Shell Eco-marathon Competition: Fuel Efficiency
100% of Final Report

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April 15, 2015
Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Luis Meza, Magin Perez and Javier Gutierrez and it is original. Excerpts from others’ work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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ABSTRACT

The main focus of this project is to manufacture and optimize a prototype concept vehicle competed in the Battery-Electric Division of the Shell Eco-marathon in April 2015. Following the design restrictions and rules that Shell provides and with collaboration from senior design team 11, the mindset of the Shell-Eco Marathon team is to build a lightweight and efficient vehicle that will ensure the best power to weight ratio and achieve an excellent km/kwh rate. Team 12 is in charge of optimizing three main components of the vehicle. Luis Meza is in charge of the bodywork, which includes the design, simulations, material selection, and testing. Magin Perez is in charge of the Chassis including material selection and testing, design and simulations. Javier Gutierrez is in charge of the energy management and power delivery for the vehicle that includes schematics, motor selection, and testing. The battery powered car was built and optimized before being taken to Detroit to participate in the Shell Eco Marathon competition in April 9th to April 12th.
1 INTRODUCTION

1.1 Problem Statement

Global warming and the burning of fossil fuels has been an issue for a very long time. At the rate of consumption around the world, these fossil fuels that are already limited will eventually be tapped out in due time. Not only is our reservoir being sucked dry, we leave a carbon foot print for every ounce of fossil fuel burnt into the atmosphere and the ozone is impacted by the greenhouse effect, increasing the global temperature. As a result, the arctic icecaps are melting exponentially and the oceanic levels are rising. The team’s solution in the battle to reduce global warming is introducing a 100% emission-free eco-friendly vehicle that has no polluting by-product.

1.2 Motivation

Producing a clean and highly efficient vehicle to win the competition is the main goal, while having an innovating design with advance energy management design along with the best power to weight ratio and most aerodynamic body is keen when trying to accomplish it. Previous teams from FIU as ranked as high as 5th place, in the Battery-Electric Division and this year’s Shell Eco-Marathon team hoped to rank higher than those previous teams so it can improve the reputation of FIU. The team worked closely with past competitors and they helped through the process of the project.

1.3 Literature Survey

This survey illustrates the rules and regulations that are applied to the functionality of the components that the car can been built to show. To create a positive and fair playing field for all participants, these rules are strictly enforced and give the SEM (Shell Eco-Marathon) team a
detailed layout of how the automobile should be. Inspections were performed on the vehicle according to these guidelines.

1.3.1 Regulation Requirements

Shell supplies access to a complete publication of the rules and regulations for each year’s competition. The team will have to be in constant awareness of the reference book to be certain that every design requirement is met and applied to the car before the manufacturing of the vehicle begins. A copy of this rule book is provided the appendix D of this report.

1.3.2 Competitor Assessment

To take a look into the competition that the SEM will be facing, the team has gathered all possible results and data that is publicly provided by past winners in the category of hydrogen fuel cell division and also the Battery-Electric division. Since most of the teams do not publish their research and data, the FIU SEM team has limited information on its competitors. Anyhow, the team will further examine and take into account past winning models not only from the competition in North America, but East Asia and Europe as well. The team will give consideration to other winners in separate categories because of the fact that the body shape and aero dynamic factor of the car is the same throughout all categories.

Figure 1: University of Colorado Denver Car [1]
The University of Denver has competed consecutively in the Shell Eco-Marathon in the hydrogen fuel cell division and have won the division two years in a row with a rate of 87.1 km/kWh in 2013 and 60.15 km/kWh in 2014. In this division they are the team to beat. The team investigated as much as possible about their car as possible. Since the rules have changed, vehicles designed for the 2015 competition cannot be open designs. The driver has to be completely covered by the car’s exterior with no exceptions. It was also found that many cars that enter the competition use light weight, lower density materials such as carbon fiber as the exterior. Some manufacturing procedures and tips were found and tried to be implemented in the construction of the panther bullet.
Figure 3 illustrates the 2nd place winner of the Shell Eco-Marathon competition in 2014. Their best result in the competition was 34.2 (m/kWh). It can again be noticed that these vehicles are open to the head of the driver. Therefore, it was a challenge to not have any feedback on effective past body designs to be guided into the most efficient one. In essence, the design considerations and alternatives are purely derived from research of aerodynamic designs and research. Figure 4 illustrates another efficient competitor in the fuel efficiency competition but it was considered that the design of the body had too much drag and better designs were easily found as alternatives. Apart from body shapes and designs of former competitors, not much information is open to the public with regards to energy management, steering, brakes, etc. The Evo Supermilage car illustrated in figure 4, is made of carbon fiber sheets. Even though this competitor uses a combustion engine, this gives a clear idea of what other teams are using for materials and gives us evident clues into how these vehicles are being constructed, since working with carbon fiber usually requires much of the same procedures. The 2015 FIU SEM team prides itself in innovation and took only some ideas from former competitors to point in the right direction but under no circumstance to try and imitate them.
1.3.3 Background Theory

Power Management:

For power management it is necessary to transfer the highest amount of energy with the minimum lost. The following equation displays the theoretical value for efficiency.

\[ \text{Efficiency (in\%) } = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100 \]

Where:

- \( P_{\text{out}} \) = Total output power delivered to the lead
- \( P_{\text{in}} \) = Total input power

If the team had incorporated the regenerative braking system the following equation is the theoretical value when 2 energy sources are present.

\[ P_S = P_P - P_L \]
Where:

\[ P_S = \text{Power delivered to the load by the secondary} \]
\[ P_P = \text{Power delivered to the primary by the source} \]
\[ P_L = \text{Power losses in the transformer} \]

**Frame:**

The chassis or frame of an automotive is essentially tasked with holding all the components together. It does this while driving and transferring all loads, both vertical and lateral that are caused by acceleration through the suspension and to the wheels. It is understood that the key to a good chassis is that the further away the mass is from the neutral axis, the more rigid it will be. The chassis will consist of Carbon-Kevlar fiber reinforcing the inner shell of a monocoque; the reason being that the main benefits of Carbon-Kevlar is that in tension the elastic modulus is such that deformations are kept to a minimum which makes for a very rigid design. Carbon-Kevlar is also known for its superior resistance from impact, fatigue, and wear and tear. Kevlar is used broadly when manufacturing sporting goods equipment, marine vessels and also in the automotive and aerospace industries. By uniting Kevlar and Carbon fibers we can observe an increase in toughness, flexibility, abrasion resistance and the benefit that the driver is most interested in is its improvement in impact resistance.

The automotive industry has provided us with a layout of how the design should be carried out and the team has considered this to be order of the design process for this component:

1. Generate concepts on paper
2. Choose a concept
3. Create and refine that concept in clay at scale
4. Larger more refined concept generated
5. Concept adjusted to fit the person and parts
6. Adjusts to fit chassis platform and suspension
7. Body changes for Aerodynamics
8. Prototypes built and tested with compromises
Body:

Designing the body of our car is a challenging part and one that requires plenty of time and attention since this component is so crucial to the performance of any energy-efficient vehicle. The main important things when bodywork is designed are the aerodynamic and the weight; our bodywork should have a low drag coefficient and be very light; so it can be very efficient. The most aerodynamic shape is the drop shaped; this one produces less air resistances; as a consequence of this a drop shaped design was chosen for our bodywork.

![Laminar flow around a good shape.](image)

![Turbulent flow around a bad shape. Drag is proportional to the size of the wake.](image)

![Too steep an angle at the rear causes separation and increased drag. The rounded front moves the separation point further back, compared to the flat fronted case.](image)

![Shallower angle with sharp cut-off (Kamm tail) leaves a smaller wake and less drag.](image)

Figure 5: Airflow [5]

When a very light body is needed, choosing the right material is an important thing. Our first option was carbon fibers. It is a light and very strong material and is commonly used wherever high strength-to-weight ratio and rigidity are required such as in aerospace, automotive and civil engineering, sports goods and an increasing number of other consumer and technical
applications. Carbon fiber is a material consisting of fibers about 5–10 μm in diameter and composed mostly of carbon atoms. To produce carbon fiber, the carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fiber as the crystal alignment gives the fiber high strength-to-volume ratio (making it strong for its size).

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2 PROJECT FORMULATION

2.1 Overview

This section shows key objectives that the team set in order to place a benchmark by which the team based its efforts. Apart from establishing highly ambitious goals for the project, there are certain specific requirements that need to be met in order to participate in the competition which are previously discussed and are attached to the appendix of this report. The FIU Shell Eco-Marathon team’s high expectations and required objectives are united to create their goals and objectives.

2.2 Project objectives

The general objective of this project is to design and build a highly efficient prototype vehicle to compete on the shell-eco marathon competition 2015. Aside from this main goal, there many specifics objectives that have to be achieved in order to give the FIU SEM team a solid chance of winning the competition; the most important are the following:

- Design vehicle capable of producing approximately 115 km/kWh, which is the old FIU record.
- Build a car with an overall weight of 110 pounds.
- Design an Aerodynamic body for the car that will have the lowest drag possible.
- Build a solid understanding of how batteries can power a vehicle.
- Produce a functional and efficient frame capable of supporting all the forces the vehicle experiences.
• Give our input into the search of alternatives energies to power all the vehicles in the world.

This list gives a limited illustration of all the personal and professional objectives the team wished to overcome. Even though representing FIU and winning a competition would give a certain level of prestige and pride, there is a lifetime lesson that will benefit the team as a whole in the skills of communication, problem solving and team work amongst many other soft skills.

2.3 Design Specifications

The Shell Eco-Marathon organization have a set of rules and specifications for the vehicles designs, in order to increase the technical challenges and the opportunities to discover and explore new technologies, as well as to increase the safety standards of the competition. Since in this competition there are two types of vehicles that you can design and build, Futurist Prototype and Urban Concept vehicles, the organization have specifications for both types of vehicles; because we are designing a Futurist Prototype we are only going to mention the design specifications for the prototypes.

According to the Shell Eco-Marathon 2015 official rules the maximum dimensions for the prototype vehicle are the following:

• The vehicle maximum height must be less than 100 cm.
• The vehicle track width must be at least 50 cm, measured between the midpoints where the tires of the outermost wheels touch the ground.
• The ratio of maximum height divided by track width must be less than 1.25
- The vehicle wheelbase must be at least 100 cm.
- The maximum total vehicle width must not exceed 130 cm.
- The maximum total length must not exceed 350 cm.
- The maximum vehicle weight, without the Driver is 140 kg.

### 2.4 Addressing Global Design

This project touches several important points regarding global learning. One of the most important is the use of alternatives fuels to power our vehicles. In the world there is a continuous search of a new type of energy sources, more efficient and less contaminating than the fossil fuels. Projects like this gives little but valuable contribution to this search and the awareness that can ultimately increase the chances to get efficient results and a cleaner planet.

One of the categories of the competition is the vehicles powered by a hydrogen fuel cell. Fuel cells generate electrical energy through the chemical reaction between hydrogen and oxygen to power the motor. Hydrogen is an efficient and environmental-friendly energy source that can easily replace the gasoline in the future to power the vehicles. Even though technology is not advanced enough for hydrogen fuel cell powered cars to be safe enough to drive, it is widely believed that with technological advantages growing in an exponential rate, before the next century we will have found an alternative to fossil fuels. Battery powered vehicles and hybrids have been on the rise these past few years. With the emerging success of the Nissan Leaf and Tesla Motor’s product line, it has been proved that an attractive battery electric automobile that consumers enjoy and like is achievable.
3 DESIGN ALTERNATIVES

3.1 Overview of Conceptual Design

Several designs of cars were taken into consideration, but only three were designed in Solidworks and compared one to the other in order to choose the best one. The first design is a car with the shape of a bullet with 2 wheels on the front and one wheel on the back; the wheels are covered by the body. The second design has the shape of a water drop with two wheels on the front and one in the back. The third and final design is also a bullet shaped body with two wheels on the front and one on the back but in this design the wheels are not covered by the body, allowing us to use less material to build the body and reducing the cost of the car.

The two first alternative designs belong to the category of the vehicles powered by a hydrogen fuel cell; but at the end for our final design, we had to choose to enter the competition in the Battery-Electric category instead of the Hydrogen fuel cell because we could not collect the funds to buy the hydrogen fuel cell.

3.1.1 Electric Motor

For the electric motor the target is a 500 Watt motor that will attach to the rear wheel that will propel the vehicle through the racetrack. The hub motor will be attached to the rear of the vehicle and the team will be focusing on how to transmit the power from the energy source to the motor distributing the weight evenly. The team had an option to choose a higher wattage for the hub motor, but would result in higher consumption of energy therefore a less efficient design. The hub motor is a brushless motor on contrary to a motor with a spindle shaft which would require a gear reduction setup adding more weight to the car which is counterproductive.
3.1.2 Energy Management

Energy management is a very important part of this prototype vehicle in order to achieve a high efficiency and reduce power loss. Our goal is to produce a central management system that will control the distribution of the power circulating within the power plant. It must monitor and transfer energy efficiently from the energy source to the motor with minimal loss. In the case of adapting a regenerative braking system, that energy must be transferred to super capacitors to then be used to power the wheel instead of the fuel cell/battery, reducing the consumption of the vehicle. Introducing an adaptive kill switch or a manual override of the management system will further reduce the overall energy consumption.

3.1.3 Frame

The team was subjected to a few different designs, most of which were clearly not suitable for this project. Some of the designs considered were the Monocoque, Tub, Backbone, and Ladder Frame.

The ultimate goal for the chassis is make it as rigid and light weight as possible. For this reason a space frame approach in the design of the chassis was the first considered. Due to the fact that the team chose a strong material as the body, it was decided to remove the idea of a space frame and implement a monocoque design with reinforcements as needed to act as a frame or chassis. This option completely removed the need for a traditional frame and focused on the body material and its construction approach to fully support all of the vehicles components. This method yields good results when dealing with weight holding, torsional rigidity and ultimately impact protection. It is relatively simple to design and not very difficult to

Figure 6: Space Frame Example [6]
build. Part of the design alternatives were to be aware of how to place the reinforcements in the inner shell of the body without compromising space for the driver and also the weight of the car. The reinforcements, consisting of strategically located strips of carbon-kevlar and carbon fiber material will give superior rigidity and stabilization to the design of the monocoque. Special care was taken when designing this part of the car to ensure the team meets all of the safety and design regulations.

Figure 7: Monocoque Shell

3.1.4 Body
The body and frame should combine to make a sturdy and structurally safe aerodynamic shell referred to as a monocoque. Its construction must consist of a carbon-Kevlar fiber sheets that can be shaped into complex parts. Since the body will produce protection for the driver and also will help to reduce the energy consumption, all the designs need to be very well studied before building it. Flow simulations in Solidworks test the aerodynamics of the vehicle and studies its reaction under static loads to test the resistance capability. Simulations of the body were done in every alternative design of the exterior so that the team could be sure that the body was going to achieve its purpose without failing.

3.2 Body Design Alternative One

This design was the first one to be considered. The body of this design has the shape of a bullet which is a very aerodynamic design. In this design all the wheels are covered by the body, in order to reduce the drag force cause by the wheels components. The form of a water drop was previously mentioned, studied and taken into account when designing these alternatives.

Figure 8: Design Alternative # 1
On this design a flow simulation study was done, to determine the drag coefficient. The input speed of the wind for the simulation was 3 m/s, so the Reynolds number was 10000.

![Figure 9: Flow simulation on Alternative Design # 1](image)

The results of this flow simulation showed us the drag force, force that was used later to calculate the drag coefficient, with this equation:

\[ C_d = \frac{F_d}{\frac{1}{2} \rho V^2 A} \]  

(Equation 1)

where:

- \( F_d \): is the drag force, which is by definition the force component in the direction of the flow velocity.
- \( \rho \): is the mass density of the fluid.
- \( V \): is the speed of the object relative to the fluid.
- \( A \): is the reference area.

Table 2: Drag coefficient of alternative design one

<table>
<thead>
<tr>
<th>Goal Name</th>
<th>Unit</th>
<th>Value</th>
<th>Reynolds number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drag Coefficient</td>
<td>Unit less</td>
<td>0.230863436</td>
<td>10000</td>
</tr>
</tbody>
</table>
3.3 Body Design Alternative Two

For this design the team went with a three wheel displacement design that consist of two wheels located on the front of the vehicle and outside of the exterior shell in order to have greater mobility when turning. By lowering the rolling resistance of the tires, an aerodynamic efficient front of the car can be achieved. The rear tire is located behind the driver connected to the motor, powered by the batteries. The rear wheel will be centered and covered by the body to reduce the drag in the rear of the vehicle.

