Chemically Engineered Car Team 2017-2018 Report

Fast and Ferrous

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Propulsion Team: Harsh Kapadia, Hieu Tran, Gayatri Pillai, Juan Sanfiel, Julian Jackson, Michael Druckman, Pragya Singh

The propulsion team's main objective was to find a chemical reaction or chemical process that could act as a power source to propel car in a **safe, efficient and economical manner**. The overall progress throughout the year can be divided into three main phases: Brainstorming, Testing, and Implementation.

In the first phase, our team considered and discussed numerous ideas such as the aluminum-air battery, the lead-acid battery, pressure-driven gas piston, and the thermoelectric generator. The pros and cons of each idea were listed methodically and discussed with the chassis team as well for feasibility. The chemistry underlying each idea was the focal point of the team's discussion, along with the economics and safety of its implementation. For example, in lead acid battery, the lead rods were extremely expensive to manufacture. Furthermore, the mechanism utilized a strong and corrosive acid, sulfuric acid ($H_2SO_{4)}$. Similarly, the idea of the aluminum-air battery was dropped due to its unreliability from our past experiences with the zinc-air battery. **Thus, we narrowed down our options to the idea of a thermoelectric generator for the propulsion mechanism primarily due to its easy design, low cost, reproducibility, and high efficiency.**

The propulsion mechanism is based on the Seebeck effect, a thermoelectric phenomenon in which a **temperature difference between two dissimilar electrical conductors leads to a voltage difference**. As we heat one end of a thermoelectric material, the electrons will move away from the hot end toward the cold end. When the electrons go from the hot side to the cold side this results in an electrical current. The voltage is directly proportional to the temperature difference between the two junctions, as shown in the equation below.

$$V = a * (T_{hot} - T_{cold})$$

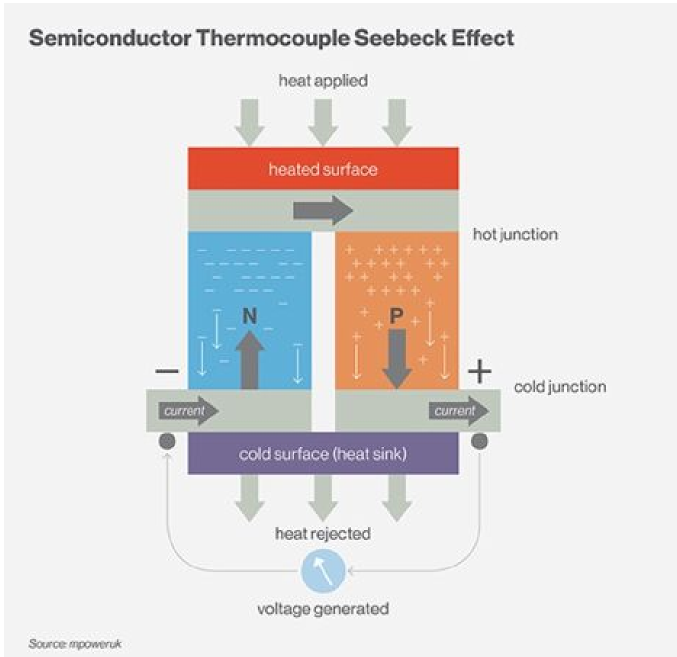


Figure 1: Schematic showing the mechanism of action of the Seebeck effect. The figure shows the flow of electrons, the direction of current, and the composition of thermoelectric plates at the molecular level

In the second phase, we had to test the proposed mechanism in the laboratory setting to ensure the feasibility of the mechanism. The heat source was chosen to be the dissolution of calcium chloride ($CaCl_2$) in dI water, which was an exothermic reaction that could generate heat very quickly. We tested this reaction in a beaker, in which we dissolved different concentrations of the calcium chloride to monitor its effect on the temperature of the solution. *Figure 2* highlights the direct correlation that we observed between the maximum temperature of the reaction mixture and the concentration of the calcium chloride.

