NAU Shell Eco-Marathon Team

Memo

To: Dr. John Tester
From: Travis Moore, Nikolaus Glassy, John Gamble, Abdul Al
Cc: Dr. Srinivas Kosaraju
Date: December 13, 2013
Re: Project Proposal

Through the many weeks, the team has worked diligently to design and finalize the engine, drivetrain, fuel and electrical systems for the Shell Eco-Marathon prototype vehicle. Through concept generation and concept selection the team selected they best solutions for the above mentioned systems. The team performed engineering analysis on the system to see how the will perform and to finalize the team's decision to use the selected concept.

The team's selected design involves using a small displacement 50 cc GY6-QMB engine produced by Honda. The GY6-QMB engine will be integrated with a fuel injection kit from Ecotrons. This combination will give the team a great starting point to be able to precisely tune for maximum fuel efficiency. The vehicle's engine will be attached to a custom 2-Stage chain and sprocket drivetrain. This drivetrain will be fitted with a custom clutch system that will meet all rules and regulations set out by Shell. Finally, the battery choice to power the electrical system will be a Deka ETX-9 battery. With these components, along with the other components from the other team, the NAU Shell Eco-Marathon Team predicts a target fuel economy of at least 550 miles per gallon.

The estimated cost for engine, drivetrain, fuel and electrical systems is $1622.94.

Shell Eco-Marathon

By
Abdul Alshodokhi, John Gamble, Nikolaus Glassy, and Travis Moore
Team 14b

Project Proposal Document

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design I – Fall 2013

Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

December 13, 2013

Table of Contents

List of Tables and Figures

Abstract

The increase in Earth temperatures as a result of the production of greenhouse gasses is a serious problem facing the planet. Many of these emissions are from automobiles. Reducing the amount of fuel consumed by cars will directly impact the amount of greenhouse gasses released. With this concept in mind, Shell created the Eco-Marathon: a competition designed to encourage research into making more fuel efficient vehicles. The Northern Arizona University chapter of the Society of Automotive Engineers will be participating in the event from April 25th-27th in Houston, TX. The overall powertrain design of the car uses a Honda GY6-QMB 50cc engine coupled with fuel injection to improve efficiency. The powertrain system will employ a dual gear reduction to reduce rotating mass and be able to achieve desired speeds. The clutch will be a custom 2 stage design to make the car meet the regulations from Shell. On a flat surface, running the engine constantly, the car is estimated to achieve 663 miles per gallon. The goal of driving the car will be to cycle the engine which will increase the fuel economy further.

Chapter 1: Introduction

Project Description:

The Shell Corporation puts on an annual competition that focuses on increasing the efficiency of fossil fueled vehicles and increasing the interest as well as the efficiency of renewable energy vehicles. The competition will be help in Houston, TX in late April. The prototype vehicle that competes will have to meet the rules and regulations set out by Shell. The purpose of this project outlined by the team's client is to design, build, and compete well with a prototype vehicle that will achieve the highest fuel economy possible.

Client:

The primary client for this project is Dr. John Tester at Northern Arizona University (NAU). Dr. Tester is involved with the student chapter of Society of Automotive Engineers (SAE). Dr. Tester has been the academic advisor for the Shell Eco-Marathon for the past couple of competitions. The secondary client for this project is the student chapter SAE because most of the funding is coming directly from the student chapter SAE's budget.

Need Statement:

Due to the significant number of vehicles running on finite resources as a means of transportation, it has become necessary to research and develop means to stretch those finite resources further. The Shell Corporation has sponsored a competition to promote this research and development in the field of fuel efficiency. The scope of this project is to design, build, test, and present a vehicle that conforms to the set requirements and constraints to produce a vehicle that will produce extremely high fuel efficiency.

Goal & Focus

The team's goal for this semester is to accurately and appropriately design an internal combustion engine powered vehicle for the Shell Eco-Marathon Competition that will have several subsystems working together to reach a fuel efficiency of at least 500 mpg. The team will be focusing on the powertrain, fuel, electrical, and the technical documentation for the competition. The team will work in conjunction with another team from Northern Arizona University that will be working on the remaining systems to complete the vehicle design.