Figure 10: Design alternative #2

A flow simulation was done in this design as well in order to see the streamlines of the fluid and calculate the drag coefficient.
3.4 Body Design Alternative Three

The last option for the design of the body had the challenge of making an extremely light car. This goal of achieving the lightest possible design gave way to the realization that if reinforcements are applied to the body with carbon fiber strips accordingly, the idea of a tubular frame chassis could be removed therefore obtaining the monoque that has been previously explained. After designing the body, simulations were performed on it to obtain important information like safety factors and drag coefficient. This information gave feedback on the efficiency of the model in order to retain certain aspects of it or change it.
3.5 Feasibility Assessment

Although the three designs were taken in consideration in terms of fabrication, weight, aerodynamic efficiency, the last design is more feasible. The last design has more capability of excelling at the Shell Eco-marathon Competition because it does not have a chassis so the cost and weight will be reduced significantly. Out of the three alternative designs, this is also the one with the lowest drag coefficient obtained in the flow simulations.

3.6 Proposed Design

The proposed design car will have a body composed of two carbon– Kevlar fiber layers and one foam layer that will function as the core material between the other two; the three compressed layers will gives the body the strength that the car needs in order to be safe. This car will be reinforced with extra layers in some specific points as the roll bar or the wall where the front
wheels will be attached. This car will have a windshield that will cover all the front part and two side windows; to gives a wide vision to the driver which encompasses one of the specific inspections that was passed at the competition which is to have 90 degree visibility to each side, followed by other visible points that were tested and will be later explained in this report.

Figure 13: Isometric View of Panther Bullet
4. PROJECT MANAGEMENT

4.1 Overview

The project management for this project is essential to the completion and quality of the end products. Since the FIU Shell Eco-marathon Team’s ultimate goal is to participate and win the competition in 2015, there will be a rigorous log of activities that are going to be carried out in order to make sure that actions and short term goals are being met. The project has been divided into three phases; design, operations and manufacturing. The design process consists of performing all studies, tests and analysis in order to ensure the design of the car meets all requirements for both safety and regulations of the competition. The design process involves all responsible members of the team to complete their assigned design of a component of the car by the appropriate time while communicating effectively with other component managers to ensure consistency and compatibility.

The operations phase focuses its efforts on several but crucial elements of this project. The operations phase will also be divided into three branches consisting of the following; treasury, sponsorship and logistics. Treasury will focus primarily in ensuring that all of the capital acquired or raised by the team will be used as efficiently as possible. Sponsorship will concentrate on the proposal, packages and benefits that will be offered to potential sponsors in order to increase funding for the manufacturing of the Panther Bullet and the communication between the FIU Shell Eco-marathon Team and company sponsors. Logistics will base its efforts in make sure all of the parts ordered in preparation for manufacturing have been paid for and have arrived at a suitable time while ensuring all of the materials and components are stored safely and organized.
Manufacturing will begin as promptly as all of the designs have approved by all component managers and all of the materials have been gathered at a set location. Construction of the car has to be carried out in an organized and efficient manner with respect to man hours and material utilization. A signed log will be kept of each hour worked on the car and what has been done.

4.2 Breakdown of Work into Specific Tasks
4.3 Gantt Chart for Organization of Work and Timeline

Table 4: Gantt chart For Shell Eco-Marathon Car

<table>
<thead>
<tr>
<th>Task</th>
<th>PLAN START</th>
<th>PLAN END</th>
<th>ACTUAL START</th>
<th>ACTUAL END</th>
<th>Duration</th>
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<th>2015</th>
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<tr>
<td>Research</td>
<td>10-Aug</td>
<td>20-Aug</td>
<td>22-Aug</td>
<td>22-Aug</td>
<td>22 days</td>
<td>Aug</td>
<td>Sep</td>
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<td>Literary Survey</td>
<td>10-Sep</td>
<td>1-Sep</td>
<td>10-Sep</td>
<td>10-Sep</td>
<td>10 days</td>
<td>Oct</td>
<td>Nov</td>
</tr>
<tr>
<td>Design</td>
<td>1-Oct</td>
<td>16-Oct</td>
<td>17-Oct</td>
<td>17-Oct</td>
<td>12 days</td>
<td>Dec</td>
<td>Jan</td>
</tr>
<tr>
<td>Calculation and Analysis</td>
<td>15-Oct</td>
<td>17-Oct</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control and Stability Analysis</td>
<td>10-Nov</td>
<td>10-Nov</td>
<td>10-Nov</td>
<td>10-Nov</td>
<td>8 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computational Aerodynamics</td>
<td>1-Dec</td>
<td>6-Dec</td>
<td>6-Dec</td>
<td>6-Dec</td>
<td>16 days</td>
<td></td>
<td></td>
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<tr>
<td>Prototype Construction</td>
<td>5-Jan</td>
<td>2-Jan</td>
<td>2-Jan</td>
<td>2-Jan</td>
<td>4 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body Construction</td>
<td>12-Jan</td>
<td>16-Feb</td>
<td>16-Feb</td>
<td>16-Feb</td>
<td>42 days</td>
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<tr>
<td>Windows Construction</td>
<td>31-Jan</td>
<td>3-Mar</td>
<td>3-Mar</td>
<td>3-Mar</td>
<td>15 days</td>
<td></td>
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<tr>
<td>Steering and Wheels Installation</td>
<td>12-Feb</td>
<td>15-Mar</td>
<td>15-Mar</td>
<td>15-Mar</td>
<td>10 days</td>
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<tr>
<td>Brake Assembly</td>
<td>20-Feb</td>
<td>17-Mar</td>
<td>17-Mar</td>
<td>17-Mar</td>
<td>3 days</td>
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<tr>
<td>Rear Wheel Assembly</td>
<td>12-Mar</td>
<td>25-Mar</td>
<td>25-Mar</td>
<td>25-Mar</td>
<td>3 days</td>
<td></td>
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<tr>
<td>Ventilation System</td>
<td>17-Mar</td>
<td>26-Mar</td>
<td>26-Mar</td>
<td>26-Mar</td>
<td>2 days</td>
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<tr>
<td>Paint and Polish</td>
<td>20-Mar</td>
<td>2-Apr</td>
<td>2-Apr</td>
<td>2-Apr</td>
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<td>Testing Runs</td>
<td>21-Mar</td>
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<td>2-3 days</td>
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<td>Optimization Modifications</td>
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<td>Competition</td>
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<td>Report</td>
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<tr>
<td>Presentation</td>
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<td>22-Apr</td>
<td>22-Apr</td>
<td>0 days</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.4 Breakdown of Responsibilities among Team Members

Magin Perez will be the chassis component manager and obtains the responsibility of gathering research and analyzing several design alternatives for the chassis. Magin also oversaw and participated mainly on the construction of the body as well as the rest of the car as needed. Since the chassis and frame were later integrated, Magin and Luis consisted of component managers as to the implementation of the support for all components and the driver. Each component manager is open to recruit their own team outside of the senior design group to participate in the design and construction of the car. This gave us a broader presence at FIU and ensured that the project will continue beyond the Spring 2015 semester. Luis Meza is in charge of the design, analysis and construction of the body. Luis created prototypes and performed
analysis both virtual and on smaller scale samples of the exterior to ensure the most effective
design for the aerodynamics and rigidity of the car. Javier Gutierrez is in charge of the energy
management and powertrain of the car. Javier will also oversee how the energy management
systems are implemented and connected in a way that it maximizes efficiency as well as energy
conservation. All of the operational duties, including but not limited to sponsorship, handling of
funds and logistics of material delivery and purchasing was tried to be assigned equally between
all team member and for every team member to be in charge of one of those responsibilities. Due
to the lack of time and amount of work being done apart from individual class load, all team
members collaborated according to the specific task at hand and available time of each person.

4.5 Discussion

Project management was carried out with extreme care and consideration for other team
members. It was established that the team would approach decision making as a democracy and a
vote was to be taken amongst all component managers to make a final verdict on choices of high
importance for the group as a whole. It is also recognized that all reputations and efforts are
linked together to create a final product that will be entered in a competition. Both soft skills and
hard skills are revealed amongst team members in this project and the way the project is
managed is a key factor in demonstrating them and improving through the experience to make
talented future engineers. Project management is a collaboration effort between two senior
design teams; therefore the FIU Shell-Eco Marathon team must be united into one goal and work
rigorously at any time available to complete all tasks necessary. Team meeting was held at least
twice a week in order to keep to the schedule. The purpose of every team meeting is to update
the entire team on parts being ordered and work being done on the car. By the end of January
2015, team meeting were being held at the student shop while work was being done on the car. Once design was concluded and the manufacturing part of the project initiated, meeting were shortened and consisted of personal concerns as time sensitive decisions had to be made. By mid February, meetings were not held any longer due to the ease in communication through the team’s mobile devices and many long nights at the machine shop.
5 ENGINEERING DESIGN AND ANALYSIS

5.1 Overview

The design and analysis of the Shell Eco-marathon car supports almost all aspects of mechanical engineering and due to the exceptional education that FIU has provided the team, many facets of mechanics of material science, statics, software simulation and more will be put into practice will the analysis of all the components independently and the car as a whole.

Shell has provided parameters in which to set in the design of the car as well as safety regulations. After a thorough analysis of the rules and regulations and choosing a design from several alternatives possible, each component will begin to take form and undergo a process of testing, simulation and prototyping. Using university provided software; all types of analysis of forces on the chassis were studied.

5.2 Monocoque Analysis

Since the design of the car was chosen to be a monocoque the team decided to abandon a space frame and adopt the concept of a hybrid chassis monocoque, due to the fact that the material chosen and the way it is manufactures would provide enough strength for the purpose of the competition as well as the safety requirements. The chassis is subjected to several loads while the vehicle is in use. It is essential to understand and identify the loads being experienced so the car can withstand the resulting stresses. The main loading on the entire car is made by the driver, due to that the power systems will be low in weight and the motor will be at the center of the back wheel. The driver loads the monocoque in cornering, accelerating and braking. During
normal operation of the vehicle we see vertical displacement on the wheels as well as cornering that takes a toll on the tires due to road surface. Impact loads, component loads and driver loads are also loading sources which are of concern. When taking into consideration the event of a crash, impulse loads should be considered on the hybrid chassis because of dynamic loads caused by sudden deceleration. The loads applied by the driver when entering or exiting the vehicle must be accounted for. While the vehicle is in use, the brake pedal will create a considerable moment that will be distributed to the monocoque as well.

One of the most importance requirements that Shell provides for the competition is that the car contain a roll bar that extends five millimeters above the helmet of the driver and can withstand at least 700 N force applied directly on it. Several simulations were performed on an equivalent roll bar. The following figures illustrate some of the resulting forces we can virtually see using Solidworks. These simulations were performed with careful consideration of material properties, layers of the material and all forces acting on it, including gravity.

**Figure 14: Strain Results of Roll Bar**
5.3 Flow Simulation Study

A flow simulation study using Solidworks was done on the body to simulate the air flowing at and on the body while the car is moving. The reaction the resulting wind forces can be observed. In the simulation we could see how the flow of the air is affected by our body and how much is the drag force that this produce to the body; allowing us to perform changes on the design in order to reduce this force.
We also calculated the drag coefficient for our body, resulting in 0.143; this drag coefficient is lower than the coefficients for our alternatives designs, making it more efficient and more aerodynamic. The following pictures shows the streamlines of the flow and the velocity of the wind which goes from 0.022 m/s to 3.406 m/s; the wind reach its higher speed in the upper part in the middle of the body, which also tell us that the pressure there is minimum.

![Figure 16: Streamlines-Flow Simulation](image)

This other picture show us where the air is applying the pressure in our body; the section of the front that is orange and yellow is where the pressure is higher, so we tried to reduce that section as most as we could on the design, to reduce the drag force.
To calculate the drag coefficient we used equation 1 that is showed in the design alternative sections. For the speed of the object relative to the air 3 m/s was used so the Reynolds number was 10000. For the reference area, a calculation was made of the area of the cross section which is 0.216 $m^2$ and the density of the air taking in consideration the temperatures and the pressure of the city of Detroit, where the competition is held, during the days of the competition we used 1.2754 kg/$m^3$.

### 5.4 Energy Management Design

After confirming the 36V Electric Battery as the energy source for the vehicle, a 36 Volt, 500 Watt brushless hub motor was choose as our propulsion system for the vehicle. Figure 18 displays the electrical schematic that was used to relay the battery with all components including the motor controller and shell’s joulemeter.
Figure 18: Electrical Schematic

BMS KU123 High Speed Controller was used to power the motor from the energy source.

5.5 Material Selection

To create the body of the monocoque, the first consideration was carbon fiber sheets. Due to the fact that weight is a major factor in the performance of the car the team then started to consider Kevlar as an alternative because of its weight. Carbon fiber is definitely stronger having a higher elastic modulus, but Kevlar is a less dense and lighter providing the strength necessary. A mixed weave of carbon and kevlar was available which provides the qualities of both materials without having to conform to one. A mix of these two materials provides stiffness and impact strength which is exactly what is needed.
The core material was chosen after taking a day course on core materials at Joe’s Auto Marine Supply in Ft. Lauderdale, Florida. A Polyurethane Foam Sheet and closed cell PVC foam (Divinycell H) were both tested. The testing of the material is covered in section seven. For the body it was considered that the closed cell PVC foam was more suitable because of its thickness and strength. Alternatives were well thought-out to the 0.2” option, and analyzed for difference in core weights. It displays at both ambient and elevated temperatures remarkable compressive strength and shear properties. Moreover, the ductile qualities of Divinycell H make it perfect for applications subject to fatigue, slamming or impact loads. It is also well-matched with practically all frequently used resins (polyester, vinyl ester and epoxy).
Laminates were initially designed to maximize compressive strength using a strain failure analysis while being aware of torsional stiffness. Both matrix and fiber failure were considered.

### 5.6 Cost Analysis

As part of the operations of the project, two team members oversaw the treasury aspect which involves the cost analysis of the project. The initial cost analysis was divided between team members within their individual components. The following table demonstrates all expenses made, whether bought this semester or previously obtained by a team member, a faculty member or the university.
Table 5: Cost Analysis

<table>
<thead>
<tr>
<th>Cost Analysis</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body</strong></td>
<td></td>
</tr>
<tr>
<td>Carbon Kevlar</td>
<td>$400.00</td>
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<tr>
<td>Methacrylate Adhesive</td>
<td>$7.51</td>
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<tr>
<td>Formula Five Mold Wax Release</td>
<td>$26.38</td>
</tr>
<tr>
<td>Divinymat H60 3mm 4lb density foam</td>
<td>$69.99</td>
</tr>
<tr>
<td>Divinymat H60 5mm 4lb density foam</td>
<td>$28.31</td>
</tr>
<tr>
<td>Duratec, Primer, Styro-Shield</td>
<td>$141.89</td>
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<tr>
<td>Tarp, Blue</td>
<td>$4.20</td>
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<tr>
<td>Spreader, Poly 6</td>
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<tr>
<td>Mixing Tip Static</td>
<td>$1.85</td>
</tr>
<tr>
<td>Tub, Poly Mix&amp;Measure 2 1/2 quart</td>
<td>$2.30</td>
</tr>
<tr>
<td>Tub, Poly Mix&amp;Measure 5 quart</td>
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</tr>
<tr>
<td>Polyuetherane Foam 2lb density</td>
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</tr>
<tr>
<td>Divinymat, H60 3, 4lb foam</td>
<td>$92.92</td>
</tr>
<tr>
<td>Electromagnet</td>
<td>$14.00</td>
</tr>
<tr>
<td>Two 22lb Magnets</td>
<td>$12.00</td>
</tr>
<tr>
<td>Acetone, Gallon Can</td>
<td>$16.21</td>
</tr>
<tr>
<td>Brush, Chip, Throw Away</td>
<td>$4.74</td>
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<tr>
<td>Roller Cover, Mohair Solvent Resistant</td>
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<tr>
<td>Polyester Boatyard Resin, Gallon Jug</td>
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<td>Sanding Pads (80-100 grit)</td>
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<tr>
<td>Plexiglas</td>
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<td>15 Paint Brushes</td>
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<td>PolyPropelyne</td>
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<td>Hinge Bracket</td>
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<td>Insulating Foam Sealant</td>
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<td>Bond Filler (1 pound)</td>
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<td><strong>Power System</strong></td>
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<tr>
<td>Item</td>
<td>Cost</td>
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<tr>
<td>--------------------------------------------------------</td>
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<tr>
<td>High C-Rate 36V 20Ah Li-Ion Battery</td>
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<td>Heat Shrink Battery Pack</td>
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<td>500 Watt Wheel Hub motor</td>
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<td>Foam Separator/ Fire Resistant Separator</td>
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<tr>
<td>Horn</td>
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<tr>
<td>Fan for Driver</td>
<td>$12.00</td>
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<td><strong>Safety and Precaution System</strong></td>
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<td>Cutoff Switch Power Source</td>
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<td>Helmet</td>
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<td>Fireproof Suit</td>
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<td>Five point Racing Harness</td>
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Table 6: Travel Expense Options

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<tr>
<td>Three Camping Tents</td>
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</tr>
<tr>
<td>Car (Gasoline) Three Vehicles</td>
<td>$1,500.00</td>
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<tr>
<td>U-Haul</td>
<td>$500.00</td>
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<tr>
<td>Overall Sum</td>
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</tr>
<tr>
<td><strong>Option B)</strong></td>
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<tr>
<td>Flight US Airways (Per Person)</td>
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</tr>
<tr>
<td>Shipping Vehicle</td>
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<tr>
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<td><strong>Option C)</strong></td>
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<td>Item</td>
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<tr>
<td>-------------------------------------</td>
<td>--------</td>
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<tr>
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<td><strong>Option D)</strong></td>
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<td>U-Haul</td>
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<tr>
<td>Overall Sum</td>
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</tr>
<tr>
<td><strong>Option D)</strong></td>
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6 VEHICLE CONSTRUCTION

6.1 Overview

For our prototype construction a uni-body shell consisting of carbon/Kevlar fiber and a special foam as a core material is being engineered. It is held by epoxy to reduce weight and increase the body’s yield strength, making it lightweight and safe. For this prototype a chassis will be excluded, instead, the team reinforced the body with another layer of the Kevlar/carbon fiber in some special sections on the body, like the roll bar or the bumper. This union of Kevlar/carbon fiber and the core material it is actually stronger than steel. It will sustain the load without any problem, furthermore, it allows the SEM team to have a very light car since we are reducing the weight by not implementing the chassis.