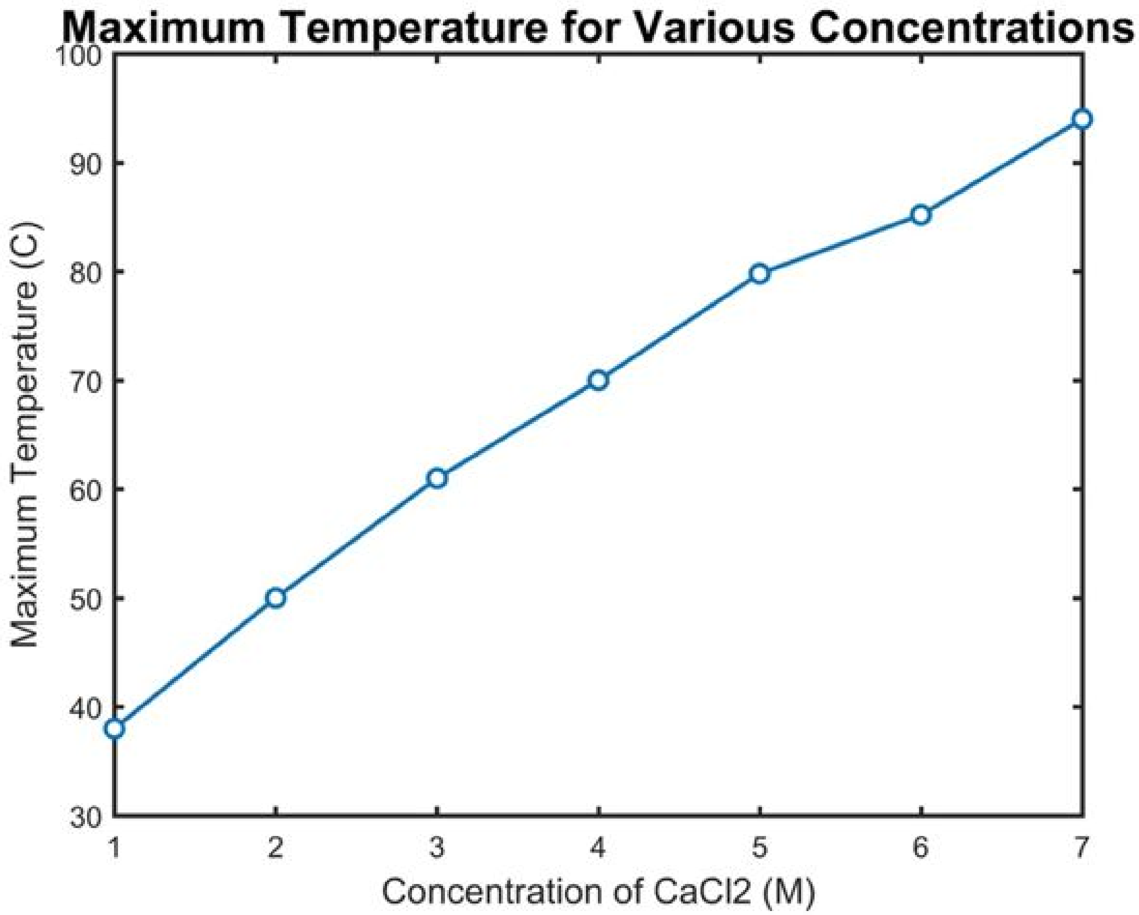


Figure 2: Graphic showing the direct correlation between the maximum temperature and the concentration of $CaCl_2$. The graph shows that 7M $CaCl_2$ is the ideal condition to run the exothermic reaction below the boiling temperature of water at 100°C.

Once we established that **7 M of $CaCl_2$** was the ideal concentration for dissolution in 200 mL of dI water, we proceeded to utilize ice as our heat sink. To achieve a deliverable voltage and amperage, we connected **10 thermoelectric plates** together, having 5 plates in series that were finally connected in parallel. These plates were glued to the bottom of an aluminum box with thermally conductive glue, to allow for the maximal heat transfer between the exothermic reaction and the plates. The final voltage and amperage produced by this battery setup amounted to **7 Volts and 1 Ampere** respectively.

In the third and final phase, we had the task of implementing the reaction on the car in a streamlined and safe manner. We ensured that the reaction was insulated through the use of **polystyrene (Styrofoam) box** in which we housed the reaction apparatus – the aluminum box and the ice. The wires of from the thermoelectric plates were soldered together as observed in

Figure 3A. Furthermore, we measured the change of voltage and amperage over time, as the car operated, and found that those parameters changed relatively slow over the required time frame to the run the car. This ensured the car could operate at the desired speed for as summarized in the *Figure 3B* below.

