2.0 Executive Summary

2.1 Product Description

2.1.1 Physical Description

InnovatioNDistillation has developed an emergency water recovery system. The product is a water distillation device, which runs solely off of human mechanical input. Specifically, cycling charges a generator. Acquired energy is transferred to heat through sequential operation of a heating cartridge and thermoelectric (TE) module. This heat boils brackish water, which is condensed on the reverse side of the TE for drinking. The entire system is comprised of three main segments: the frame, gearing and power transmission, and the boiling and distillation system. These divisions are integrated to provide the structure, energy, and control needed to produce potable water through distillation. These three systems are discussed briefly.

The frame was constructed through manipulation of a Huffy road cycle. An indoor bicycle training stand was used to raise the rear tire and provide the needed stability. An original bicycle frame was chosen for two reasons: first, for its proven mechanical integrity. A Frame Trade Study was performed to analyze the forces and moments created on a cycling structure. It was found that a collapsible fabricated frame could be constructed using steel or titanium tubing, but would be heavier and cause lower factors of safety than a purchasable cycle. Secondly, a road bicycle creates an established geometric advantage in pedaling applications. To seize the most energy out of the mechanical input through pedaling there is no better human position to be in than that achieved while on a bicycle. This was discovered through collaboration with cycling specialists.

The power transmission assembly includes the sprocket system and generator. The Wind Stream and Power 280 W generator was chosen based on its performance in several key areas. Power output, torque input, and input rotations per minute were several of the essential categories researched (See Generator Trade Study). The original bicycle sprocket and chain system was utilized. Also, a large sprocket was attached to the rear wheel and a small sprocket to the generator shaft. A second chain connected these two and provided the gearing ratio needed to spin the generator shaft at the desired rate.

The distillation system was comprised of the boiler, heating cartridge, thermoelectric (TE) module, condenser, and piping. The heating cartridge was chosen based on its ability to transfer energy directly to the water within the boiler (See Heating Element Trade Study). The TE is the crucial interface that assists in boiling the water on the top and condensing the water on the bottom. With an electrical input the module creates a temperature gradient between its two faces by transferring energy from the cool side to the warm side. Energy is dissipated as heat during operation which further assists in the boiling process. The boiler consists of a small thermos and was selected based on its insulation and heat resistant characteristics. It is also conducive to drilling fabrications necessary to integrate the heating cartridge and TE module. The condenser was fabricated out of aluminum plating and implements a series of fins housed in a diffusive rectangular box. The Condenser Trade Study highly influenced the integration of this component by analyzing a range of fin sizes, quantities, and arrangements.

2.1.2 Key Features

The main goal of InnovatioNDistillation was to distill as much water as possible with a provided amount of energy. Striving to achieve a relative COP of greater than 1, such as that seen in a refrigeration cycle, was important. This is why the product implements the joint TE module and heating element. The key feature that controls this system is the sequential operation embedded intelligence. In order for the TE to work in equilibrium, energy flowing out of the hot side (that in contact with the water) must equal the energy absorbed by the cool side (that in contact with the steam). If energy is not dissipated at this critical rate than temperatures could become too low or too high and the performance of the TE would be compromised. To prevent this from occurring, the sequential operation intelligence monitors the temperatures seen on the two sides of the TE. If critical combinations of temperatures are reached than the input energy from the generator is reverted to the heating cartridge. This is controlled through series transistors and, in the prototype, a manual switch and LED's mimic this automation. Because the TE is the key to maximizing performance, controlling it effectively has also become a key feature of the system.

2.2 Design Relevance

InnovatioNDistillation has built its emergency water recovery system to assist in and alleviate the primary issues following natural disasters. Through collaboration with professionals much information was gained:

> Natural disasters, as well as some human-caused disasters, lead to human suffering and create needs that the victims cannot alleviate without assistance. Examples of disasters include hurricanes, tornadoes, floods, earthquakes, drought, blizzards, famine, war, fire, volcanic eruption, a building collapse, or a transportation wreck. When any such disaster strikes, a variety of international organizations offer relief to the affected country. Each organization has different objectives, expertise, and resources to offer, and several hundred may become involved in a single major disaster.