6.2 Description of Vehicle

The first priority of the prototype or final car is to be safe for the driver and strong enough to properly maneuver around the track with all vehicle components. After it is established that a suitable safety factor for the design is met, then the construction process will focus on the optimizing of the drag coefficient for the body, and weight reduction for the whole car.

The following descriptions are some of the basic descriptions of the car:

- High: 22 inches from bottom to top of the body
- Length: 80 inches
- Width: 20 inches
- Wheels size: 16 inches
- Two wheels on the front outside the body, and one wheel on the back inside the body
- Back wheel traction
• Steering system on the front wheels
• Brakes: Disk brakes
• Engine: 24V electric motor with 350 watts
• Energy Source: Lithium Batteries

6.3 Vehicle Design

The body of the car was designed in Solidworks, following all the dimensions specifications that Shell-eco marathon set up. The body was designed to be big enough to fit one person inside with the rear wheel, motor battery, steering system and a seat with a hardness but as small as possible, to have a light car by having the least material possible. On Solidworks both inner and outer carbon-kevlar layer and the middle layer made out of foam was designed separately and then assembled together in order to have a realistic model similar to the one that was built. This Solidworks model was used to make the mold used to build the body.

Figure 21: Exploded View Of Solidworks Model
6.4 Manufacturing of the Body

After a rigorous journey to agree and choose the final material that was previously described, and having chosen the core material that would go between the layers of carbon-kevlar fiber, the team first was challenged with developing a plug. A plug is the sculpture or replica of the car where the fiber and core material would be laid on to create the body.

The team first started with blocks of Styrofoam that were glued together to create a long enough block that would resemble the car’s exterior as closely as possible. To obtain the correct dimensions, a plotter was used to print a paper of the actual size of the floor as well as the section views at several key points that were to scale of the actual car. Rodrigo Cabrera, a member of the team of the Shell Eco-marathon competition was gracious enough to allow us to use his house to create this portion of the plug. An important observation is that no one in the team had ever worked with these types of materials or done anything similar.

A few employees at the Joe’s Auto Marine Supply store offered exceptional advice that gave the team great direction in the creation of the body. With the advice provided, the team decided at this point to attempt a process called Vacuum Infusion. Vacuum Infusion is by far the most effective process in making a shell using fibers, for example; fiber glass kayaks, boat hulls, etc. Since the learning curve to achieve a successful Vacuum Infusion process for the body of the panther bullet was too large and would not allow us to finish the body in time to be able to attend the Shell Eco-marathon 2015 in Detroit, the team chose another route.

Vacuum Infusion involves administering the resin to a fiber covered mold by way of a tube into a bag that has its air being suctioned from another tube using a pump. This process guarantees the least amount of resin needed to create a strong and uniform distribution of resin to the shape across the fibers.
After the Styrofoam was cut into the shape of the body, the team used a body filler paste to cover the Styrofoam uniformly to achieve a closer resemblance to the body designed virtually. After filling all of the holes and imperfection of the Styrofoam with body filler, the team sanded the filler down to the shape of the vehicle. Mold release wax was also purchased at Joe’s Auto Marine Supply and the team applied about eight to ten coats of wax. The purpose of this wax is to prevent the carbon-kevlar fiber to stick to the plug. Letting the wax dry, the team proceeded to apply carbon-kevlar fiber strategically to the body in order to cover it completely and uniformly applied a special resin that needed to be activated by MEK (methyl ethyl ketone). Much care was taken with the chemical MEK since it is highly toxic if exposed to the skin or its fumes being inhaled into the lungs. After two layers of carbon-kevlar fiber, the core material was placed on the fiber. The core material, Divinycell H that was previously discussed in section 5.5 was used to cover the most part of the car using the same resin that was used for the fiber. After the team ensured that enough core material was covering the fiber, several more coats of fiber were applied above to sandwich the core material between the fibers.

After this rigorous and time consuming process, the team cut out the top compartment that would serve as the entry point for the driver and the rear compartment that would later be used to put components such as the battery, rear wheel and controller into the car. Using an electric circular saw, the team cut out the parts where windows would be placed.

6.5 Manufacturing of Windshield

The windshield of the vehicle has a great deal of importance in weight in the performance. Since this is a fuel-efficient competition, the aerodynamics of the body are paramount in preserving energy. The more aerodynamic the body, the less force it needs to
displace across the track. After designing an efficient model for the body of the Panther Bullet, the team proceeded to cut the front nose of the vehicle where the windshield should go. After researching what material should be chosen to mold into the nose, the team first attempted a process called vacuum molding. A box was created using plywood that measured 4 feet by 3 feet with a height of 4 feet. Gas burners were placed inside of the box followed by aluminum sheets covering the inside faces of the plywood box. A sheet of LEXAN poly-carbonate glass with a thickness of 1/8 of an inch was placed above the burners. After about 40 seconds of heating, it was visually noticeable that the sheet was getting quite malleable. The team proceeded to flip the glass several times with the hopes to achieve a completely malleable glass that would be place on the nose that was cut from the vehicle to create the shape. This procedure failed due to that the burners did not provide an even application of heat to the glass and bubbles started to form directly above the gas burners.

After some more research and consideration to the process, the team approached Alejandro Osorio, an FIU alumni and Mechanical Engineer from the graduating class of Fall 2014. Mr. Osorio owns a business which creates and services furniture for events of all kind. He
also owns an oven to heat acrylic glass which is 4 feet by 10 feet with a height of 1 foot, which he built and operates himself.

![Figure 23: Plexiglas With Frame Molding Nose of Car](image)

The team approached him to use this oven to achieve an even heat application to the glass in order to shape it properly. This time the team used a standard plexiglass of 1/8 inch width. Luis Meza and Magin Perez created a wooded frame around the bounder of two glass pieces one of 4x3 feet and another of 4x4 feet. We first tested a smaller piece of the same material at 282 Fahrenheit for one minute intervals until acquiring the malleability desire to mold the nose of the car.

Once the temperature and time that the plexiglass had to be left in the oven, the team proceeded to place the frame plexiglass pieces into the oven. After two trials; first with the 4x3 foot laminate followed by the bigger 4x4 foot, it was evident that the procedure had failed. The reason this procedure failed at this juncture of time was because of the instability of the frame on
the plexiglass and because a bigger since plexiglass would have to be used for such a complex molding procedure.

With time being of the essence in achieving the desire shape of the windshield, a comprise was made to not make the entire nose from one molding of a large plexiglass, but rather to divide the molding of the nose in two separate plexiglass molded shapes that would be attached by a silicone paste.

6.6 Rear Motor Mount Design

For the rear hub motor, two aluminum brackets were fabricated with a center channel for each mounting shafts to slide through and align the tire to the body. Each bracket has a fabricated centerline that aligns the body to stand 4 inches from the ground. Luis Rojas helped weld supporting ribs to the brackets to help withstand any type of buckling on each support when exposed to all forces such as the weight of the vehicle, torque of motor, and torque of rear braking. Figure 24 displays the fabrication of the brackets.

Figure 24: Luis Rojas Welding
7. Testing and Evaluation

7.1 Overview

The team has extensively used all the resources available by the university to ensure all of the designs optimization and performance. First, in the design stage, Solidworks software was used to design and simulate all of the components necessary for the car. Throughout the design stage, these virtual simulations gave an understanding and knowledge that later helped to further understand the behavior of the car while being operated. All of the weak points in the body and chassis were determined in order to apply reinforcements that provided the sturdiness required at critical points. Forces such as gravity, weight and loading were simulated to attain a result of stress and deformation, so we can guarantee a safe and efficient design. After the construction of the car, testing was done progressively as each reinforcement was applied. The weight of the car was periodically measured but not appropriately recorded after each component manufacturing stage to ensure the least weight possible which is directly related to the performance that the vehicle will show at the Shell Eco-Competition. Testing is a very important part of this project especially because of the rigorous inspections it saw at the SEM (Shell Eco Marathon) 2015 competition.

7.2 Material Testing and Results

Once going through a rigorous process in choosing the materials, a rectangular model of laminate was completed in order to understand the manufacturing process and to test different core materials. Figures 25 and 26 illustrated a block of Poly foam material that was chosen not suitable for the cars surface because of its weakness and its thickness.
These blocks were simulated by replicated a version of a three point bend test that can give information as to the deflection in relation with the load of the model. The core of the specimen failed with 120 N of force which is much less than required. The most important factors in the performance of the laminate panels are panel geometry, relative thickness and material properties of the skin and core material.
7.3 Improvements of the Design

Improvements were made to the design by selecting a more suitable material which was previously stated to be the closed cell PVC foam (Divinycell H) which withstood up to 898 N force applied directly to the shell of the body. This overpasses the requirement of the roll bar having to withstand 700 N, which puts into question the necessity of further layer of material to reinforce the roll bar which would add to the total weight of the vehicle. Further testing was carried out to ensure rigidity and safety for the driver. The testing results are congruent with the analysis performed on Solidworks demonstrated in figure 15 which indicated a maximum deflection of 2.44 mm which is satisfactory. After competing in the Shell Eco Marathon and taking notes from other competitors, there were lots of ideas that identified to be great improvements for our design. One the first improvement was to have a larger front end windshield that can be completely detachable, that not only improved visibility for the driver but also help ease the emergency exit that was also a required inspection. Increasing the size of the front windshield also allows for a taller driver, as the current design with the latch roof door limits the space for a taller driver to safely exit the vehicle within the 10 seconds need to pass the inspections. Figure # shows an example of the large windshield on the University of Colorado Team.
Figure 27: University of Colorado Boulder Car

Improvements could be made on the steering system by adding a front axle, which would help distribute the load onto the axle and not the body, helping reduce the flexing on the carbon fiber body. Other steering designs such as having 2 joysticks on the left and right side of the car would help increase the space for the driver and visibility. Another improvement that could be made but not crucial is to have a quick release button for the seatbelt harness instead of the latch with would also decrease the time to exit the vehicle in an emergency situation.

7.4 Evaluation of Experimental Results

After finishing the initial shell of the vehicle without the compartments or windows having been cut out the team performed a static load test on the car of 700 Newtons in the form of pounds. The team carefully placed 150 pounds directly on the roll bar and observed and measured if any displacements or cracks were made. The 150 pounds that were placed were in the form of a team member that weighed 149.6 pounds to start directly on the top of the vehicle’s roll bar carefully while applying his weight gradually while holding on to two separate team members. After cutting out the entry hatch and the rear lid where some of the components such as the rear wheel and energy system will reside, the team again placed weight on the roll bar, carefully analyzing if any effects would take place. This experiment saw some deformation and therefore two more strips of carbon fiber were added to ensure strength. Once the wall of separation between the driver and the energy management and battery was attached inside of the shell, which is also a requirement of the competition, and all of the reinforcement strips were placed, the team completed a final testing phase to make sure the vehicle meets the requirements of the roll bar load. 700 Newtons of force was again placed carefully on the top of the roll bar and analyzed. The results of this experiment were that the roll bar did not deform visually, nor
did it crack or twist. This gives the team confidence in the sturdiness that this competition requirement was met successfully. Ultimately, the inspection at the SEM 2015 for safety and that the roll bar withstands 700 newtons of force was passed.

Once all of the components are running and all of the wheels are successfully in place, the FIU Shell Eco-Marathon team performed final static and motion analysis with respect to the conditions that the vehicle will experience in the competition in Detroit. Testing was done not only on the body and roll bar but all of the components in the form of forces being tested on them and visually analyzing if any effects were present. Test runs were performed to ensure that the floor and body could endure all specified turns and the weight of the driver on the floor.

Figure 28: 896 N Stress Testing
7.5 Testing and Inspections at the Competition

The team needed to pass 10 different technical inspections in order to be able to compete in the race. They are meant to make every car as safe as possible, and to have a fair competition. Three attempts were made until all inspections were passed.

The following are the main inspections:

Driver Weight In:

![Driver Weigh In](image)

Figure 29: Driver Weigh In

The driver needs to weigh less than 150Kg to be able to race; the team’s driver was 55.8Kg. This inspection is to set standard parameters for all drivers so there is a fair competition.
Vehicle Weight In:

The vehicle needs to weigh less than 150Kg to be able to participate in the race. The team’s vehicle weighed 50Kg. This inspection is to set parameters for all vehicles so that there is a fair competition.

Turning Radius:

Figure 31: Turn Radius Test
Drivers needs to be able to turn smoothly across the track. This test is to make sure the vehicle can go through an 8-meter radius turn.

**Vehicle Dimensions:**

![Figure 32: Vehicle Dimension](image)

The vehicle needs to be able to pass through the structure to be able to race. This inspection is to make sure cars do not bump into each other while racing due to the width of the racetrack.
Visibility and Horn:

![Image of visibility test](image)

Figure 33: Visibility Test

Driver needs to have a visibility of 180 degrees. This tests is to make sure the driver can see all vehicles while racing on the track.

The horn needs to be higher than 85db, it was 91db. This test is to make sure the other vehicles can hear you while passing them.
Seatbelt and Row bar:

![Figure 34: Seatbelt Test](image)

The seatbelt needs to be safely installed in the vehicle with an ergonomic feel to the driver. The vehicle must be lifted by the harness with the driver inside to test its rigidity. This technical inspecting is to make sure the driver is safe in case of a crash.

The row bar needs to be able to withstand 70N of force. This technical inspection is to make sure the car’s structure is good and it will not collapse or fail during the race.
Energy Verification:

![Energy Verification](image1)

Figure 35: Energy Verification

All connections need to be properly made including the joulemeter, which is needed to measure the energy consumption. This technical inspection is to check if the vehicle propulsion and energy system is correct.

Braking:

![Braking](image2)

Figure 36: Brake Test
The vehicle needs to be able to brake, both front and rear independently on a 25-degree ramp.

This test makes sure that the vehicle has the adequate braking power.

**Vehicle Design:**

![Vehicle Design](image)

Figure 37: Vehicle Design

This is an overall inspection about the assembly and safety of the vehicle. A rigorous check on all components were made such as the steering, braking, harness, motor, wheels, etc. to verify that the vehicle is race ready
Vehicle Exit:

The driver needs to be able to exit the vehicle without assistance in less than 10 seconds. This test is in case of an emergency or malfunction of the car, the driver can be able to get out and distant herself from the vehicle as fast as possible. Cinthya Enriquez, FIU Driver accomplished this under 7.4 seconds.