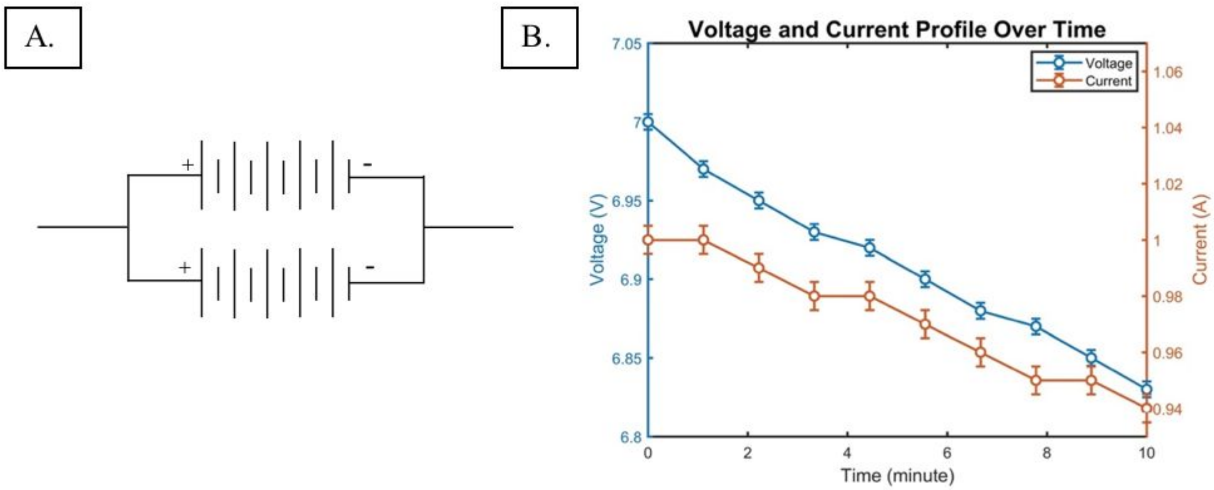


Figure 3: Schematic showing the final setup of the Battery along with data from its operation. (A) Circuit diagram displaying the arrangement of the connectivity of the thermoelectric plates (B) Graphic representation of the voltage and current measurements produced from the battery as a function of time of operation

Stopping Team: Christopher Domalewski, Hayden Good, Tarush Gupta, Lily McGonagle, Charles Ndiaye, Milena Nino, Michael Shen, Daniel Xenes, Casey Zhu