Objectives

Table 1.1 shows the group objectives, their corresponding benchmarks, and the units of measurement.

Table 1.1: Objectives

Objective	Benchmark	Unit of Measurement
Start-up to desired RPM	Time	Seconds
Achieve max speed of 17mph	Velocity	MPH
Shut down systems in 1 second	Time	Seconds

Operating Environment

- Tuning Environment
    - The initial tuning will be done in Flagstaff for engine break in and preliminary testing
    - The vehicle will also be tuned and tested in Phoenix before the competition to obtain a better idea of potential results due to the lower elevation (1200 ft. above sea level)
- Competition Environment
    - The competition will take place in downtown Houston, TX from April 25th to the 27th
    - Practice, tuning, competition, and presentation will take place in Houston.

Constraints

The following is the list of constraint set out by the rules and regulations from Shell:

- The engine must be fueled by gasoline.
- The engine must not combine fuel and oil (no 2-stroke engines).

- The starter must not provide forward propulsion.
- Effective transmission chain or belt guards:
    - To protect driver or technician.
    - Made of metal or composite material.
    - Rigid enough to withstand a break.
- Clutch system must be equipped, with the internal combustion engines
- Manual Clutch:
    - Must have starter motor inoperable with the clutch engaged
- Automatic clutch:
    - Motor starting speed must be below engagement speed of the clutch
- Fuel must be Shell Regular Gasoline (87) or E100 (100% Ethanol)
- Fuel tank must be APAVE certified and a volume of either 30,100,or 250 cc
- Fuel tank must be mounted in a zero degree position and at least 5cm below the roll bar
- Air Intake must not contain any fuel or blow-by gas
- Internal and external emergency shut-down systems must shutdown the ignition and fuel supply
- External system must be permanently mounted to body
- External system must have a latching red push button and be labeled with a 10cm by 3cm wide red arrow on a white background·
- Fuel line between tank and engine may not contain any other elements
- Fuel lines must be flexible and clear in color and not prone to expansion
- Teams cannot increase or decrease the fuel temperature
- Float chambers must include a drain valve at the bottom of the carburetor to ensure fuel level goes down in the fuel tank
- Maximum on-board voltage must not exceed 48V nominal
- Only one on-board battery and the battery must maintain a constant ground
- Electrical circuits must be protected from short circuit and overload
- Electric horn must be 85 dBa and pitch of 420 Hz
- Electrical starter can only operate when ignition and fuel systems are activated
- Electrical starter must not provide propulsion

- A red starter light must be installed on the rear of the vehicle with a luminescence of 21W and be clearly visible from both sides
- Starter and starter light must be extinguished by the time the rear wheel crosses the start line

Chapter 2: Concept Generation and Selection

Engine System

The engine selection for the Shell Eco-Marathon car is one of the most important aspects for the vehicle's success. Since the goal is to improve fuel efficiency, finding a motor that will be able to power the vehicle while using the least amount of power is important. Since the engine will be cycled on and off during the competition, overall motor efficiency was deemed more important than total power output. Most current small engine choices suffer from the same design flaw: they are carbureted. Carburetors deliver fuel less efficiently than fuel injection, hurting fuel economy. Finding a motor that was fuel injected or that could be easily modified to become fuel injected is a priority.

Motor compression ratios are another way to improve engine efficiency. It is possible to improve engine compression by changing parts but using a motor that has a higher compression ratio to start with is a better option. As a small school, our budget is limited, so finding the best cost/performance ratio for the motor is important.

3 main engine options were considered: a Honda GY6-QMB 50cc, a Honda GX25 25cc, and a Honda GX35 35cc. Figure 2.1 shows the GY6-QMB, figure 2.2 shows the GX25, and figure 2.3 shows the GX35. The engines were compared in terms of their power output, compression ratio, aftermarket support, starter type, clutch type, initial fuel consumption, and cost. Table 2.1 shows the decision matrix used to compare the engines. Engines were scored with possible values of 1, 5, and 10 with 10 being the best possible score and 5 being the worst. The score is then weighted by the importance, giving the final total score.