7.6 Competition Results

Three trials were completed in the shell eco marathon competition by the FIU Team. Each run must consist of completing 7 laps around the track and a time constraint was set at 25 minutes. Much improvements were shown as every lap and trial went on. Different strategies were executed by the driver in order to optimize each run. The team’s target lap time was an average of 3 minutes and 30 seconds in order to reduce the amount of acceleration, correlating to less energy consumption. A crucial tactic that help reduce consumption was actively cutting the energy source with the secondary kill switch, activated by the driver. Figure 39 - 42, and table 7 displays the results from the SEM runs.
Figure 41: Battery Electric Leaderboard

<table>
<thead>
<tr>
<th>Pos</th>
<th>Country</th>
<th>No</th>
<th>Institute &amp; team name</th>
<th>Attempts</th>
<th>Best result</th>
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<tbody>
<tr>
<td>1</td>
<td></td>
<td>301</td>
<td>Mater Dei High School</td>
<td>?</td>
<td>724 km/kph</td>
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<tr>
<td>2</td>
<td></td>
<td>302</td>
<td>DUKE ELECTRIC VEHICLES</td>
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<td></td>
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<tr>
<td>10</td>
<td></td>
<td>316</td>
<td>Universidad Nacional Autonoma De Mexico</td>
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<td>115 km/kph</td>
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Figure 42: Half Technical Approved Teams
Table 7: Competition Results

<table>
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<tr>
<th>Trial</th>
<th>Joulemeter (Watt/sec)</th>
<th>Time (min)</th>
<th>Results (km/KW*h)</th>
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<tr>
<td>4 (Assumed Values)</td>
<td>200000</td>
<td>24:15.85</td>
<td>180</td>
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</table>

→ Judges left Joulemeter off during this trial

7.7 Discussion

Testing time was limited and brief in order for the team to complete the car in time to be able to compete. Using the knowledge obtained in past semesters, especially the Mechanics of Materials Lab course at the FIU Engineering Center, the team had a better understanding of what factors to study and how to recreate some of the experiments that were performed in the previously mentioned lab in order to obtain all data necessary to make material selection and design decisions. As the car was manufactured the frame and body component managers worked diligently in designing support and reinforcement ideas in order for the car to be as solid and strong as possible. For future teams working on this project, this year’s team would recommend to create an identical prototype and perform rigorous testing before actually building the final shell of the vehicle.
8 DESIGN CONSIDERATIONS

8.1 Assembly and Disassembly

For the design of the body shell and chassis, we went along with designing a Uni-Body or monocoque design of the car in order to save weight and cost for the project as a whole. For the assembly of the body, a three dimensional skeleton was produced as a base for the mold on the car. Once satisfied with the flow simulations and stress analysis produced on Solidworks, we printed out section views of the vehicle at a 1:1 scale in order to set up the mold that consisted of a combination of plywood and foam. In figure 43 displays the end product of the foam skeleton of the body. Once shaped to our design a layer of primer is applied to maintain the integrity of the mold. Once dried, wax is applied on it to have a nice smooth non-adhesive surface to apply our Kevlar-Carbon Fiber material to the body. We applied 2 layer of the Kevlar-Carbon fiber material with a center core material to provide strength and sturdiness to the body.

Figure 43: Foam Skeleton
8.2 Maintenance of the System

In order to maintain a clean and strong mold for the body, many steps were to be taken care of. With the development of the foam skeleton, we had to make sure that we had straight and cured plywood in order to design a mold to the specs of our Solidworks design. Also maintaining the foam inserts clean and shaved to the curvature of the body was crucial to maintain the aerodynamic aspect of the vehicle. For the primer on the mold, we applied 6+ coats of wax in 20 minute intervals in order to let the wax settle on the primer. Figure 44 displays the wax application on the primer.

![Figure 44: Waxing the Primer [Magin and Javier]](image-url)
8.3 Regular Maintenance

Once the mold was prepared for the fiber and resin, it was important to lay out the Carbon-Kevlar fiber material and have it cut out with the exact measurements of the mold before the process of pasting the fibers and core material onto the mold. Once cut out, we had to make sure to maintain the integrity of the fiber by rolling them up accordantly in order to prevent the weaves of the fiber to separate. Figure 45 displays the “Panther Bullet” Team cutting the fiber layouts.

Figure 45: Cutting Out Layers [Lawrence, Rodrigo, Luis, Dr. Tremante, Magin, Javier, Curtis, and Pradeep]
8.4 Major Maintenance

Once the mold was ready for the Kevlar-Carbon fiber material application, it was crucial that the process was as clean as possible. Throughout this process it was important to have the mold in room temperature to let every section of the process cure appropriately. We first applied the inner layer of fiber material onto the mold that was completely waxed and prepped 24 hours in advance. Using a high strength resin for the fiber, Polyester Resin Boatyard, we applied the first layer of fiber and added the resin onto the fiber. It is very important to fully apply the resin to all of the body with even layers of adhesive. Once the first layer of fiber was applied, 24 hours was given for the resin to cure and develop a strong profile. Once cured, we applied our core material, Laminate Bulker Divinycell Divinymat, onto the first later to the fiber. Figure 46 displays the core material application. Once again we applied the resin onto the core material, making sure that is was fully submerged within the cracks and crevices of the core materials, and applying even layers throughout the body. After this step is completed we gave the mold 48 hours in order to cure completely. Finally we applied the final and exterior of fiber onto the core material the same way as the first layer, completing our mold. Figure 47 displays the final steps in our mold application.
Environmental Impact

Within the construction of the body the team tried to be as environmentally friendly with the process. The team purchased recycled wood that was treated and cured. The team made sure to dispose of our waste with an eco-friendly state of mind by recycling all paper and plastic.
based material when found. The team also made sure to use the proper amount of resin for each layer to prevent waste and disposing of any leftover resin.

8.6 Risk Assessment

It was made sure to take all of the safety precaution seriously when constructing the body. Since dangerous and toxic chemicals were being used, safety glasses, gloves, and masks where all used to keep the team safe as each process was being carried out. Proper knowledge of operating power tools were known and studied by each team member. Mixing the resin with the catalysis was done under careful conditions and appropriate environments with proper safety gear. The workspace was ventilated and recyclable paper was use to clean up any spillage.
9 DESIGN EXPERIENCE

9.1 Overview

Overall the design experience has been a positive one due to learning new ways to construct the vehicle by using composite materials such as our Kevlar-Carbon fiber material for the overall Uni-Body design. Learning how to work with these composites and the resins to apply it with has been an enjoyable experience for the team as a whole. Provided a better funding, a vacuum forming could have been done in order to bond composites used for the body, making it stronger and possibly less material uses making it lighter. Many volunteers (Errick Santana, Fernando Rojas, Luis Rojas), contributed in the design of the car.

9.2 Standards Used in the projects

The Shell Eco-Marathon rules and regulations held a high standard in the requirements for the design of the vehicle. Appendix D states standards used in the construction of the vehicle.

9.3 Contemporary Issues

Some issues that were encounter in the manufacturing of the vehicle were the vacuum forming of the windshield. Difficulties were found when heating a larger sheet of plexiglass to the correct temperature without burning it before having the ready for the vacuum. Section 7.4 elaborates on the process for the plexiglass.
9.4 Impact of Design in Global and Societal Context

The team’s design on an alternative energy source driven vehicle has numerous positive global and societal impacts. Developing a trend on electric and other low to non-emission vehicles will help protect the environment from the increase of carbon footprint that is present with the use of today’s gasoline vehicles. Also exploring new ways to increase the km/h/wh efficiency of a vehicle will greatly reduce energy consumption along with lowering the cost of oil. It is important emphasis a new clean alternative that not only will help one area of the world but that can be implemented across the globe within various geographical regions. Applying these new technologically advance innovations in the automotive industry, will help further develop the skill of future engineers that will be responsible in propelling the next generation of fuel efficient vehicles.

9.5 Professional and Ethical Responsibility

Safety was the number one responsibility on the teams list from the start of the project. Developing a safe and secure vehicle for the driver to drive was important. Everything from the structural analysis, to the circuits of the power supply had to be designed safely. The project exposed the team to ethical and professional decision making which help develop their skills when exposed to the safety of the product to others.

9.6 Life-Long Learning Experience

The team as a whole grew a lot from this project. Manufacturing skills has been further developed. Exposure to new composite materials, team building, and time management also
were tested. Analytical thinking and problem solving skills were tested for each component. Engineering decisions were made when budget cuts required the team to change over the project from the hydrogen fuel cell to a battery electric power vehicle. All these experience better shaped the teammates to become even more prepared for the engineering field. The team will take all these experiences and apply it to post graduation projects.

9.7 Discussion

The design experience was an experience that the team will forever remember. Learning how to work with one another was key to completing the vehicle on time. Working around the clock and learning from every components help the team better understand the final product and how each components and its function collaborated to complete the vehicle.
10 CONCLUSIONS

10.1 Conclusion and Discussion

Our objective is to engineer and optimize the most fuel-efficient vehicle to win the Shell Eco-Marathon. As we continue to grow as a team and improve on our design, we learn from our past experiences and implement them to future alternatives. We found for our timeframe that we have spent valuable hours in design alternatives and simulations to further optimize our proposal. Simulations of aerodynamics on the body to stress analysis on the chassis ensure us that we are meeting our standards for safety and efficiency. Once our final prototype was design and passed our simulation testing, we began the process of constructing the body. It was a long and challenging but, the team accomplished the final design of the body. Once the body was fully cured we made some preliminary experimental testing by applying static load to find if the body withstands the required payload within the competition rulebooks.

10.2 Evaluation of Integrated Global Design Aspects

The positive global design impacts are very important to the team. Turning the page on alternative fuels for future vehicles is the first step in advancing the fuel systems for future concept vehicle that will be produced. Designing a hydrogen fuel vehicle ensures us a 100 percent clean product with zero carbon emissions. Achieving the highest possible miles per kilowatt ratio will help our statement on conserving energy for a new platform of vehicles that can be powered by hydrogen fuel cells.
10.3 Evaluation of Intangible Experiences

Some intangible experiences came with the difficulties on the design and simulations of the prototypes. We had to have a high learning curve when it came to optimizing the simulations and took various trial and error with the design. Tweaking the body and the chassis was very important and challenging at first, but with dedicated time and patience, we finally started to understand the areas that we first had trouble grasping such as calculations of the drag and other stress factors of our prototypes.

10.4 Future Work

Some future recommendations are starting an official Shell Eco-Marathon Club in order to continue competing every year and have new underclassmen get involve in alternative engineering activities that will help develop their skill furthermore. Establishing a club strictly for the Shell Eco-Marathon competition will help set up funding for future work, along with the benefit of having multiple iterations of the vehicle to work off of and make improvements every year. Another option for future work is to work with another type of category such as gasoline, diesel, or ethanol with guidance of an advisor having a qualify level of expertise in order to optimize the design. A consideration can be made in order to reiterate the next model vehicle as a diesel power engine with guidance of Dr. Brian Reding. Taking into consideration all the improvements pointed out in section 7.5, the next generation of the Shell Eco-Marathon vehicles can be further improved, and a positive trend of FIU competitors for SEM can be started.
Appendix A: Raw Calculations

- Force analysis for propulsion system

\[ F = C_r N \]
\[ F = 0.0025 (1110) \quad C_r = 0.0025 \]
\[ F = 2.78 \text{ N} \]

\[ F = m a \]
\[ m = 113.34 \text{ kg} \]
\[ a = 0.5 \text{ m/s}^2 \]
\[ F = 114 \text{ N} \]

\[ K = \frac{1}{2} m v^2 \]
\[ m = 113.34 \text{ kg} \]
\[ v = 5 \text{ m/s} \]
\[ K = 1412.5 \text{ Joules} \]
\[ K = 1412.5 \text{ Joules} \times \frac{1}{5} \text{ sec} = 282.5 \text{ Joules} \]
Total Force Need For Power

\[ \Sigma F = \text{Rolling Force} + \text{Drag Force} + \text{Linear Acceleration} \]

\[ \Sigma F = 120 \text{ N} \]

Target Watts For Motor = 500 Watts
- Drag Coefficient calculation for the body

\[ C_d = \frac{2F}{\rho V^2 A} \]

\[ A_{\text{total}} = A_1 + A_2 \]

\[ A_1 = \frac{\pi (20.28 \text{ cm})}{2} = \frac{\pi (0.2028 \text{ m})}{2} \]

\[ A_2 = (15 \text{ cm}) (60 \text{ cm}) = (0.15 \text{ m}) (0.6 \text{ m}) \]

\[ = 0.09 \text{ m}^2 \]

Area = 1855.6 cm² = 0.1855 m²

\[ V = 3 \text{ m/s} \]

\[ \rho = 1.20 \text{ kg/m}^3 \]

\[ Re = 10,000 \]

\[ C_d = \frac{2F}{\rho V^2 A} \]

\[ C_d = 0.23 \]
Appendix B: Description of the Construction process in Spanish

CONSTRUCCIÓN 6 VEHÍCULO

6.1 Información general

La construcción de el cuerpo consistió en una fibra de carbono / Kevlar y una espuma especial como un material de núcleo, reforzado con epoxi para reducir el peso y aumentar la resistencia para evitar la deformación del cuerpo, y para que sea ligero y seguro. Para este prototipo no estamos implementando un chasis; en cambio estamos reforzando el cuerpo con otra capa de fibra de carbono / Kevlar en algunas secciones especiales sobre el cuerpo, como el roll bar o parachoques. Porque, esta unión de fibra Kevlar / carbono y el material del núcleo es realmente más fuerte que el acero; por ende sostendrá la carga sin ningún problema; Además, nos permiten tener un coche muy ligero ya que estamos reduciendo el peso al no implementar el chasis.

6.2 Descripción de el vehículo

La primera prioridad es que el vehículo sea seguro para el conductor y lo suficientemente fuerte como para maniobrar adecuadamente por la pista con todos los componentes del vehículo. Las descripciones siguientes son algunas de las descripciones básicas del coche:

• Alto: 22 pulgadas de la parte inferior a la parte superior del cuerpo
• Longitud: 80 pulgadas
• Ancho: 20 pulgadas
• Tamaño de las ruedas: 16 pulgadas
• Dos ruedas en la parte delantera fuera del cuerpo, y una rueda en la parte posterior dentro del cuerpo
• tracción en la rueda trasera
• Sistema de dirección en las ruedas delanteras
• Frenos: Frenos de disco
• Motor: 24V motor eléctrico con 350 vatios
• Fuente de energía: baterías de iones

6.3 Diseño de Vehículo

El cuerpo del coche fue diseñado en Solidworks, siguiendo todas las dimensiones que especifica Shell-eco maratón. El cuerpo fue diseñado para ser lo suficientemente grande para una persona en el interior con la rueda trasera, batería del motor, sistema de dirección y un asiento con un cinturón de seguridad de 5 puntos pero lo más pequeño posible para tener un coche ligero

6.4 Fabricación del Cuerpo

Después de un riguroso estudio para acordar y elegir el material final que se ha descrito anteriormente, y después de haber elegido el material del núcleo que iría entre las capas de fibra de carbono-kevlar, el equipo primero fue desafiado con el desarrollo de un molde para crear el cuerpo

El equipo comenzó con bloques de espuma de polietileno que fueron pegadas entre sí para crear un bloque que se asemejaría más cerca posible al exterior del coche. Rodrigo Cabrera, miembro del equipo de la competición Shell Eco-marathon tuvo la gentileza de permitirnos utilizar su casa para crear esta parte del molde. Una observación importante es que nadie en el equipo nunca había trabajado con este tipo de materiales o hecho algo similar. Unos empleados de tienda Auto Marine Supply del Joe ofrecen asesoramiento excepcional que le dio a la gran dirección en la creación del cuerpo. Con el asesoramiento proporcionado, el equipo decidió en este momento para intentar un proceso llamado vacío de la infusión. Vacío de la infusión es de
lejos el proceso más eficaz en la fabricación de una carrocería utilizando fibras, por ejemplo; kayaks en fibra de vidrio, cascos de barcos, etc. dado que era muy complejo y no contábamos con el tiempo suficiente, el equipo optó por otra vía.

Después de la espuma de polietileno se cortó en la forma del cuerpo, el equipo utilizó una pasta de relleno para cubrir uniformemente la espuma de polietileno para lograr una semejanza más cerca del cuerpo diseñado. Un modelo de dos dimensiones a gran escala de la planta fue impreso utilizando el plotter disponible en Office Depot. Varias secciones entre la parte delantera y trasera del coche también fueron impresas y el lugar en consecuencia para ser utilizado como una guía para formar el relleno de espuma de poliestireno y el cuerpo. Después de llenar todos los agujeros y las imperfecciones el equipo lijo la espuma para darle forma al vehículo. La Cera de para sacar el molde también fue comprado en Joe Auto Marine Supply y el equipo aplicó entre ocho y diez capas de cera. El propósito de esta cera es evitar que la fibra de carbono-kevlar se pegue a el molde. luego el equipo procedió a aplicar la fibra de carbono-kevlar estratégicamente para el cuerpo con el fin de cubrir completamente y aplica de manera uniforme una resina especial que necesita para ser activado por MEK. se tuvo mucho cuidado con el MEK ya que es altamente tóxico si se expone a la piel o sus vapores. Después de dos capas de fibra de carbono-kevlar, el material del núcleo se colocó sobre la fibra. El material del núcleo, Divinycell H que se discutió anteriormente en la sección 5.3 se utilizó para cubrir la mayor parte del coche con la misma resina que se utilizó para la fibra. Después de que el equipo se aseguró de que material de núcleo suficiente estaba cubriendo la fibra, varias más capas de fibra se aplicaron por encima para intercalar el material del núcleo entre las fibras.