New Stopping Team

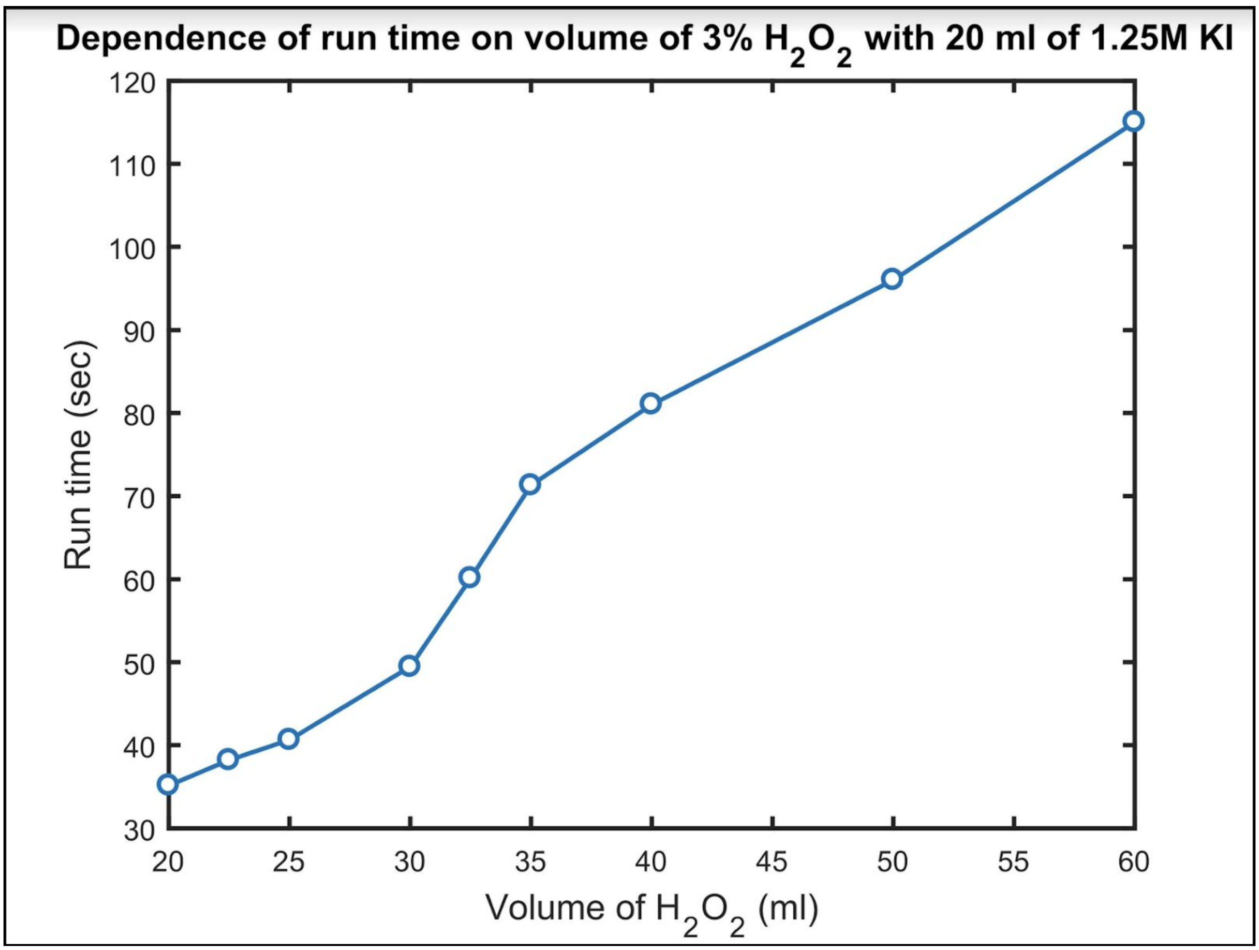
During the Fall '17 semester, we examined a number of potential stopping mechanisms, all of which utilized the catalytic decomposition of hydrogen peroxide by potassium iodide:

$$2H_2O_2(l) \rightarrow O_2(g) + 2H_2O(l)$$

Specifically, we used 3% H_2O_2 and 1.25M KI solution made from dissolving 20.75g KI salt in 100 mL DI water. This reaction produces liquid water and oxygen gas as products. Our goal was to create a stopping mechanism based on the pressure increase caused by the buildup of oxygen in a sealed rigid container.

Our first proposed mechanism involved a syringe connected to the reaction vessel through plastic tubing. The increased pressure resulting from products of the decomposition reaction would push the syringe plunge out, eventually pressing a switch that would stop the car. This mechanism was not used due to the unpredictability of syringe movement, difficulty in adhering to safety rules, and flawed design (multiple leakage points).

We instead used a pressure switch to stop the car. By closing a circuit at a specific pressure, the pressure switch allowed more accurate control the "threshold pressure" that would stop the car and would be less prone to leakage and inconsistencies. The metal tube fittings used in the pressure switch also allowed easy installation of a pressure gauge and relief valve, both of which were required components in any pressure (>1 psig) mechanism.