Figure 2.1: Honda GY6-QMB

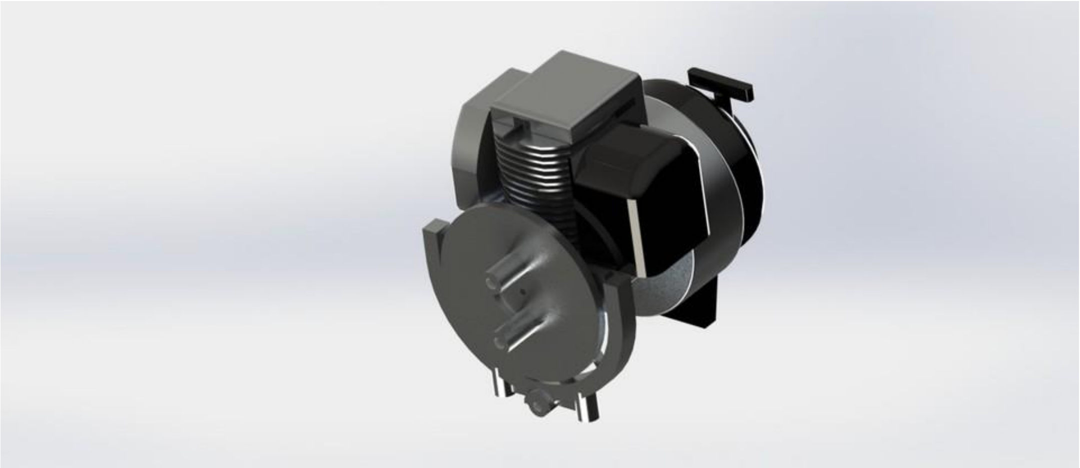


Figure 2.2: Honda GX25

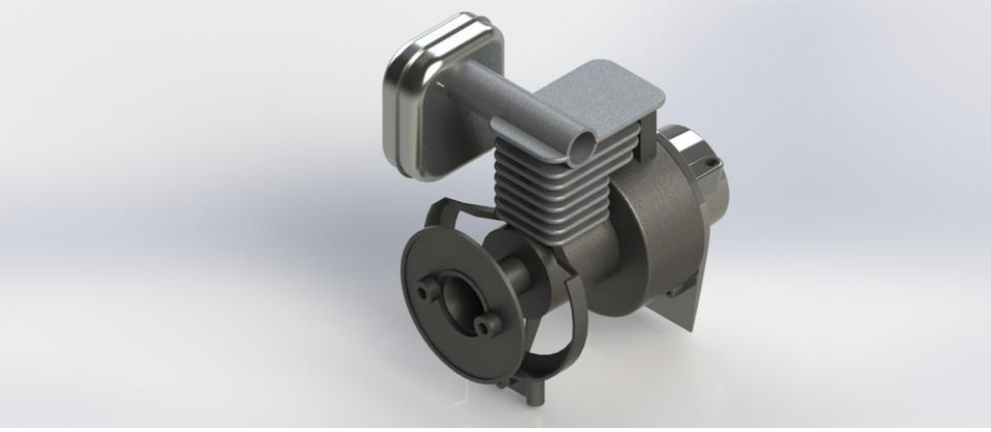


Figure 2.3: Honda GX35 Engine

Table 2.1: Engine Selection Decision Matrix

	Weighted Percentage	**Honda GY6-QMB**	**Honda GX25 25cc**	**Honda GX35 35cc**
Power Output	5%	1	10	5
Compression Ratio	25%	10	1	1
Aftermarket Support	20%	10	1	1
Starter Type	10%	10	1	1
Clutch Type	10%	10	1	1
Initial Fuel Consumption	10%	1	10	5
Cost	20%	1	5	10
Total	100% (10 points)	6.85	3.15	3.4

In the category of power output, least is the best. The car will be light, so it will not take a lot of power to achieve the desired speed. The GY6-QMB produces 2.1 kW at 6500 rpm and 3.1 N-m at 5500 rpm, the GX25 produces 0.72 kW at 7000 rpm and 1 N-m at 5000 rpm, and the GX35 produces 1 kW at 7000 rpm and 1.6 N-m at 5000 rpm [1]. The GX25 would produce enough power to move the car, while not producing any more than we need. Consequently, the GX25 scored the highest in this category followed by the GX35 and last was the GY6-QMB.