Después de este proceso riguroso y que consumió mucho tiempo, el equipo cortó la puerta superior que serviría como punto de entrada para el conductor y el compartimiento trasero
que posteriormente sería utilizado para poner componentes tales como la batería, la rueda posterior y del controlador en el coche. El uso de una sierra circular eléctrica, el equipo también cortó las partes donde se colocarían posteriormente las ventanas.
Appendix C: Description of the Construction process in German

6 FAHRZEUGBAU

6.1 Übersicht


6.2 Beschreibung der Prototyp


Nachfolgend werden einige der grundlegenden Beschreibungen des Autos:

• Hoch: 22 Zoll von unten nach oben auf dem Körper

• Länge: 80 Zoll

• Breite: 20 Zoll

• Räder Größe: 16 Zoll
• zwei Räder an der Vorderseite außerhalb des Körpers, und ein Rad an der Rückseite im Inneren des Körpers
• Zurück Traktion
• Lenksystem an den Vorderrädern
• Bremsen: Scheibenbremsen
• Motor: 24V-Elektromotor mit 350 Watt
• Energiequelle: Ionen-Batterien

6.3 Fahrzeugdesign
Der Körper des Autos wurde in Solidwork entwickelt, nach allen Dimensionen Specifications, die Shell-Eco-Marathon seted up. Der Körper wurde entwickelt, groß genug, um eine Person im Inneren mit dem Hinterrad, Motorbatterie, Lenkung und einen Sitz mit einer Härte, aber kleine posible passen, um ein leichtes Auto sein müssen; auf Solidwork inneren und äußeren Carbon-Kevlar-Schicht und die midle Schicht aus Schaumstoff hergestellt wurde separely getan und dann, um ein realistisches Modell, ähnlich dem, das gebaut wurde müssen zusammengebaut werden. Das Solidwork-Modell wurde verwendet, um die verwendet werden, um den Körper zu bauen Form zu machen.

6.4 Herstellung des Körper
Nach einer strengen Reise zu vereinbaren, und wählen Sie das letzte Material, das zuvor beschrieben wurde, und nachdem das Kernmaterial, das zwischen den Schichten aus Carbon-Kevlar-Faser gehen würde gewählt, das Team zunächst mit der Entwicklung eines Plug in Frage
gestellt. Ein Stecker ist die Skulptur oder Nachahmung der Auto, wo die Faser und Kernmaterial würde, um den Körper zu schaffen verlegt werden.

Das Team begann mit Blöcken aus Styropor, die miteinander verklebt wurden, um eine ausreichend lange Block, der der Fahrzeugaußenseite, wie ähnlich wie möglich sein würde. Rodrigo Cabrera, ein Mitglied des Teams des Shell Eco-marathon Konkurrenz war so freundlich, uns zu erlauben, sein Haus zu verwenden, um diesen Teil der Plug erstellen. Eine wichtige Beobachtung ist, dass niemand im Team immer mit dieser Art von Materialien gearbeitet oder etwas Ähnliches getan hatte. Einige Mitarbeiter an der Joes Auto Marine Supply Shop angeboten außergewöhnliche Beratung, die das Team bei der Erstellung des Körpers gab große Richtung. Bei der Beratung zur Verfügung gestellt, entschied sich das Team, an dieser Stelle einen Prozess namens Vakuuminfusion versuchen. Vakuuminfusion ist bei weitem das wirksamste Verfahren zur Herstellung einer Schale unter Verwendung von Fasern, zum Beispiel; Fiberglas Kajaks, Bootsräume, etc. Da die Lernkurve, um eine erfolgreiche Vakuuminfusion für den Körper des Panthers Kugel zu erreichen war zu groß und würde uns nicht erlauben, den Körper in der Zeit zu beenden, um den Shell Eco-marathon teilzunehmen 2015 in Detroit, wählte das Team einen anderen Weg. Vakuuminfusion beinhaltet die Verabreichung des Harzes zu einer Faser bedeckte Form durch ein Rohr in einen Beutel, der seine Luft von einem anderen Rohr mit Hilfe einer Pumpe abgesaugt. Dieses Verfahren garantiert die geringste Menge an Harz erforderlich, um eine starke und gleichmäßige Form über die Fasern zu schaffen.

Nachdem das Styropor in die Form des Körpers schneiden, verwendet das Team einen Körper Füllstoffpaste die Styropor gleichmäßig bedecken, eine engere Ähnlichkeit mit dem Körper ausgebildet zu erzielen. Ein Vollausschlag zweidimensionales Modell des Bodens wurde mit der an Office Depot Plotter gedruckt. Mehrere Abschnitt zwischen der Vorder- und Rückseite des

Nach dieser strengen und zeitraubender Prozess, schneiden das Team aus dem oberen Fach, das als Einstiegs punkt für den Fahrer und Fond, die später verwendet würde, um Komponenten wie Batterie, Hinterrad und Steuerung in den Wagen gesetzt werden dienen würde. Mit einem elektrischen Kreissäge schneiden das Team aus den Teilen, in denen Fenster würde platziert werden.

Herstellung von Windschutzscheiben

Nach etwas mehr Forschung und Berücksichtigung der Prozess, näherte sich das Team Alejandro Osorio, eine FIU Alumni und Maschinenbauingenieur aus der Abschlussklasse von Herbst 2014. Mr. Osorio besitzt ein Unternehmen, das für Veranstaltungen aller Art erstellt und Dienstleistungen Möbel. Er besitzt auch einen Backofen zu Acrylglas, die 4 Fuß durch 10 Fuß mit einer Höhe von 1 Fuß, den er errichtet und betreibt selbst zu erwärmen.
Das Team kam auf ihn zu, um diesen Ofen zu verwenden, um eine gleichmäßige
Wärmeanwendung auf das Glas zu erreichen, um sie richtig zu gestalten. Dieses Mal das Team
verwendet ein Standard-Plexiglas von 1/8 Zoll Breite.

Luis Meza und Magin Perez erstellt einen bewaldeten Rahmen um das bounder aus zwei
Glasstücke eines 4x3 Meter und weitere von 4x4 Meter. Wir zuerst ein kleineres Stück aus dem
gleichen Material bei 282 Grad Fahrenheit für einminütigen Intervallen getestet, bis Erfassen der
Formbarkeit Wunsch, die Nase des Fahrzeugs formen.

Sobald die Temperatur und die Zeit, die das Plexiglas musste im Ofen bleiben, ging das Team
um die Rahmenplexiglasstücke in den Ofen stellen. Nach zwei Studien; zuerst mit der 4x3 Fuß
Laminat gefolgt von der größeren 4x4 Fuß, war es offensichtlich, dass das Verfahren versagt.

Der Grund für diesen Vorgang an dieser Stelle der Zeit ausgefallen war wegen der Instabilität
des Rahmens auf dem Plexiglas und weil eine größere da Plexiglas müssten für eine solche
komplexe Formverfahren verwendet werden.

Mit vorerst das Wesen bei der Erreichung der gewünschte Form der Windschutzscheibe wurde
ein umfassen, um die gesamte Nase nicht zu machen von einem Formteil aus einem großen
Plexiglas, sondern die Form der Nase in zwei getrennten Plexiglas teilen Formteile, das wäre
durch eine Silikonpaste befestigt werden.
Appendix D: Shell Eco-Marathon Rules and Regulations

ABOUT THE RULES

a) The full Rules for Shell Eco-marathon 2015 events in Asia, Europe and the Americas are comprised of the Shell Eco-marathon Official Rules 2015 Chapter I, hereinafter referred to as "Official Rules" (this document) and the specific Chapter II of the region where the Shell Eco-marathon takes place, which can be downloaded from the ‘For Participants’ section of the Shell Eco-marathon website once available.

b) It is the responsibility of every participating team to ensure the full Rules are read and understood. In order to highlight rule changes and aid the understanding of frequently misunderstood rules, several tools have been used in this document:

i. Text set in red indicates a change/addition/amendment to the previous year’s Rules.

ii. Text set in italic indicates a note or explanation of the rule above to aid its understanding. The text set in italic itself does not form part of the Rules itself.

iii. Links are used throughout this document to improve navigation.

iv. Hyperlinks to videos and drawings are used throughout this document to explain certain rules and illustrate acceptable and non-acceptable solutions.

c) In this document functions and roles are defined as follows:

i. ‘Organisers’ – the specific Shell company that organises the Shell Eco-marathon event in a particular region as named in Chapter II, and all persons acting on its behalf.

ii. ‘Team’ – group of individuals with a team name and one vehicle that has been accepted for entry to the Shell Eco-marathon competition.

iii. ‘Participant’ – member of a Team.

iv. ‘Team Manager’ – a Participant that has been appointed on the event registration document as single focal point for his/her team towards the Organisers.

v. ‘Race Director’ – person appointed by the Organisers, who is responsible to manage and sanction all on-track activities.

vi. ‘Track Marshall’ – person appointed by the Race Director to act on his/her behalf, in particular to ensure on track safety and observe on track rule compliance.

vii. ‘Fuel Marshall’ – person appointed by the Organisers, works as member of the technical team and supervises fuelling activities in line with the requirements of these rules.

viii. ‘Technical Director’ – person appointed by the Organisers, who is responsible to ensure the technical standards and integrity of the Shell Eco-marathon competition.
Article 1:  ACCEPTANCE

a) The entry forms must be sent completed, with all necessary documents, to the Organisers who will accept Teams based on the quality of the proposed entry packet. All decisions by the Organisers regarding the acceptance of Teams are final.

b) By fact of their entry, Participants accept all the provisions of the present Official Rules and agree to abide by all decisions made by the Shell Eco-marathon Organisers. The Organisers reserve the right to modify, delete or add any article of the present Official Rules. In such an event, the Teams will be notified. The Organisers are solely empowered to pronounce on cases not provided for in the present Official Rules.

c) The Organisers reserve the right to modify, postpone or cancel the competition for any reason including for reasons of force majeure due to, including but not limited to, adverse or extreme weather conditions, the occurrence of a natural disaster, acts of terrorism or safety concerns. No claims for compensation will be accepted.

d) The Participant is aware that photo, audio and video recordings will be made of the event. By entering the Shell Eco-marathon, the Participant permanently relinquishes all rights in respect of these photos, audio and video recordings, which are made by third parties, the Organisers and its affiliates. Shell companies may use said photo, audio and video material for internal and external communications and own presentations (including but not limited to promotions, advertising, internet presence, TV and radio reports and press reports).

Article 2:  ENTRIES

a) For each entry, a Team Manager and a Driver must be designated. A Reserve Driver may also be designated.

b) The Team Manager must be a student member of the team currently enrolled at the institution. In case all team members are legal minors, the teacher has to act as the Team Manager.

c) The Team Manager can only be responsible for one vehicle. He/she may also be a Driver for that vehicle, but only for that vehicle.

d) The Team Manager is the Team’s sole official liaison with the Organisers. All information will be addressed to him/her. For the purposes of the project, he/she will be responsible for the Team, must speak on behalf of the Team and must be able to understand and speak English.
Article 4: IDENTIFICATION

a) Logos, official partner streamers and racing numbers must be fixed to the vehicle body in accordance with the diagram provided (see Chapter II) such that they can be clearly read during any public presentation, in promotional films and on all photographs for team use, school use, press or promotional material.

b) Under no circumstances may the Shell logos, the partner streamers or racing numbers be modified, either on the vehicle or on any other documentation. It is prohibited to cut the stickers supplied by the Organisers. Their dimensions are as follows:
   i. For each side and for the front of the vehicle: a Shell logo, 20 x 20 cm.
   ii. For each side and for the front of the vehicle: racing numbers, 20 x 26 cm.
   iii. For each side, on the lower part of the body: a partner streamer, 90 x 6 cm.

c) A mandatory 10 cm space must be left free on all four sides of the Shell logo.

d) Any other sponsor names/logos must be smaller than the Shell logo. The sponsor stickers must fit within a total area of 400 cm² (empty space included).

e) The trademarks or logos of direct competitors of event partners, tobacco companies and alcoholic drinks producers are prohibited. Trademarks and logos of other energy companies require the prior written approval of the Organisers. This rule applies to all vehicles and all team members’ apparel.

f) In the event of a breach of this rule, the Organisers reserve the right to remove any sponsor logos.

g) All vehicles are subject to the Organisers’ approval concerning these provisions.

Article 5: COMPLIANCE

a) Only those vehicles that comply with the present Official Rules are allowed to participate. No vehicle will be allowed on the track for practice or competition until the Organisers have approved it. The decisions of the Organisers are final in all matters concerning the compliance of vehicle design and construction with the present Official Rules.

b) The Organisers reserve the right to rescind vehicle approval upon further or more detailed checks. The Organisers must be notified of any modifications to the vehicle after inspection. Non-compliance with this rule will lead to vehicle disqualification.

c) Vehicles complying with all safety rules but not with some of the other technical rules will not qualify for the competition, however may be allowed on the track for practice or demonstration at the discretion of the Technical Director.

Article 6: PROTESTS

The Team Manager is the only person authorised to lodge protests. Protests must be brought to the attention of the Technical Director via the results desk. Depending on the nature protests must be lodged within the following times:
Article 7: DISPUTES
In the event of any disputes, all decisions made by the Race Director are binding and final.

Article 8: PENALTIES
a) Non-compliance with the driving rules will result in a formal warning, invalidation of the best overall attempt or disqualification of the Team, depending on the severity of the breach.

b) The Organisers will exclude, disqualify or otherwise penalise any Participant who, in the judgement of the Race Director, has gained an unfair advantage as a result of any breach of these Official Rules, hindrance of other Participants, departure from the normal course, or any act or omission capable of misrepresenting performance, especially with regard to fuel consumption or method of propulsion.

c) During the competition, the Driver or the Team Manager must report to the Organisers any movement made or attempted by means other than the vehicle’s own motive power. In such an event, the attempt in question will not be taken into account. If this type of incident is not reported, all the Team’s attempts will be invalidated.

d) The Organisers will apply the following penalties:
   1st infraction:    Formal warning
   2nd infraction:   Best overall attempt invalidated at the end of the competition
   3rd infraction:   Immediate Team disqualification.
2. SAFETY

Article 9: SAFETY RULES
a) As with any Motorsport activity there should be an understanding that certain inherent risks will be present. Recognising and controlling these risks are vital for the wellbeing of people and local surroundings. Safety is an essential consideration for the Organisers. These Rules are to protect all individuals and surrounding areas and are in no way intended to curtail the spirit of the competition. Any activity deemed unsafe or outside of the spirit of the event will be met with appropriate action by the event Organisers.

b) Therefore, compliance with safe driving and sporting rules, as well as any instructions given by Track Marshals is mandatory for everyone. All Participants must comply with the safety measures and must notify Organisers about any anomalies or incidents. In the event that dangerous conditions are present leave the area immediately. During the event the paddock area will be monitored by the Organisers to assist Teams to comply with safe practices.

c) The Race Director is responsible for and has the final authority in determining the safe conditions for track operations in regards to weather.

d) Non-compliance with any of these Rules may lead to disqualification from the competition at the sole and absolute discretion of the Organisers.

DRIVING RULES

Article 10: DRIVING KNOWLEDGE AND TEST
a) Only the registered Driver and the Reserve Driver will be authorised to drive the vehicle.

b) Drivers may be questioned about their knowledge of the driving rules during inspection. The Organisers reserve the right to deny track access to Drivers with insufficient knowledge of the Rules.

c) Driving on-track: In the interest of safety it is important that Drivers learn and apply smooth and predictable driving techniques, e.g. thinking well ahead, avoiding sudden directional changes, and being fully aware of other vehicles around them.

Article 11: DRIVING UNDER THE INFLUENCE OF ALCOHOL/ILLEGAL SUBSTANCES
a) Driving under the influence of any alcohol and or illegal substance(s) is forbidden. This applies to all Drivers and Reserve Drivers entering the track.

b) Procedures for alcohol or substance testing are detailed in Chapter II.

c) Any breach will be penalized in line with Article 6: and the following additional penalties:
   i. Any alcohol and/or substance related breach of the rules will be treated at least as ‘2nd infraction’ of the Team, even if no prior violation has occurred.
Article 12: BRIEFING
The attendance of the daily Drivers’ Briefing is mandatory for the Team Manager and all registered Drivers every day. Failure in attending these Briefings by the Team Managers and Drivers will disqualify the team from practicing and/or competing that day.