As shown in the “Finished Car” image under the Chassis team section, a Buchner flask sealed using a septum stopper was used as the reaction vessel. Although a standard rubber stopper was initially used, the septum stopper was determined to be more consistent in controlling the rate of air leakage. A low pressure gauge (0-15 psig) and 10 psig relief valve were used. The pressure switch was calibrated to a contact setting of 1.5 psi with a tolerance of ±0.5 psi. To begin the reaction, a plastic tube attached to the pressure switch was securely fastened to the flask nozzle and sealed with Parafilm. Next, hydrogen peroxide was poured into the empty Buchner flask. Once all other preparations on the car were completed, the potassium iodide solution was added to the hydrogen peroxide within the flask. Immediately after pouring the potassium iodide, the septum stopper was pulled over the top of the flask. As the H2O2 decomposed, the generation of oxygen gas increased the internal pressure of the flask, eventually tripping the gauge, completing the circuit connecting the battery and motor, and allowing the car to run. Depending on the volumes of each chemical used, the time for the pressure to reach the contact setting of 1.5 psi ranged from 50 to 100 seconds. Similarly, the car's total distance traveled depended on the volumes of reagents used. Over the course of several weeks, experimental data concerning the runtime and distance based on various reagent volumes was collected. After each run, the septum stopper was removed, followed by the Parafilm and plastic tubing. Between runs, the stopper and flask were washed with tap water and dried with Kimwipes. All chemical residue was disposed of in a sink.

Research and Development Team

During the Fall '17 semester, the Research and Development team (formerly the Old Stopping team) explored the color changing crystal violet decomposition reaction whose mechanism is shown below:

$$[(H_3C)_2NC_6H_5]_3C^+ \;+\; OH^- \rightarrow [(H_3C)_2NC_6H_5]_3COH$$

The stopping reaction involved a photo sensor sending a stopping signal to the the car's motor by detecting the the dark purple solution change to a colorless solution upon the addition of NaOH. After spending a few weeks optimizing the reaction, we were able to manipulate the reaction to react within a 40 sec - 1:30 minute time frame. In further testing our proof of concept, we tested the solution with the photosensor from previous years however were not able to achieve positive results. We found that the photo sensors used in the past was providing unreliable and inconsistent results when tested in ambient conditions. We arrived to this same conclusion when we bought other types of photo sensors/photoresistors and tested it with our reaction. The probe was not showing consistent results and so we began to test whether inserting the probe in the liquid would change this. After some testing, we ruled this out and then looked at the reaction itself and questioned whether the starting concentration was dark enough. We increased the concentration of the crystal violet purple solution however we did not see any difference. Our team decided to revisit the iodine clock reaction with old and new photoresistors however arrived to similar inconclusive results. After much dialogue, we decided to abandon the idea of using a color changing reaction and photo sensor combination to stop the car and instead focused our efforts on assisting the new stopping team to prepare for the competition. In the future, our team recommends veering away from using a color changing reaction due to reliability issues with photosensors/resistors and also with the purpose of differentiating ourselves from the rest of the competition. One idea that our team had considered in the beginning of the year was possibly looking into a stopping mechanism that involved a pH changing clock reaction detected by a pH sensitive probe.

Chassis Team: Christopher Lin, Abraham Gomez, Jessica Harsono, Luis Rodriguez

Car Design:
Our vehicle is made primarily of lightweight clear acrylic and fastened together by screws with glue for integrity reinforcement. The car has two levels; the first has a casing for bearings, which hold two metal axles attached each to two wheels. On the first level, we have mounted the stopping mechanism, while on the top we have mounted the propulsion mechanism. The propulsion mechanism is connected to a pressure switch attached to the stopping mechanism that works as ON/OFF which is then connected to an emergency ON/OFF switch, and then to the motor. Finally, our car has space to carry a weight load attached to the back of the vehicle by Velcro. The weight load carrier is a 750 mL plastic water bottle. Each chemical reaction occurs inside a container that serves as a safety measure in case any spills take place during the loading of the solutions, or while the car is running. All components on the car are also secured by Velcro to serve as an extra method of reinforcement.

In addition, apart from the compartmentalization offered by our two levels, we made an effort to make sure the wiring of the car was optimally convenient. This meant that the wires went around the Standard-Wall Unthreaded PVC Pipe to get out of the way from the stopping mechanism. We soldered a 9V battery clip to the end of our wire coming from the motor and another one to the end coming from the battery so that these could be separated and connected when we wanted to test the car. This brought upon complications along with its advantages. Although we could easily transport the components (battery) and car since they were separable, the 9V battery clip wires that were to be soldered were sizably thinner compared to the wiring from the end of the wire of the motor and battery. This made it harder to solder since any soldering that did not fully leave the wires connected took away at the power the motor received and greatly reduced the efficiency. It is recommended that next time, if the same wiring layout is used, to solder wires that are the same width so that the connection and soldering can be more straightforward. Although our overall circuit design was efficient by requiring little wiring and no Arduino, it proved to be a main problem during competition. Specifically, one of the soldered wires snapped just before the car's second run, rendering the entire car nonfunctional. A way to account for this in the future is to ensure strong soldering of wires, or to have a backup system built in on the car that can be easily switched to in case one of the main wires breaks again.