Compression ratio of an engine is an important measure of thermodynamic efficiency: the higher the ratio, the more efficient the motor. Since the motor will be cycled, overall efficiency is just as important as initial fuel consumption. The GY6-QMB starts with a compression ratio of 10.5:1 while the GX25 and GX35 both have compression ratios of 8.0:1 [1]. The GY6-QMB scored the highest possible points in this category while the GX25 and GX35 scored the lowest.

The GY6-QMB is mostly used on scooters and motorized bicycles while the GX series motors are primarily used for applications like lawn and garden equipment. Most people do not modify their gardening tools while many people modify their scooters. The GY6 has considerably more aftermarket parts support than either the GX25 or the GX35. This is important because it makes replacement parts much cheaper. It also means that there is more ability to modify the motor to improve efficiency with off-the-shelf components instead of custom making many parts.

Using an electric starter would make it possible for the driver to cycle the motor on and off while driving. Since the plan to improve vehicle efficiency is to cycle the motor, having an electric starter is much better than having a magneto starter. The GY6-QMB is the only motor of the 3 considered to have an electric starter, giving it the maximum number of points for the category.

The GY6 is the only motor of the 3 that includes a clutch setup with the engine assembly. Consequently, it receives the maximum number of points and the GX25 and GX35 receive the minimum number.

The initial fuel consumption of the motor, not the projected final goal. The measurements are taken at their max power output rpm. As expected, the smallest engine uses the least fuel. The GX25 uses 0.54 L/hr at 7000rpm, the GX35 uses 0.71 L/hr at 7000rpm and the GY6-QMB uses the most fuel at 1.04 L/hr at 6500 rpm [1]. While the engines would be modified to improve the fuel economy, it is a good idea to start with a motor that uses as little fuel as possible. The GX25 receives the maximum number of points and the GY6-QMB receives the fewest.

The cost category was measured by taking the cost of 2 of each engine. Ordering 2 engines is important so that there is a spare in case one of the engines experiences problems. Cost estimates for the GX25 and GX35 engines were provided by AZ Power and Lawn while the estimate for the GY6 was from e-bay. The GX25 was $537.29 [4], the GX35 was $510.39 [5], and the GY6 was $619.90 [6]. The GX35 received 10 points for being the cheapest, while the GY6 received 1 point for being the most expensive.

Drivetrain System

For our vehicle, we came up with three possible drivetrain systems. However, the way of delivering the torque from the engine to the wheels can lead us to our goal which is getting to a high fuel efficiency point for our vehicle. The three types are: shaft & gearbox drivetrain system, CVT belt system, and a chain & sprocket drivetrain system. See figure 2.4 for an example of a belt-driven CVT system and figure 2.5 for a roller chain and sprocket system. In order to choose the best possible drivetrain for our vehicle, a decision matrix will show us the advantages and disadvantages for every system.

Shaft and gearbox drivetrains can be seen in most types of cars. And, it is the best method of delivering highest torque from the engine to the wheel. The engine’s torque needs to be delivered to the rear wheel, and the engine will also be in the back of the vehicle. However, we need the best drivetrain that can obtain our requirements, and helps us to get to the highest possible fuel efficiency for our vehicle. Keeping in mind that this drivetrain will increase the weight of our vehicle, and this is a disadvantage point for this drivetrain.

The CVT belt will deliver the needed torque from the engine to the wheels with an advantage of controlling the gear ratio, which will help us with the fuel efficiency. However, the CVT belt will add weight to the vehicle but less than the shaft and gearbox drivetrain. Installing this drivetrain to our vehicle will consume more time.

