to use nitrogen canisters for the cooling system, but the cost-to-performance ratio of the nitrogen was very poor. The pressure in the nitrogen canisters is not as sufficient as other alternatives and will result in less cooling over time. Using pressurized gases like CO_2, O_2, and H_2 will serve as a more cost-efficient gas and be more pressurized, allowing the gas to expand, creating a cooler effect for the athlete.
    - ➢ Using a proper purge tool is necessary for the product, which will determine the flow rate of the gas and the amount of leaked gas generated from the system. A small, cheaper option like a CO_2 bike purge tool would be cost-efficient and easy to set up. While more expensive options might regulate the flow of gas better, it would likely be larger and more restrictive on the person wearing the shirt, and may cause more leaks if they are not fixed to the tubing properly.
    - ➢ Smaller canisters are preferred for the product due to their versatility and easy accessibility in athletic practices and overall activities. The size of these canisters should range from 16-18g of the gas you want to use, but you could use larger canisters that range from 80 - 100g. The large canisters would be easier to use in a scenario where they could be on the sideline of a game or in an area with minimal activity. It would likely be harder to move around and cost much more than the smaller canisters, but produce a more effective and longer cooling experience Thus, if a person is focused on financially efficient canisters while also keeping minimal work, then the smaller canisters would be the correct move.

Design Recommendations or Project Improvements:

The cooling shirt should be a double-layered construction using elastic and breathable fabrics such as spandex, polyester, and nylon. These materials provide the compression fit, flexibility, and airflow required for performance. It is recommended that reinforced stitching with elastic or cotton thread be used to ensure long-term durability. The shirt should incorporate a system of fabric strips between the layers that secure the tubing in place without chafing the wearer, preferably from friction-reducing fabrics against the tubing material.

For better usability, we could incorporate a zipper system on the bottom of the shirt for quick insertion or removal of the tubing, easy access for washing, and the ability to carry out minor repairs or modifications without having to dismantle seams that play a crucial role. Tubing should be made from flexible, durable materials such as TPV, TPE, or similar soft plastics, which can withstand impacts and motion with continued cooling. Similarly, softer tubings have reduced chances of kinks or dents in order to maintain good flow throughout the usage of the product.

The tubing should be securely attached to the gas port, with high-strength tape or another reinforcement method, preventing detachment during movement. A pattern of small controlled openings along the tubing may be one way of controlling internal pressure to allow for an even distribution of airflow, with the provision that such a system remains structurally safe and stable. Hard metals or rigid tubing materials should be avoided because of their weight, sharp edges, and susceptibility to damage under physical activity.

For cooling, small gas canisters coupled with a compact purge tool can provide effective and mobile use. While smaller 16–18 g canisters are preferred for active athletic use, larger volumes may be acceptable for stationary configurations, such as on the sidelines. A good purge tool allows regulation of the release and eliminates wasted leaks; smaller versions incorporate more easily into wearables. Though various choices in gases provide several cost-to-performance trade-offs, the system shall focus on safe, easily available options that expand and cool properly.

The CO_2 canisters can prove to be tedious if many players on a team have a cooling vest, as the canisters would then be a waste to use all of them. So, if in a sports game or practice, using a large CO_2 container or air compressor on the sideline would be more efficient and less tedious over time if the user plugs the port straight into the large container. The waste from canisters would be less, and the cost would be more effective, which is why, if plausible, it is recommended for a larger compressed container for multi-player practices.