Article 13: ACCESS TO THE TRACK AND TEST LAP
a) Vehicles must pass a safety inspection prior to accessing the track for practice runs. A safety sticker will be clearly affixed once the vehicle has passed the inspection.
b) For practice runs, only vehicles with a safety sticker will be allowed on the track.
c) For the competition, only vehicles with safety and technical inspection stickers will be allowed to compete.
d) The Organisers will allow opportunity for Team Managers and Drivers to inspect the track, i.e. before any vehicles are allowed on the track. For further details please refer to Chapter II.
e) After pre-start measurements have been completed, teams must be ready to start their attempt within two minutes or return to the paddock.

Article 14: PUSHING THE VEHICLE
At no time on the race track are drivers allowed to push their vehicle or have it pushed, including to start the run or to cross the finish line.

Article 15: RACE DIRECTION
It is forbidden to drive in reverse gear or to drive against the race direction.

Article 16: RADIO COMMUNICATION
The use of hand-held communications is forbidden in the vehicle. However, the use of a “hands-free” kit is allowed as long as both hands of the driver remain on the steering system.

Article 17: OVERTAKING
Drivers are required to give clear passage for other vehicles wishing to overtake.
a) Drivers in overtaking vehicles must sound their horn and pass with caution. The Driver of the overtaking vehicle is responsible for the safety of the manoeuvre.
b) Drivers of the vehicles being overtaken must use their mirrors and must not change course suddenly.
c) On the track, overtaking is authorised on both the right and the left, as long as the above-mentioned safety rules are followed.
Article 18: BREAKDOWNS AND OTHER INCIDENTS

a) Intentional stopping on the track is forbidden unless it is required by the competition, e.g. for UrbanConcept vehicles.

b) The Driver is allowed 30 seconds to attempt to restart the vehicle from within its driving position.

c) If a vehicle breaks down or is involved in a minor disabling accident on the track, the Driver must immediately make every attempt to drive the vehicle to the side of the track and wait in the vehicle for the Marshalls to arrive.

d) In an emergency, the Driver must get out of the car and wait in a safe place off the track for the Track Marshals to arrive and recover him/her and the vehicle.

e) It is forbidden to carry out repairs on the track. In the event of a flat tyre, even when near the starting line, a new start will not be granted for the attempt in question.

Article 19: OFF-TRACK VEHICLE MOVEMENTS

a) All vehicles must be parked inside the designated paddock area or directly in front of it. When off the track, vehicles must be moved without the use of the engine. They must be pushed or pulled. Testdriving in the paddock area is forbidden.

b) Track Marshals will notify the Race Director of any breaches and any unsafe or unfair behaviour.

DRIVER & EQUIPMENT

Article 20: DRIVER WEIGHT

a) The minimum Driver Weight is:
   Prototype vehicles – 50 kg
   UrbanConcept vehicles – 70 kg

b) The Driver Weight is defined as the weight of the person driving the vehicle including full driving gear and communication devices. If the Driver Weight does not meet the minimum weight requirement ballast needs to be fitted to the vehicle. This ballast must be provided by the Team, and must be effectively tied down and secured to the vehicle to ensure no danger for the Driver in the event of collision or roll-over, and also must be easily detachable for weighing. For UrbanConcept vehicles, the ballast must be placed in the luggage. Any ballast provided must not serve any other purpose than adding weight to the vehicle. It must not be of any use to the vehicle or the driver during the competition.

   Tools, sharp objects and liquids cannot be used as ballast. Adjustable ankle/wrist weights are acceptable but must not be worn by the driver.

c) Drivers (in full driving gear, including communication devices) and their ballast may be weighed before or after each attempt. A weight loss of up to 1 kg during an attempt will be tolerated.

Article 21: HELMETS

a) For practice and competition, Drivers must wear Motorcycle or Motorsport style helmets that comply with the safety standards specified in Chapter II of the Official Rules of each Shell Ecomarathon event (bicycle/riding/skating type helmets are not permitted). Helmet labels must be clearly readable. Helmets worn by the Driver and Reserve Driver will be subject to inspection.
Article 22: DRIVER CLOTHING

a) All Drivers must wear a racing suit as the outermost layer of clothing (fire retardant highly recommended). Casual clothing and street wear are not permitted. Chapter II provides further guidelines regarding the racing suit specifications and availability. Wearing synthetic outer clothes or underwear is strictly forbidden for Drivers when seated in their vehicle.

b) Gloves (covering all fingers fully) and shoes are required and must be provided by the team; bare feet or socks only are prohibited.

Article 23: DRIVER COMFORT

Please note that in the event of hot weather conditions high temperatures could be attained inside the vehicle, potentially affecting Driver comfort and/or causing heat stress.

a) It is recommended to properly ventilate the inside of the vehicle to provide cooling to the Driver.

b) It is recommended to provide sufficient drinking liquids to the driver for the duration of an attempt. If fluid containers are provided to the driver(s), these containers must be hands free, e.g. camelback style or bottles secured inside the driver’s compartment with flexible feed straw.

c) It is recommended to equip the vehicle with an effective sunscreen.

d) The Organisers reserve the right to restrict individual driving time by any means at their sole discretion, e.g. shortening the distance, requesting driver change (pit stop), limit maximum number of attempts per driver per day, etc.

TEAM SAFETY EQUIPMENT

Article 24: EQUIPMENT AND MATERIALS

Teams are required to provide and use the following at the event:

a) Gloves for general work: leather or canvas material.

b) Gloves for fuel or motor oil handling: Chemical resistant.

c) Safety glasses for all Team members. (Disposable types are permitted).

d) Hearing protection for all Team members. (Approved Earplugs or muffs).

e) Duct tape to secure any cords or cables lying on the pit floor.

f) Lift stands or appropriate raised platform for vehicle tuning and repairs.

g) Own tools and materials.

h) Each Team must provide an extinguisher for their pit area with a minimum extinguishing capacity of 1 kg in addition to the vehicle’s extinguisher suitable for “ABC” class of fires. The extinguisher must be accessible in the Team’s specific pit area. The extinguisher must be full (i.e. never used) and have a manufacturing or expiry date. If the extinguisher does not have an expiry date the unit will be acceptable (i.e. valid) if it was manufactured within the past three years. Any extinguisher beyond the expiry period that has been re-inspected and tagged with an official dated recertification will also be permitted.
3.  VEHICLE DESIGN

3A – GENERAL

Article 25:  VEHICLE DESIGN

a) During vehicle design, construction and competition planning, participating Teams must pay particular attention to all aspects of safety, i.e. Driver safety, the safety of other Team members and spectator safety.
   i. Prototype vehicles must have three or four running wheels, which under normal running conditions must be all in continuous contact with the road.
   ii. UrbanConcept vehicles must have exactly four wheels, which under normal running conditions must be all in continuous contact with the road. A fifth wheel for any purpose is forbidden.

b) Aerodynamic appendages, which adjust or are prone to changing shape due to wind whilst the vehicle is in motion, are forbidden.

c) Vehicle bodies must not include any external appendages that might be dangerous to other Team members; e.g. pointed part of the vehicle body. Any sharp points must have a radius of 5 cm or greater, alternatively they should be made of foam or similar deformable material.

d) Vehicle body panels must be rigid with an appropriate stiffness not to be prone to changing shape due to wind.

e) The vehicle interior must not contain any objects that might injure the Driver during a collision.

f) Windows must not be made of any material which may shatter into sharp shards. Recommended material: Polycarbonate (e.g. Lexan)

g) Any cover of the energy compartment (engine/motor/transmission/battery, etc.) should be easy to open for quick inspection access.

h) All parts of the drive train, including fuel tank, hydrogen system components, etc. must be within the confines of the body cover.

i) All objects in the vehicle must be securely mounted, e.g. bungee cords or other elastic material are not permitted for securing heavy objects like batteries.

j) All vehicles must have a solid floor and frame that prevents any part of the driver’s body from contacting the ground.

k) All vehicles (including Prototypes) must be fully covered. Open top vehicles are not allowed. Vehicles that look like bicycles, tricycles or wheelchairs are not acceptable.
Article 26: CHASSIS/MONOCOQUE SOLIDITY

a) Teams must ensure that the vehicle chassis or monocoque is designed wide and long enough to effectively protect the driver’s body in the case of collisions or rollovers. The Organizers will exclude any vehicle whose construction is deemed to be dangerous.

A monocoque is a construction that supports structural load by using an object’s external skin as opposed to using a frame.

b) The vehicle chassis must be equipped with an effective roll bar that extends 5 cm around the driver’s helmet when seated in normal driving position with the safety belts fastened.

If this position impairs the driver visibility it will be deemed that the roll bar is not adequate. The effectiveness of the roll bar and driver’s visibility will be validated simultaneously, i.e. the driver must not be in such position that he or she must raise their head or torso above the roll bar to pass the visibility test.

c) This roll bar must extend in width beyond the driver’s shoulders when seated in normal driving position with the safety belts fastened.

It is permissible to either use a tubular or panel type roll bar. If a ‘tubular roll bar’ is used, it must be made of metal. A panel roll bar is the rigid partition separating the cockpit from the engine compartment. Such a panel roll bar must be an integral part of the vehicle chassis or integrated in a monocoque.

d) Any roll bar must be capable of withstanding a static load of 700 N (~70 kg) applied in a vertical, horizontal or perpendicular direction, without deforming (i.e. in any direction).

Article 27: PROPULSION AND ENERGY STORAGE SYSTEM ISOLATION

a) A permanent Bulkhead must completely separate the vehicle’s propulsion and energy storage systems from the driver’s compartment.

This means engines, fuel cells, fuel tanks, batteries (both propulsion and auxiliary), hydrogen cylinders, Super Capacitors, etc. must be placed outside the driver's compartment behind the bulkhead. The purpose of the bulkhead is that in the event of a fuel leak or fire, it prevents liquids and/or flames and/or smoke reaching the driver. Pay particular attention to avoid any gaps and holes between the body and the bulkhead. It is recommended to seal gaps with materials such as metal/aluminium sheeting or aluminium tape.

b) This bulkhead must be of fire retardant material and construction.

c) The bulkhead must effectively seal the driver’s compartment from the propulsion and fuel system.

d) The bulkhead must prevent manual access to the engine/energy compartment by the driver.

e) If holes are made in the bulkhead to pass through wires, cables, etc. it is essential that the wires/cables are protected by a grommet or similar protective material to prevent chafing or damage. All gaps/holes must also be filled.
Article 28:  VISIBILITY

a) The Driver must have access to a direct arc of visibility ahead and to 90° on each side of the longitudinal axis of the vehicle. This field of vision must be achieved without aid of any optical (or electronic) devices such as mirrors, prisms, periscopes, etc. Movement of the Driver’s head within the confines of the vehicle body to achieve a complete arc of vision is allowed.

The driver’s helmet must be 5 cm below the roll bar at all times.

b) The vehicle must be equipped with a rear-view mirror on each side of the vehicle, each with a minimum surface area of 25 cm² (e.g. 5 cm x 5 cm). The visibility provided by these mirrors, and their proper attachment, will be subject to inspection. An electronic device must not replace a rear-view mirror.

c) In technical inspection visibility will be checked in order to assess on-track safety by using 60 cm high poles spread out every 30° in a half-circle, with a 4 m radius in front of the vehicle.

d) For UrbanConcept vehicles wet weather visibility is also mandatory (see Article 52:).

Article 29:  SAFETY BELTS

a) The Driver’s seat must be fitted with an effective safety harness having at least five mounting points to maintain the Driver securely in his/her seat. The five independent belts must be firmly attached to the vehicle’s main structure and be fitted into a single buckle, specifically designed for this purpose. The mounting points should be fitted so that the belts will self-align with the direction of the load.

b) The safety harness must prevent any upward or forward motion of the driver’s torso. Any slack in the harness must be adjusted by using the seat belt length adjuster. The adjuster must be located as close as possible to the connection point. The crotch strap mounting point should be behind the chest line and the topmost straps should be at an angle of at least 10° below the shoulder line.

c) The safety harness must be worn and fastened at all times to prevent the driver from having any free movement when the vehicle is in motion.

d) The fitness for purpose of the harness and its fitting will be evaluated during technical inspection. For Prototype cars this will be done by raising the vehicle with the Driver on board using the safety harness buckle as the lifting point; this must be capable of withstanding 1.5 times the Driver’s weight.

e) The Urban Concept vehicle safety harness must be specifically manufactured for motorsport use (e.g. certified or compliant with FIA standards).

Article 30:  VEHICLE ACCESS

a) It is imperative for Drivers, fully harnessed, to be able to vacate their vehicles at any time without assistance in less than 10 seconds.

b) Prototype vehicles must be equipped with a sufficiently large opening for the cockpit. The driving position must be designed so that emergency services can easily extract the Driver from his/her vehicle, if necessary.
c) For Prototype vehicles, the said opening may be enclosed wholly or partly by means of hinged, detachable and/or folding doors, provided that a release mechanism is easily operable from inside and that the method of opening from the outside is clearly marked by a red arrow and does not require any tools.

d) For UrbanConcept vehicles, the opening release mechanism must be easily and intuitively operable from the inside and the outside of the vehicle. The method of opening from the outside must be clearly marked by a red arrow and must not require any tools.

e) It is forbidden to use adhesive tape to securely close the Driver’s opening from the outside.

Article 31: HORN

a) Each vehicle must be equipped with an electric horn mounted towards the front of the vehicle, in such a manner that is effectively audible to other vehicles and track marshals. With the vehicle in normal running condition, it must emit a sound greater than 85 dBA when measured 4 meters horizontally from the vehicle.

b) The horn must have a high tone (pitch) of equal or greater than 420 Hz.

Article 32: ON-BOARD FIRE EXTINGUISHER

a) Each vehicle must be fitted with a fire extinguisher (ABC or BC type). All Drivers must be trained in the use of said fire extinguisher. This extinguisher must have a minimum extinguishant capacity of 1 kg (2 lb for US application); equivalent size extinguishers are not permitted. The extinguisher must be full (i.e. never used) and have a manufacturing or expiry date. If the extinguisher does not have an expiry date the unit will be acceptable (i.e. valid) if it was manufactured within the past three years. Any extinguisher beyond the expiry period that has been re-inspected and tagged with an official dated recertification will also be permitted.

b) Plumbed-in extinguishers may be located in the engine compartment and must discharge into the engine compartment. Triggering systems must be located within the cockpit and be operable by the Driver in his/her normal driving position.

c) Hand held extinguishers must be located within the cockpit and be accessible to the Driver once they have vacated the vehicle. These should be securely mounted to prevent movement while driving/biking. In the event of a fire, Drivers should first exit the vehicle and then if possible, remove the extinguisher and attempt to extinguish the fire if safe to do so.

d) The on-board fire extinguisher does not replace the need for an adequate fire extinguisher for the team’s garage area.

Article 33: DRIVER POSITION

For safety reasons, the head-first driving position is prohibited. The driver position should be such that the helmet is 5 cm below the roll bar AND that the visibility for the driver is unimpaired at the same time.
Article 34: CLUTCH AND TRANSMISSION
a) All vehicle propulsion must be achieved only through the friction between the wheels and the road.
b) All vehicles with internal combustion engines must be equipped with a clutch system.
c) For centrifugal/automatic clutches the starter motor speed must always be below the engagement speed of the clutch.
d) For UrbanConcept only: The vehicle must have ‘idling capabilities’, i.e. the vehicle must remain stationary with the engine running.
e) For manual clutches the starter motor must not be operable with the clutch engaged. An interlock is required to facilitate this functionality.
f) Please refer to Article 64: regarding starter motor requirements.
g) The installation of effective transmission chain or belt guard(s) is mandatory.
   This is required to protect driver or technician when working on the car in the event of the chain or belt breaking. It must be made of metal or composite material rigid enough to withstand a break.

Article 35: EXHAUST SYSTEM
a) The exhaust gases must be evacuated outside the vehicle body.
b) Exhaust pipes must not extend beyond the rear of the vehicle body.
c) All vehicles are expected to comply with reasonable environmental standards, e.g. amount of smoke and odour emitted.

Article 36: SOUND LEVEL
The sound level of the vehicle must not exceed 90 dBA when measured 4 metres away from the vehicle.
   Maximum sound levels will be measured and recorded at the start line and teams exceeding the permissible level will be notified with a request for correction within a reasonable timeframe.