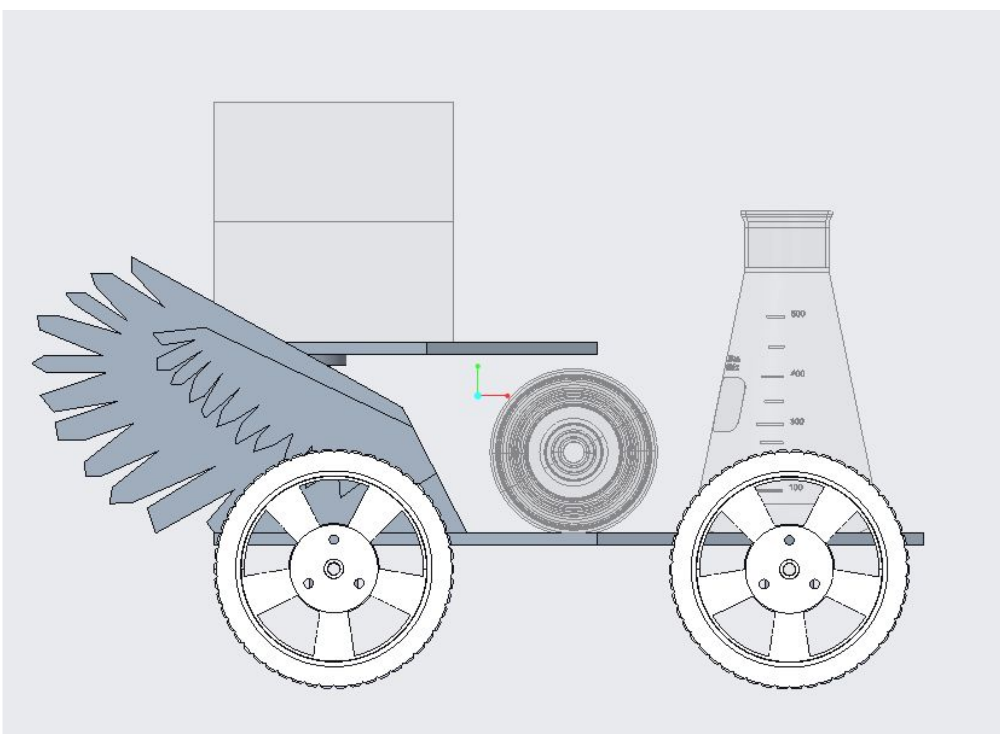
Additionally, the motor we selected was finicky, requiring the team to run the motor with no load to "discharge" any stored resistance before being able to use it normally. This wasn't too much of a problem because the other reactions needed time to build up, therefore leaving a time window to discharge the motor, but this was still inconvenient. When the motor did run and the car moved forward on the tarp during competition, it experienced problems creating enough torque to overcome the added friction from the folds and bumps on the tarp. Although the motor could be heard, the car itself seemed to stall and move at a slower speed than on smooth ground. This could be due to the belt slipping, the gear ratio being too low, or the motor being too weak altogether. Suggestions include replacing the motor with a different model, or performing more tests in order to understand and tweak the current motor so that its behavior is completely predictable. Lastly, we made the mistake of putting the wheel's axles and gluing on the wheels before putting in an intact motor belt. We had to glue the belt for the majority of the year, which caused problems and jumps when the belt would break. For design day, we fixed this issue by taking the car apart and putting in a new belt, but this should be a mistake that does not happen again.