Of these many organizations it was found that over half of them assist in providing potable water to victims (Other Information – Disaster Relief Organization Table). This is due to the fact that dehydration, hunger, and lack of sanitation are the major causes for death post-disaster. To give disaster victims more independence and ability to sustain health for longer periods of time InnovatioNDistillation has created the distillation device. A product such as this could either be bought by those in high disaster-risk areas, or distributed by disaster relief organizations.

Competition in this market includes any product that alleviates dehydration issues in times of disaster. This includes bottled water and advanced filtering and purification mechanisms, which are currently heavily distributed in times of disaster. After discussing these issues with professionals from Red Cross it was found that a major problem with current distributions and relief is that supplies run out quickly. InnovatioNDistillation's product is suited for continued use and provides a means for unlimited clean water over time. If distributed by disaster relief organizations than the device can be reused from one relief effort to the next, which would make this product extremely unique.

2.3 Design Process Used

Much emphasis was placed on achieving an efficient, high quality design process due to the strict budget and rigid time constraints. Therefore, the design process was broken down into four stages—1) Project Definition and planning, 2) Specification Definition, 3) Conceptual Design, and 4) Prototype Development (See Other Information – Ullman's Mechanical Design Process).

2.3.1 Project Definition and Planning

Within this first section of the design process several crucial tasks were performed. First of all, team positions were assigned such as prototype supervisor and group leader. This provided responsibility and accountability for each member. Next, research was performed in several areas of importance, such as distillation and human power generation, to provide the group with background information regarding the project (See Other Information – Research). The target market was defined early (See Other Information – Target Market/Goals) along with quantifiable goals to guide upcoming design decisions. Most important within this phase was the development of a Gantt chart to monitor progress and create internal deadlines for the team (See Other Information – Gantt Chart). Last of all, a preliminary budget was created to estimate the allocation of the funds provided.

2.3.2 Specification Definition

Still early in the design process was the specification definition section. Here InnovatioNDistillation identified the customer and researched the prospective of the project. These two tasks were performed in order to generate the engineering specifications that our product would potentially meet. Identifying the customer included contacting several disaster relief organizations (See Collaboration). From here it was determined what type and style of product would be useful and for what specific situations it could be applied. As a result of this, the competition was benchmarked (See Other Information – Competition). Products such as filtration mechanisms, iodine tablets and even bottled water were explored. This helped the team understand the need for the product. For example, no product currently on the market could provide an unlimited source of potable water. These realizations were made parallel with researching the potential of the project. Issues such as the boiling and distillation processes were analyzed. Human power production was investigated as well. Grasping the physics behind each component of the product was necessary for creating realistic engineering specifications. Following this, these quantifiable engineering specifications were defined (See Other Information – Design Requirements). These results heavily influenced further design decisions.

2.3.3 Conceptual Design

This section accounts for a large portion of the time committed by team InnovatioNDistillation. Although this was the third stage in the process, certain aspects were approached right from the beginning such as concept generation. Each group member created a concept sketch to share during the initial team assembly phase (See Other Information – Initial Concepts). When defining the market, ideas were continuously being brought up and reflected upon. Finally, several options were being considered during the development of the engineering specifications that aided in visualizing and quantifying the goals of the project. It was after this point, however, in which the critical concept evaluation was done. This primarily involved four trade studies each pertaining to an imperative piece of the project (See Supporting Information – Technical Documentation). For example, one trade study was done that analyzed the feasibility and applicability of several heating elements to be used within the boiler. Key product components were continuously being analyzed at this point as well. For instance, the ability of a thermoelectric module to be used simultaneously as a heating and cooling device was investigated. Design decisions were continuously being made during this extensive period of formulation and evaluation. Specific components were selected based on the facts gained from analysis, the updated budgeting information, and the performance speculations.

2.3.4 Prototype Development

The last stage of the design process was the prototype development. Actual assembly, component integration, and testing and troubleshooting were performed in this phase. The influence of early design decisions became evident in this stage of the development. The more work that was done to ensure compatibility of elements early in the design, the more apt they were come together as intended. In problem areas quick analysis, evaluation, and design decisions had to be made. For example, the integration of the generator shaft and small sprocket deviated from the original design due to the large clearance and therefore a compatibility-filler was fabricated. Finally, with a working prototype several performance tests were made (Other Information – Performance Testing).