Article 37: EMERGENCY SHUT-DOWN
The purpose of the emergency shutdown system is to disable the propulsion system of the vehicle. Different types of propulsion systems require different measures to accomplish this:
-a) Spark ignition engines (gasoline, ethanol, CNG) will require the emergency shutdown mechanism to shut down the ignition. It is not necessary to isolate the accessory battery.
b) Compression ignition engines (diesel, GTL) will require the emergency shutdown mechanism to shut off the fuel or air flow. It is not necessary to isolate the accessory battery.
c) For Battery Electric vehicles the emergency shutdown mechanism must provide a physical isolation
   c) For Battery Electric vehicles the emergency shutdown mechanism must provide a physical isolation of the propulsion battery from the vehicle electrical system. If relays are used, the relays must be a normally open contact type. The use of a power controller or other logic systems to drive an isolation device is not permitted.
d) For Hydrogen vehicles see Article 65:e).
e) There must be both an internal and an external shutdown mechanism.
   i. The internal emergency shutdown mechanism is for driver operation and can be designed in any effective way.
   ii. The external emergency shutdown mechanism must be at the rear of the vehicle and permanently installed on a non-detachable part of the bodywork.
   iii. A red arrow (on a white background) at least 10 cm long and 3 cm wide at the widest point must be positioned on the vehicle body to indicate clearly the exterior position of the emergency shutdown actuator.

f) The following external emergency shutdown mechanisms must be used for the following propulsion energy types:
   i. Compression ignition engines (diesel, GTL) — latching red push button or push/pull red lever
   ii. All other propulsion energy types — latching red push button

g) In addition to the above devices, all vehicles must be equipped with a ‘dead man’s safety device’ that automatically shuts down engine or motor power in case the driver becomes incapacitated. This device may consist of a spring loaded accelerator lever or a dead man switch.

Article 38: ADDITIONAL INSPECTIONS

a) After passing technical inspection, the replacement and/or alteration of the engine, any vehicle wiring, or any other vehicle part must be re-approved by the Organisers.

b) After any significant incident to the vehicle, it must be re-inspected.

c) At any time, the Organisers may perform unannounced inspections on the vehicles.
3B – PROTOTYPE GROUP

Article 39: DIMENSIONS

a) The vehicle maximum height must be less than 100 cm.
b) The vehicle track width must be at least 50 cm, measured between the midpoints where the tyres of the outermost wheels touch the ground.
c) The ratio of maximum height divided by track width must be less than 1.25.
d) The vehicle wheelbase must be at least 100 cm.
e) The maximum total vehicle width must not exceed 130 cm.
f) The maximum total length must not exceed 350 cm.
g) The maximum vehicle weight, without the Driver is 140 kg.

Article 40: NOT USED

Article 41: TIRES, WHEELS, AXLES AND WHEEL HUBS

a) All types of tires and wheels are allowed.
b) Any type of wheel rim may be used. Rims must be compatible with the dimensions of the selected tires in order to satisfy safety standards.

Teams must take into account the fact that bicycle wheels are not generally designed to support substantial lateral cornering forces, such as may be found in Shell Eco-marathon vehicles at certain speeds.

The wheel axles must be designed for cantilever loads (like in wheel chairs) rather than for load distributed equally on both sides (like in bicycles).

c) Wheels located inside the vehicle body must be isolated from the Driver by a bulkhead.
d) Any handling or manipulation of wheels by the Driver is forbidden from the moment the vehicle is at the starting line until it crosses the finish line.
e) All installations must be carried out in a way that there is no likelihood of the wheels coming into contact with other parts of the vehicle (i.e. cables, wires, hoses, and engine compartment components like batteries, etc.). These must be safely mounted/secured so that they cannot interfere with the turning wheel during driving and cause accidents.

Article 42: TURNING RADIUS AND STEERING

a) Only front wheel steering is permitted. If the Organisers are not satisfied with the effectiveness and/or control of a vehicles steering system, this vehicle will be removed from the competition.
b) The turning radius must be sufficient to enable safe overtaking as well as negotiating the turns of the track. If the Organisers suspect that the turning radius of a vehicle is insufficient for the track, the vehicle will be required to negotiate a vehicle handling course.
c) The vehicle handling course will require a turning radius of 8 m. This is to verify driver skills and steering precision, i.e. that it has no play or delay.
The turning radius is the distance between the centre of circle and the external wheel of the vehicle. The external wheel of the vehicle must be able to follow a half circle of 8 m radius in both directions.

d) Electrically operated indirect steering systems are permitted providing they are operated by a steering wheel or similar (rotary potentiometer), joystick operation is not permitted. When electronic steering systems are used, then in event of release of the steering wheel by the driver or electrical failure, the vehicle should revert to the straight ahead position.

Article 43: BRAKING

a) Vehicles must be equipped with two independently activated brakes or braking systems; each system comprising of a single command control (lever(s) working together or foot pedal), command transmission (cables or hoses) and actuators (callipers or shoes).

b) One system has to act on all front wheel(s), the other on all rear wheel(s). When braking on two steering wheels at the front, two actuators (callipers or shoes) have to be used (one on each wheel), commanded by only one command control. In addition, the right and left brakes must be properly balanced.

c) The rear system must work on each wheel, unless they are connected by a common shaft in which case they can have a single system.

d) It must be possible to activate the two systems at the same time without taking either hand off the steering system. Foot control is recommended.

e) The effectiveness of the braking systems will be tested during vehicle inspection. The vehicle will be placed on an incline with a 20 percent slope with the driver inside. The brakes will be activated each in turn. Each system alone must keep the vehicle immobile.

f) During practice or competition runs the brakes must be protected against any adjustments by the driver. The effectiveness of the protection to ensure compliance will be evaluated during technical inspection and rechecked before entering the track. In addition, vehicles will be checked at the finish area. Any protection system that has been compromised will invalidate that run and a penalty may be issued by the Organisers.

g) The use of a hydraulically controlled braking system is highly recommended.

   Cable operated systems are allowed as long as they are effective and pass the brake test.
4. ENERGY SOURCES

4A - GENERAL

Article 53: ENERGY TYPES

Vehicles may only use any one of the following energies:

a) Internal Combustion:
   i. Shell FuelSave Unleaded 95 (Europe and Asia)/Shell Regular 87 (US) Petrol/Gasoline.
   ii. Shell FuelSave Diesel (Europe)/Shell Diesel (Asia and US).
   iii. Ethanol E100 (100% Ethanol)
   iv. Shell Gas to Liquid (100% Gtl)
   v. CNG

   * The gasoline and diesel provided by the Organisers during the competition are the Shell fuels prevalent in the local market where the event takes place. For testing and tuning purposes in the teams’ home countries where Shell fuels may not be available it is recommended to use the locally available Unleaded 95 (87 US) or Diesel instead.

   ** Ethanol E100 and Shell Gas to Liquid will be ranked jointly in one prize category called ‘Alternative Fuels’ on an energy content corrected basis.

   *** The fuel provided by the Organiser for the CNG category will be pure Methane.

b) Electric Mobility:
   i. Hydrogen.
   ii. Battery Electric.

   In order to allow teams to plan ahead when building new vehicles or redesigning drive trains the following change to Article 53 is intended to be put in place for the 2016 season:

   Due to their insignificance for real-world mobility applications solar cells will no longer be allowed in Battery Electric vehicles.

Article 54: RESULTS CALCULATIONS

a) All live results displayed at on-site monitors as well as the internet during the competition are provisional until verified and published by the Organisers after the completion of the event, usually within 3 days after the event.

b) Results for the Internal Combustion Category will be expressed in kilometres per litre (km/l) (i.e. theoretical distance covered using energy of Shell FuelSave Unleaded 95 (Europe and Asia)/Shell Regular 87 (US) Petrol/Gasoline equivalent) corrected to a temperature of 15 °C on a tank-to-wheel basis.

   Regardless of the fuel used, the ranking will be determined from this equivalent consumption of Shell FuelSave Unleaded 95 (Europe and Asia)/Shell Regular 87 (US) Petrol/Gasoline. This calculation will be performed using the net calorific value (NCV), which represents the quantity of
energy released per unit mass or volume of fuel during complete combustion yielding steam and carbon dioxide.

d) Typical NCV values (mass basis) for different fuels are given in the table below. The NCV values (vol.) at 15 °C are calculated on the day of competition by multiplying the actual mass-based NCV by the fuel density at 15 °C.

<table>
<thead>
<tr>
<th>ENERGY TYPE</th>
<th>NCV BY MASS (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell FuelSave Unleaded 95 (Europe and Asia), Shell Regular 87 (US) Petrol/Gasoline</td>
<td>42,900</td>
</tr>
<tr>
<td>Shell FuelSave Diesel (Europe), Shell Diesel (Asia and US)</td>
<td>42,600</td>
</tr>
<tr>
<td>Ethanol E100</td>
<td>29,900</td>
</tr>
<tr>
<td>Gas to Liquid</td>
<td>44,000</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>119,920</td>
</tr>
<tr>
<td>CNG</td>
<td>30,010</td>
</tr>
</tbody>
</table>

For example, if a distance of 1,000 km is covered with one litre of Shell FuelSave Diesel, whose corresponding energy is 35,600 kJ (if we assume a fuel density of 0.837716 kg/l at 15 °C), this represents 0.0280 km covered per kJ. Since the energy from one litre of Shell FuelSave Unleaded 95 is 32,010 kJ (if we assume a fuel density of 0.746106 kg/l at 15 °C), this corresponds to a corrected distance of 895 km (rounded to the nearest unit). The final result for a vehicle having covered 1,000 km with one litre of diesel fuel (at the reference temperature of 15 °C) will thus be 895 km for the equivalent of 1 litre of Shell FuelSave Unleaded 95 (also at the reference temperature of 15 °C).

e) Results for Battery Electric vehicles will be expressed in kilometres per kilowatt hour (km/kWh) and will be determined by using joulimeters which are supplied by the Organisers.

f) Fuel Cell vehicles will use a flow meter to measure the H₂ consumed. The results will be calculated using the NCV of H₂ listed above and expressed in km/m³ hydrogen.

g) The results for hybrid vehicles will be expressed based on the primary energy used.

**Article 55: FUELS SUPPLY & HANDLING**

a) Only the fuels listed in Article 53, as provided to the Participants by the Organisers during the event, are authorised for use during practice and competition.

b) Supplies adequate for practice and competition will be made available to all teams at the event.

c) No additives may be added to the fuel. Only the energy derived from the combustion of the fuel in the presence of air alone within the engine system may be used for forward propulsion. No other material that could serve as engine fuel may be used at any time during the event.

d) Participants handling fuel must wear safety glasses and chemically resistant gloves.

e) No additives, catalysts, water injection, or fuel treatment devices are allowed.

**Article 56: ENGINE LUBRICANTS**

The Organisers will provide engine oil for use by the Participants.
Article 57: VEHICLE ELECTRICAL SYSTEMS

a) For safety reasons, the maximum voltage on board of any vehicle at any point must not exceed 48 Volts nominal and 60 Volts max (this includes on-board batteries, external batteries, Super Capacitors, fuel cell stack, solar cells, etc.).

Battery definition: A ‘battery’ is defined as a source of electrical energy, which has exactly two connectors and comes as a single unit. This single unit may contain more than one subunit.

b) For all vehicles only one on-board battery is allowed. For ICE and hydrogen fuel cell vehicles this is the accessory battery (see Article 57.g), for battery electric vehicles this is known as the propulsion battery.

c) If Lithium-based batteries are used, Battery Management Systems (BMS) tailored to this chemistry must be installed to control and protect the battery against risk of fire. The BMS must provide cell balancing and over-voltage protection during off-track charging. For Emobility vehicles, the additional requirement of cell level over-discharge, over-current and over-temperature must be provided as part of the on-vehicle system. The BMS must AUTOMATICALLY isolate the battery, without operator intervention, if a limit or out of range condition is reached on any of the above parameters. For Lithium-based accessory batteries, the BMS cell balancing and over-voltage protection may be contained as part of the off-board charger. The maximum capacity of any Lithium-based battery used in any propulsion energy class vehicle is 1,000 Wh. For batteries not rated in Wh, the VAh rating is calculated by multiplying the amp-hour rating of the battery by its nominal voltage. Protection for Lithium-based battery charging, whether in or out of the vehicle must be provided, see Article 24(i).

d) All batteries and Super Capacitors must be short circuit protected. Protection may be in the form of a fuse, fusible link, or a current interrupting device (circuit breaker). Automatic reclosing current interrupting devices are not allowed. Short circuit protection devices must be located on the positive conductor and as close as possible to the battery or Super Capacitor itself. The rating of the short circuit protection device must be such that the battery or Super Capacitor will be able to supply enough short circuit current at all times to open the device. For vehicles with a starter motor, the starter motor cable is NOT required to be protected.

e) All vehicle electrical circuits must be protected against electrical overload. Overload protection may be in the form of fixed current limits within electric controllers or by the insertion of individual circuit fuses. For Internal Combustion vehicles, overload protection is required for the motor controller, ignition system, and other accessory load electrical circuits.

f) The accessory battery (see Article 57.g) must maintain a negative ground.

g) The accessory battery provides for all allowed electrical needs such as safety devices (horn, windscreen wipers, lights, hydrogen sensors, hydrogen relays and hydrogen shutdown valve).
ignition, fuel injection control, starter motor, and ventilation/cooling fan for the driver. For Internal Combustion vehicles only the accessory battery may also be used for engine management systems.

The capacity of the accessory battery must be sufficient to power all the accessory loads with a sufficient safety margin. An accessory battery load analysis will be reviewed during technical inspection to validate sufficient battery capacity. The accessory battery is not allowed to power compressors, blowers, engine cooling systems or motors.

h) The Organisers reserve the right to request Teams to install one joulemeter, intended to measure the quantity of energy provided by the accessory battery. If this amount of energy exceeds the power typically required to operate the starter motor, horn and safety devices the competitor will be disqualified.

i) Both propulsion and accessory batteries must be installed outside of the driver’s compartment behind a bulkhead (see 0).

j) The following devices may be powered by batteries other than the propulsion or accessory battery provided they use built-in batteries: radio communication system, GPS system, data loggers excluding engine management units, driver ventilators.

k) All electrical/electronic enclosures built and populated by the teams must be made of transparent material or at least have a transparent cover to allow the technical inspectors to view the contents.

**Article 58: TECHNICAL DOCUMENTATION**

a) Competitors need to provide technical documentation in 2 stages:

i. Prior to the event during the online submittal process (see Article 58: b). This documentation serves only to verify that the teams have an understanding of the Rules. Online approval in no way constitutes a pre-approval for the Technical Inspection phase.

ii. At the event (see Article 58: c) This should be a precise technical description of the vehicle. During technical inspection, the documentation will be compared against the vehicle. Deviations between the technical documentation and the vehicle will be required to be reconciled prior to passing technical inspection.

b) Technical Documentation – prior to event:

i. Competitors must provide, through the online submittal process, documentation on the vehicle energy supply and propulsion system. It is not necessary to submit detailed component specifications or electrical schematics as part of the online submittal process.

ii. Energy supply block diagram

   The online submitted energy supply block diagram and associated text description must contain information describing the energy flow and component function for the vehicle energy systems. Specific items to be included in the block diagram for each energy category are listed below:

   - ICE (liquid fuels): engine, fuel tank, fuel line, carburetor/injector, pressure relief valves, pressure regulators, pressure gauge, compressed air bottle, vehicle cutoff mechanism
- **ICE (CNG)**: Engine, regulator, cylinder, solenoid valve, fuel line, vehicle cutoff mechanism
- **H2**: Fuel cell, cylinder, flow meter, solenoid valve, regulator, flow meter, motor controller, motor, super capacitor, vehicle cutoff mechanism
- **BE**: Motor, battery/BMS, fuse, wiring, e-stop switches, motor controller, vehicle cutoff mechanism

### iii. Propulsion system block diagram

The online submitted propulsion system block diagram and associated text description must contain information describing the propulsion mechanism for each energy category below:

- **ICE/CNG**: Engine/Motor to road (engine, transmission, clutch, wheel, motor, super capacitor, motor controller)
- **H2**: Motor to road
- **BE**: Motor to road

### c) Technical Documentation – at event (to be reviewed during Technical Inspection)

1. Competitors must have available for inspection with the vehicle printed documentation describing selective technical aspects of the vehicle. The printed documentation must be bound and divided into the following sections. The specific required sections for each energy category are defined below:

   **ICE (liquid and CNG) energy category**
   - Energy Supply Diagram
   - Propulsion System Diagram
   - Electrical Schematic
   - Hybrid System
   - Battery/BMS

   **Battery Electric energy category**
   - Energy Supply Diagram (Electrical Schematic)
   - Propulsion System Diagram
   - Battery/BMS
   - Motor/Motor Controller
   - Solar Panel

   **Hydrogen category**
   - Energy Supply Diagram
   - Propulsion System Diagram
- Battery/BMS ++
  + If included in the vehicle
  ++ If a Lithium-based accessory battery is included in the vehicle

ii. The minimal contents of each of the above required sections are defined below.

- Energy Supply Diagram: include updated diagrams and associated descriptive text as defined in Article 58 (b) above.

- Electrical Schematic: provide a vehicle level schematic showing all vehicle wiring and associated components and connections. The schematic should include component values such as voltage levels and fuse ratings. Schematics of components such as the engine management system or fuel cell controller are not required in this section.