Car Cost:

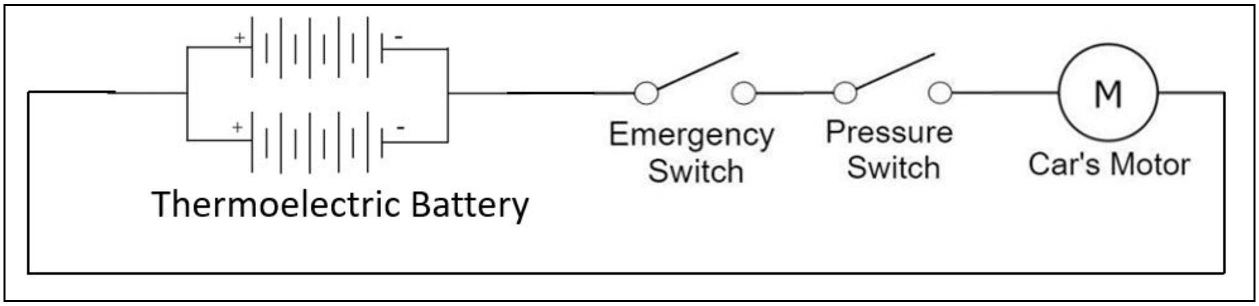
McMaster & Amazon			
	Units	Cost per unit	Final cost
Standard-Wall Unthreaded PVC Pipe	1	11.4	11.4
Ball Bearing	1	30.89	30.89
Clear Acrylic Sheet	2	16.33	32.66
Lightweight Timing Belt Pulley	1	8.2	8.2
Rotary Shift	2	12.17	24.34
Tamiya 4-Speed High Power Gearbox H.E. 72007	1	13.99	13.99
Light Up Scooter Replacement Wheel	1	14.95	14.95
Trigger Action Bar Clamp	2	12.23	24.46
Total			**$112.09**

Standard Wall Stainless Steel Pipe Nipple Threaded on one end	4	1.5	6
Pressure Relief Vent	4	1.72	6.88
Standard Wall Stainless Steel Pipe Nipple Threaded on both ends	5	2	10
Steel Threaded Pipe Fitting	3	7.98	23.94
Corrosion Resistant Pressure Gauge	1	73.87	73.87
Stainless Steel Barbed Tube Fitting	1	3.69	3.69
Worm Drive Clamps for Firm Hose and Tube1	1	5.87	5.87
BUD Industries CU-247 Aluminum Econobox	1	20.17	20.17
Total			**$150.42**

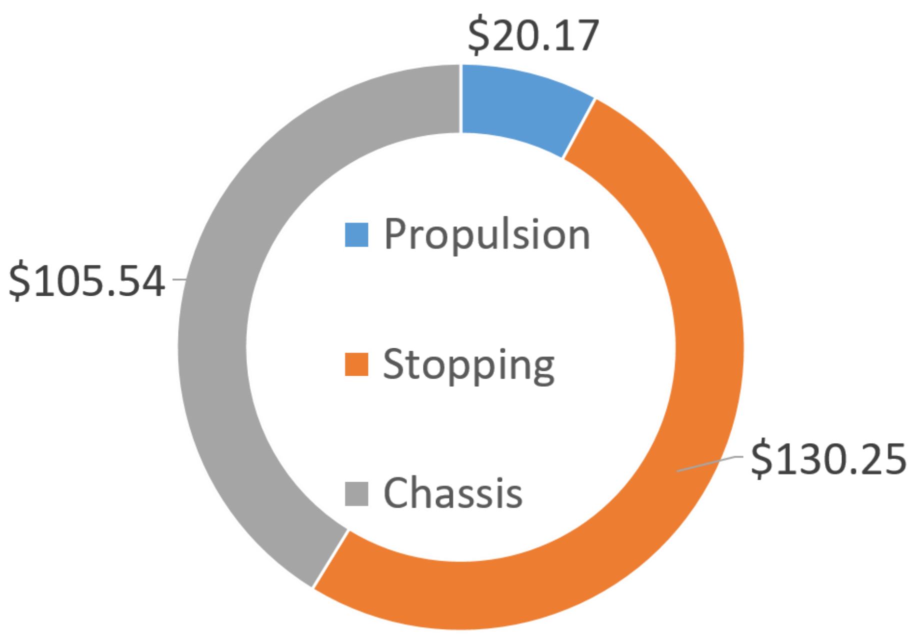
Car CAD:



Car Circuitry:



Car Cost Diagram:



VEHICLE COST

- Total Cost: $255.96
- Cost per Run
  - Propulsion: $16.00
  - Stopping: $1.17

Finished Car:

We did not end up using wings because there was not enough room on the car.