2.4 Options Considered

While making final design decisions there were two major options being considered. The main difference between the two options concerned the distillation system. The first option implemented a transcritical refrigeration cycle to power the boiler and condenser, while the second alternative consisted of a thermoelectric module and heating element in its place. The focus of each was reusing the energy given off by the steam when condensing. The two competing schematics are seen in figures 1a and b below.

Both designs implement the same power generation system, shown simply in the schematic as a pedal-chain system, which drives a generator. The key features of each option and the technical difficulties associated with each are shown in table 1. Notice that while the transcritical refrigeration cycle is a well known technology it would be very expensive and demand the precise integration of multiple components. The compact and durable thermoelectric solution became the best fit for the application despite the uncertainty of the technology.

2.5 Solutions Selected

2.5.1 Key Components

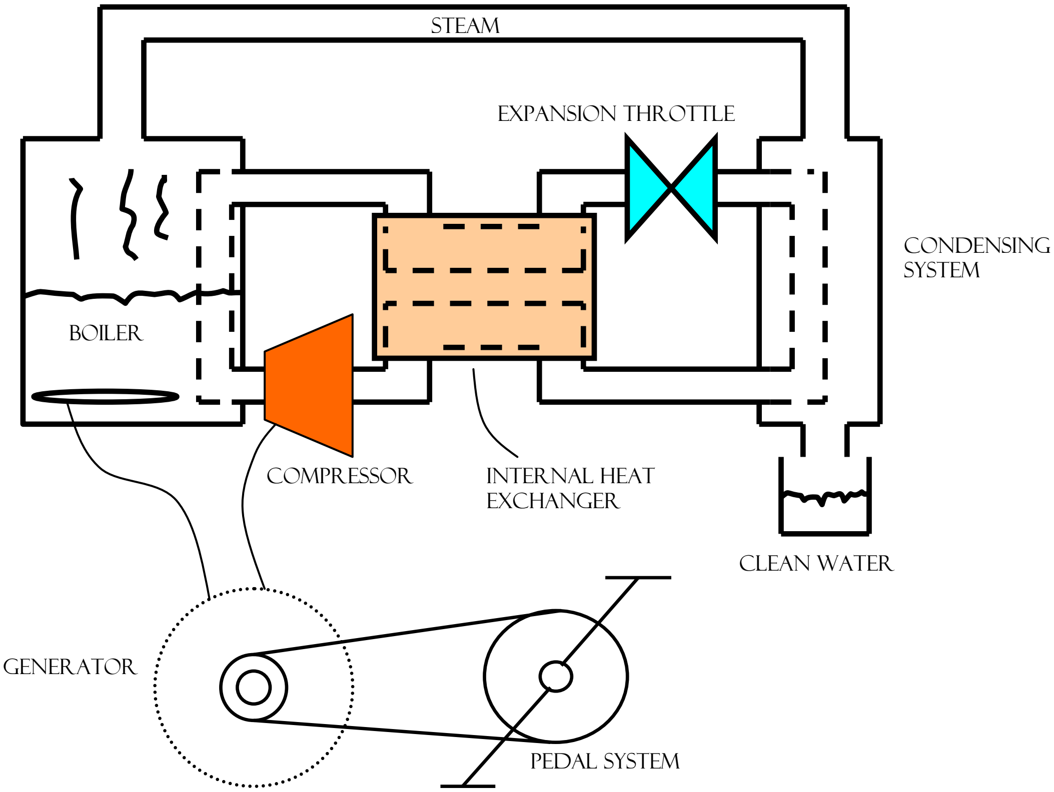

***Figure 1:** Transcritical CO_2 vapor compression cycle – Option 1*

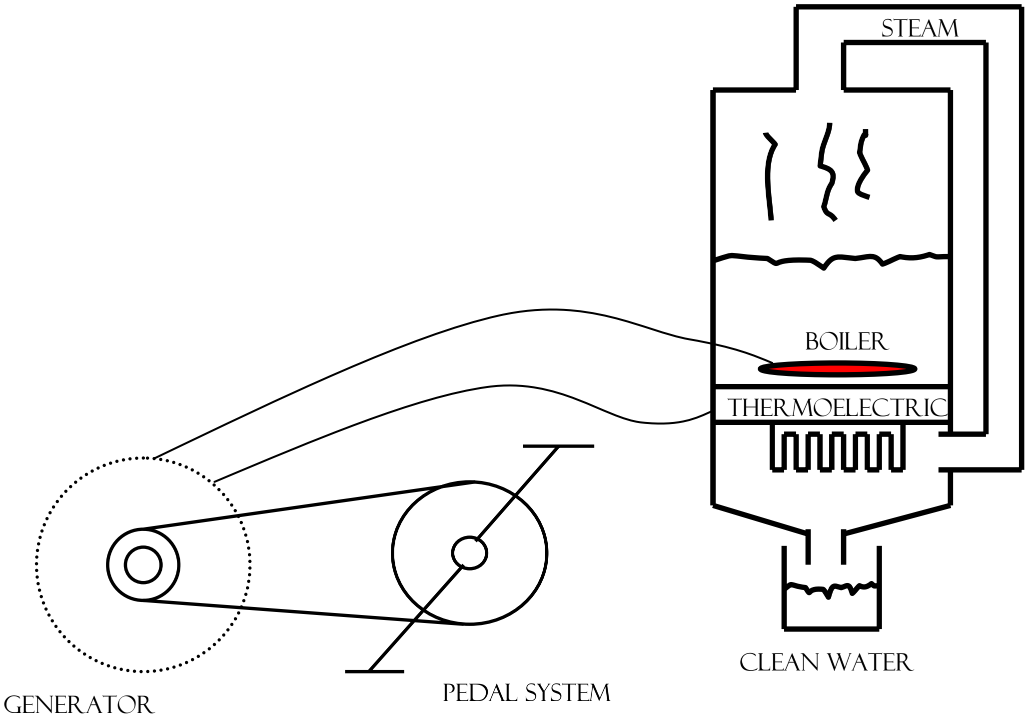

***Figure 2:** Thermoelectric module and heating element – Option 2*

Table 1: *Quality Features and Technical Challenges of Options Considered*

CO$_2$Transcritical Cycle		**Thermoelectric Module**	
Quality Features	**Technical Challenges**	**Quality Features**	**Technical Challenges**
COP > 1	Assembly / Piping	Component reduction – TE module heats boiler and cools condenser	Relatively new technology (not often used in heating applications)
Well known technology	Reduce size	Compact and mobile	Boiler / Condenser interface
Maximize efficiency	High pressure CO$_2$ – Sealing	COP very close to 1	Pipe insulation
	Safety Risks	Simple design	Sequential Operation