- Hybrid System: include manufacturers’ component specifications at the lowest level of purchased components. Include diagrams describing the power flow into and out of the hybrid system. Include super capacitor documentation (see the Super Capacitor section below).

- Battery/BMS: (For Lithium-based batteries only) Provide battery/BMS manufacturer component specifications at the lowest level of purchased components. At minimum, the battery documentation should include cell chemistry, cell electrical characteristics, cell series and parallel configurations, battery voltage, and current ratings. The BMS data MUST include:
  1. Cell over-voltage and under-voltage protection limits
  2. Battery overcurrent limit (not required for accessory battery)
  3. Operation of cell balancing (how and when)
  4. Battery overtemperature limit (not required for accessory battery)
  5. How the BMS will protect the battery when an over-voltage, under-voltage, over-current or over-temperature condition is reached, i.e., how will the BMS protect or isolate the battery, in the case of Battery Electric Vehicles, when these limits are reached?

- Motor/Motor Controller: Provide motor/motor controller manufacturer component specifications at the lowest level of purchased components. For Battery Electric Vehicles, include design documentation on the purpose built motor controller. The documentation may contain control flow diagrams, motor controller and sub-component schematics, PCB board layouts. Also include software documentation if software was written as part of the motor controller development.

- Solar Panel: Provide solar panel/MPPT manufacturers components specifications at the lowest level of purchased components. At minimum, provide cell and panel dimensions and electrical specifications (Ve, Isc). Provide MPPT electrical specifications including max operating voltage and max current.

- Super Capacitors: Provide super capacitor manufacturer component specifications at the lowest level of purchased components. At a minimum, include super cap system rated voltage and max current.
4C – ELECTRIC PROPULSION

Article 65: FUEL CELLPOWERED VEHICLES

(a) Fuel system

i. Participants must provide a description and a precise technical drawing of the fuel supply system.

ii. The fuel system must be easily accessible for inspection and measurements.

iii. The fuel cell must run by itself. The electricity needed for temperature regulation, fan, compressor, electronic management system for the fuel cell and the electric motor must be supplied by the fuel cell and not by the accessory battery.

iv. The hydrogen system must be designed as follows:

$$ \text{H}_2 \text{ cylinder} \rightarrow \text{Pressure regulator directly attached to the cylinder} \rightarrow \text{Emergency shutdown valve directly attached to the outlet of the pressure regulator} \rightarrow \text{Flow meter} \rightarrow \text{Fuel Cell} $$

v. The flow meter must be fixed at the inlet of the fuel cell. Both must be at the same pressure.

(b) Hydrogen cylinders

i. FC-powered vehicle must use a compressed hydrogen cylinder, referred to hereafter as a cylinder, as provided by the Organisers during the entire event. Only one cylinder may be fitted to a vehicle at any time.

ii. Cartridges and any other means of hydrogen storage are not permitted.

iii. For Prototypes vehicles, the following cylinders will be provided:

Europe: B04 cylinder, 0.4 litre of hydrogen at 200 bar (7 cm/33 cm) 1.4 kg

America: Exchange cylinder ~ 152 bar

5.3”X17.1” (13.5 cm x 43.4 cm), 8.6 lbs (3.9 kg)

Asia: Catalina MD cylinder, 2.9 litre of hydrogen @139 bar (11.1 cm x 42.4 cm), 2.4 kg

iv. For UrbanConcept vehicles, the following cylinders will be provided:

Europe: B1 cylinder, 1 litre of hydrogen at 200 bar (10 cm x 35 cm) 2.57 kg

and

B04 cylinder, 0.4 litre of hydrogen at 200 bar (7 cm/33 cm) 1.4 kg

America: Exchange cylinder ~ 152 bar

5.3”X17.1” (13.5 cm x 43.4 cm), 8.6 lbs (3.9 kg)

Asia: Catalina MD cylinder, 2.9 litre of hydrogen @139 bar (11.1 cm x 42.4 cm), 2.4 kg

v. Cylinders must be installed on the vehicle under the supervision of a Fuel Marshal. Participants are not allowed to keep any cylinders in their possession overnight. Upon arrival at the circuit, Team Managers must contact the Fuel Marshal, who will organise all relevant logistics.
c) Ventilation
   The vehicle body must allow for ventilation at the highest point of the fuel cell compartment,
   providing an orifice with a minimum opening of 5 cm². Another 5 cm² opening must be provided
   at the highest point of the driver compartment.

d) Hydrogen detector
   i. A hydrogen sensor must be installed in the fuel cell compartment, near the main ventilation
      orifice mentioned above. This hydrogen sensor must drive the emergency shutdown valve
      and relay mentioned below. The trip level of the hydrogen sensor must be tuned to 25% of
      the LEL (Lower Explosive Limit) of hydrogen, i.e. 1% of hydrogen in air. A test will be carried
      out during the technical inspection.
      
      For commercial Fuel Cells with integrated H₂ detector it is still required to fit a H₂ sensor
      as described above.
   ii. The reset of the hydrogen detector, i.e., the hydrogen sensor and its electronics, must be
       done manually via a switch located in the fuel cell compartment. This switch must not be
       accessible by the Driver from the cockpit.

e) Emergency shutdown valve and relay
   i. The hydrogen supply circuit must be equipped with a solenoid emergency shutdown valve.
      This valve must be normally closed in the absence of electricity.
   ii. The power supply to the motor must be automatically cut off at the same time as the above
       emergency shutdown valve is activated. This is to be achieved by a suitable fail-safe relay.
   iii. This valve and relay must be activated by any of the following three scenarios:
      1. Through hydrogen detection as explained above
      2. Through the emergency push-button located on the outside of the vehicle. A red arrow
         (on a white background) at least 10 cm long and 3 cm wide must be positioned on the
         vehicle body to clearly indicate the place of this emergency push-button. (Note: It must
         not be part of the detachable bodywork used to allow driver access)
      3. Through another emergency push-button, accessible by the Driver in driving position
   iv. In case of activation by one of these three scenarios, the valve and relay must act
       simultaneously.
   v. These three scenarios will be tested during Technical Inspection and before each attempt.

f) Pipes and connections of the hydrogen circuit
   i. In all cases, piping and connectors of the hydrogen circuit must be designed for hydrogen
      use. The Team Manager must be able to present during the technical inspection the
      technical data sheets from the manufacturer of these piping and connectors to show that they
      are suitable for hydrogen use.
      The use of PTFE pipes is recommended. PU tubing should not be used as this tends to leak.
   ii. If the pressure in the hydrogen circuit is higher than 1.5 bar absolute (≈0.5 bar above
       atmospheric pressure) piping must be made of steel and connectors must be
       screw/compression type.
   iii. If the pressure in the hydrogen circuit is lower than 1.5 bar absolute (≈0.5 bar above
       atmospheric pressure) flexible piping and unscrewed connectors are accepted.
   iv. PTFE (Teflon) sealing tape must not be used because it can damage the flow meter. In any
       case Participants are responsible for damage to the flow meter due to wrong connections.
g) Purge pipe
If a purge pipe is needed, its end must be located outside the vehicle.

h) Measurements and Equivalencies
i. The consumption of hydrogen is measured by an embedded flow meter. The flow meter will be checked/calibrated by the Organisers before Technical Inspection.

ii. The flow meter must be purchased from the Organisers.

iii. The volume of hydrogen consumed is posted in normal litres. The display of the flow meter must be easy to read from outside the vehicle, when the vehicle body is closed. It must be inaccessible by the Driver in normal driving position.

iv. The serial number on the hydrogen flow meter must not be covered or removed.

i) Oxygen and air reserves
The use of non-replaced oxygen or compressed air reserves is forbidden.

j) Super Capacitors
i. If an embedded electric storage device is part of the powertrain, it must be of capacitor type, referred to hereafter as ‘Super Capacitor’. Other types of embedded electric storage device (Pb, NiMh, etc. batteries) are forbidden.

ii. The state of charge of the Super Capacitor will be checked before and after each run by measuring the Super Capacitor voltage. Two measurement points (Super Capacitor voltage + and - a labelled “Super Capacitor voltage”) must be installed outside the vehicle to allow the voltage measurement on the starting line.

iii. The voltage registered after the run must be at least equal to the voltage registered before the run. In the event of the contrary, the Super Capacitor must be recharged by running the fuel cell until their voltage is equal to the voltage registered before the run. The additional

k) External starter battery
i. An external battery can be used on the starting line to start the fuel cell system. As soon as the vehicle starts to move, this battery must be unplugged.

ii. If an external battery is used, two connectors must be installed outside the vehicle to allow a quick connection and fuel cell system start on the starting line. These external connectors must be securely fastened to the vehicle.

iii. As mentioned in Article 57.4, it is mandatory to power the hydrogen detector and the horn using the accessory battery. This battery must also power the emergency shutdown valve, relay and lighting system for UrbanConcept vehicles.

l) Electrical circuit/Electronics
i. All wiring associated with the accessory battery circuit must be clearly distinguishable from the propulsion system by physical isolation or the use of different wire colours.

ii. A fuse must be installed on the positive terminal of the fuel cell stack. Its melting current (expressed in Amps) must be less than the active area (expressed in square centimetres) of one cell of the stack. For instance, if the active surface of one cell of a 20 cell stack is 60 cm², the melting current of the fuse must not exceed 60 A.

iii. If a Super Capacitor is used in the circuit, a fuse must be installed on the positive terminal of the Super Capacitor pack. The fuse rating must be less than or equal to the maximum usable power divided by the rated voltage.
Article 67: BATTERY ELECTRIC VEHICLES

a) The drive train in the ‘Battery Electric’ category is restricted to a maximum of one electric storage device, and up to two electric motors, with associated control units. The electric motors may be purchased, purchased-and-modified, or purpose-built. The motor controller MUST be purpose-built for the Shell Eco-marathon. Modifications to purchased motor controllers are not acceptable. Motor controllers built from sub-components such as single-board computers, power stages, etc. are encouraged. If a unit is developed incorporating the motor controller into one or more single printed circuit boards (PCB) the text “SEM” needs to be included in the mask of the PCB etching.

b) Only lithium-based batteries are permitted as electric storage devices. The vehicle must be equipped with a metal tray under the battery suitable to prevent a battery, in the event of a fire or battery event, from burning through the vehicle body and dropping to the ground.

c) The vehicle must be equipped with a Battery Management System (BMS) to control and protect the battery against risk of fire as defined in Article 57.a:

Any BMS for propulsion batteries must provide an AUTOMATIC isolation of this battery in the event of any measured parameters getting out of their designed range.

d) The Lithium-based battery and any accessory circuits are subject to the maximum voltage defined in Article 57.a.

e) Solar cells MAY be integrated into the vehicle electrical circuit. If solar cells are included they must meet the following requirements:

i. The solar cells must be fully integrated into the natural contour of the vehicle’s body. They must NOT form an independent structure or be part of any other structures protruding from the vehicle. This will be checked during Technical Inspection at the event. It is highly recommended that prior to the vehicle build/modification you send pictures/drawings/sheets to the Shell Eco-marathon email address to ensure compliance.

ii. The maximum voltage present at any point in any circuit, before or after the maximum power production (MPP) controller, must not be greater than defined in Article 57.a.

iii. For a Prototype vehicle, the total combined surface area of the solar cells shall be less than 0.17 m² (e.g. 10 cells of 5x5 inches or 7 cells of 6x6 inches).
iv. For an UrbanConcept vehicle, the total combined surface of the solar cells shall be less than 0.65 m² (e.g. 40 cells of 5x5 inches or 27 cells of 6x6 inches).

v. The output of the solar cells will be measured through a joulemeter. The joulemeter will be connected in the vehicle electrical circuit before the motor joulemeter and after the solar cell MPP controller, if equipped.

vi. The calculation of the race result (expressed in km/kWh) will be based on the Net propulsion energy supplied by the battery only, excluding the propulsion energy contributed by the solar cells, i.e. Net propulsion energy – motor propulsion energy – solar propulsion energy. The amount of solar energy used in this calculation will be limited to no more than 20% of the motor propulsion energy used during the run. The motor propulsion energy includes both, the energy consumed by the motor and the motor controller.

f) Participants are required to present electrical schematics at Technical Inspection (see 0).

g) All batteries must be placed outside the Driver’s compartment behind the bulkhead and securely mounted. Bungee cords or other elastic materials are not permitted for securing the battery (see 0).

h) All vehicles must be equipped with one joulemeter located between the battery and the motor controller(s), and, if equipped with solar cells, a second joulemeter for the solar output as described in Article 67a(iii) above, to measure the vehicle propulsion energy consumption.

i) The Organisers will provide the joulemeter(s) for the duration of the event. A security deposit may be required for the joulemeter.

j) Joulemeter(s) must be positioned so that the display can be easily read from outside the vehicle.

k) The joulemeter(s) must be inaccessible to the Driver in his or her normal driving position.

l) All electrical circuits must be protected as defined in 0.

m) On the starting line, Fuel Marshals will reset the joulemeter(s) to zero, and then the vehicles will have access to the track to start their attempt under the same distance and time conditions as specified for their respective vehicle class.

n) At the finish line, Fuel Marshals will read the joulemeter(s) display.

o) All ‘Battery Electric’ vehicles which complete a successful run will be classified in descending order of fuel economy, expressed in km/kWh.
### 5. AWARDS AND PRIZES

#### 5A – ON-TRACK AWARDS

**Article 70: AWARD OVERVIEW AND PRIZES**

All on-track prizes and trophies below are awarded twice, once for Prototype and once for UrbanConcept vehicles.

<table>
<thead>
<tr>
<th>SHELL ECO-MARATHON ON-TRACK AWARD</th>
<th>ASIA AMERICAS</th>
<th>EUROPE</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell FuelSave Gasoline Winner</td>
<td>$2,000</td>
<td>€1,500</td>
<td>Prize Money, Trophy, onstage Winners Ceremony</td>
</tr>
<tr>
<td>Shell FuelSave Gasoline Runnerup</td>
<td>$1,000</td>
<td>€750</td>
<td>Prize Money, Certificate in mail</td>
</tr>
<tr>
<td>Shell FuelSave Gasoline 3rd place</td>
<td>$500</td>
<td>€375</td>
<td>Prize Money, Certificate in mail</td>
</tr>
<tr>
<td>Shell FuelSave Diesel Winner</td>
<td>$2,000</td>
<td>€1,500</td>
<td>Prize Money, Trophy, onstage Winners Ceremony</td>
</tr>
<tr>
<td>Shell FuelSave Diesel Runnerup</td>
<td>$1,000</td>
<td>€750</td>
<td>Prize Money, Certificate in mail</td>
</tr>
<tr>
<td>Shell FuelSave Diesel 3rd place</td>
<td>$500</td>
<td>€375</td>
<td>Prize Money, Certificate in mail</td>
</tr>
<tr>
<td>Alternative Fuel Winner (E100+G1)</td>
<td>$2,000</td>
<td>€1,500</td>
<td>Prize Money, Trophy, onstage Winners Ceremony</td>
</tr>
<tr>
<td>Alternative Fuel Runnerup</td>
<td>$1,000</td>
<td>€750</td>
<td>E100 or G1; Prize Money, Certificate in mail</td>
</tr>
<tr>
<td>Alternative Fuel 3rd place</td>
<td>$500</td>
<td>€375</td>
<td>E100 or G1; Prize Money, Certificate in mail</td>
</tr>
<tr>
<td>CNG</td>
<td>$2,000</td>
<td>€1,500</td>
<td>Prize Money, Trophy, onstage Winners Ceremony</td>
</tr>
<tr>
<td>CNG Runnerup</td>
<td>$1,000</td>
<td>€750</td>
<td>Prize money, Certificate in mail</td>
</tr>
<tr>
<td>CNG 3rd place</td>
<td>$500</td>
<td>€375</td>
<td>Prize money, Certificate in mail</td>
</tr>
<tr>
<td>Battery-electric Winner</td>
<td>$2,000</td>
<td>€1,500</td>
<td>Prize Money, Trophy, onstage Winners Ceremony</td>
</tr>
<tr>
<td>Battery-electric Runnerup</td>
<td>$1,000</td>
<td>€750</td>
<td>Prize Money, Certificate in mail</td>
</tr>
<tr>
<td>Battery-electric 3rd place</td>
<td>$500</td>
<td>€375</td>
<td>Prize Money, Certificate in mail</td>
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<tr>
<td>Hydrogen Fuel Cell Winner</td>
<td>$2,000</td>
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<td>Prize Money, Trophy, onstage Winners Ceremony</td>
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<td>Hydrogen Fuel Cell Runnerup</td>
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</tr>
</tbody>
</table>
Appendix E: Pictures Gallery

- Mold construction
• Vehicle Construction
• Shell Eco Marathon 2015
References:

healing_sandwich_panels_Restoration_of_compressive_strength_after_impact