	Budget – Many critical components	Rugged	

After analyzing the feasibility of each option the thermoelectric module was selected. The product would consist of a 4 x 4 cm TE module that would contact the bottom of the boiler and the top of the condenser to provide a temperature gradient benefiting the operation of both systems.

A cartridge heater will be used to assist the boiling of the water and will work in sequential operation with the TE module. The heater will be two inches long and be fully submersed in the water to ensure all energy is transferred to the water (Heating Element Trade Study). The condenser will consist of an array of aluminum fins that will be cooled such that the steam will readily condense after entering. The precise arrangement was determined in the Condenser Trade Study. Twelve ¼” thick fins are aligned with ¼” gaps to maximize the condensation and ensure the water runs down the sides. The piping in which the steam will travel from the boiler to the condenser will be well insulated so that no energy is lost through condensation before the condenser is reached.

2.5.2 Strengths and Weaknesses

The design option chosen will be very compact and rugged. The boiler and condenser integration allows for the mobility of a single unit. The critical components, including the TE module and heating element, will be tightly integrated to the system and will be resistant to being dropped from at least three feet high. This option is much less complicated than the transcritical cycle, and therefore removes many unforeseen difficulties that could arise during development.

Although the system is much simpler the technology is relatively new. There is a potential that essential steam flow rates will not be reached and the TE module will not assist in boiling and condensing as intended. Although the goal of the sequential operation is to ensure the TE’s success, it is not guaranteed.