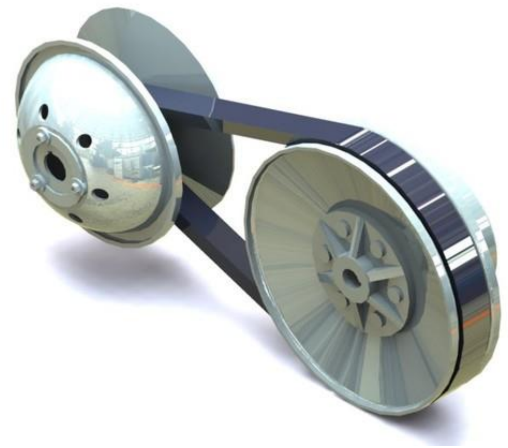


Figure 2.4 - Example of a CVT Belt System

Roller chain and sprocket drivetrain systems are the best drivetrain in terms of saving weight and simplicity. As for bicycles, the same chains will be used for this drivetrain. In order to control torque coming from the engine to the rear wheel a small transmission will be used to increase or decrease the speed on the rear wheel. Keeping in mind that the maximum average speed needed to be achieved is 17mph.

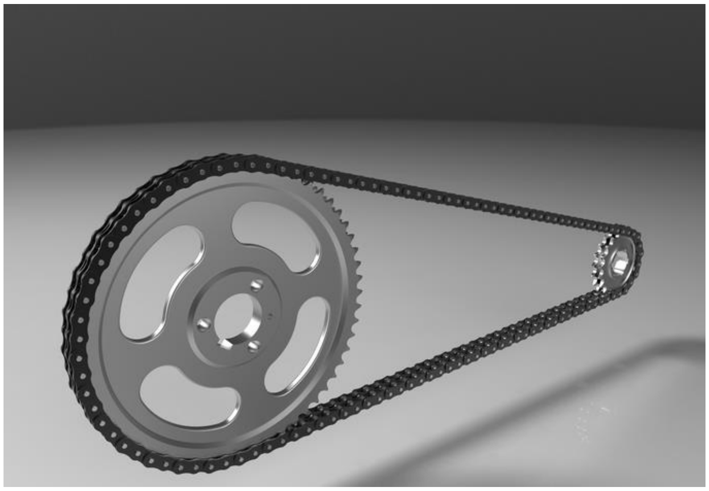


Figure 2.5 - Example of a Roller Chain Drivetrain System

Table 2.2 shows the decision matrix used for the drivetrain selection.

Table 2.2: Drivetrain Decision Matrix

	Low Weight	High Reliability	High Simplicity	Low Cost	Total
Relative Weight	30%	30%	10%	30%	100%
Shaft & Gearbox Drivetrain System	1	5	2	3	2.9/5
CVT Belt system	4	3	3	3	3.3/5
Roller Chain & Sprocket System	5	3	5	5	4.4/5

Low weight is about how light the drivetrain is, for example the lightest drivetrain in the decision matrix is the roller chain & sprocket system. It is important that the weight gets a high percentage, because one of our goals is to achieve a minimum vehicle weight in order to maintain high efficiency. And, the Low weight category is measured in pounds.

High reliability is about how long this drivetrain will stands without any issue. This category should have a high weight percentage, because of its importance in the vehicle. Shaft & gearbox drivetrain gets the highest reliability compare to the other drivetrains.

High simplicity deals with how long it is going to take the team to implement and install the drivetrain into the vehicle. This category had the lowest weight percentage because our team have the time to install any type of the three possible drivetrains.

Low cost deals with how much does it cost to get the needed drivetrain. Because of the low available budget, this category will get a high weight percentage same as the first two categories.

As for the drivetrain decision matrix, an estimated numbers were chosen for every aspect. However, the rank for this decision matrix starts from 1 to 5 as a maximum number. According to our decision matrix, the best choice for the drivetrain will be the roller chain & sprocket system (4.4 out of 5), because it satisfy our main goal which is to reach the lowest weight for a drivetrain possible. Also, the roller chain & sprocket system is reliable, simple to build and has a low cost. Therefore, the drivetrain for our vehicle will be the roller chain & sprocket system.

Fuel System

The team came up with three different concepts for the fuel system. Each one of these concepts is based upon the same idea that the team is limited to gasoline as a fuel source. The team is also limited to many other constraints related to the fuel system. The team must use a Shell Eco-Marathon approved fuel tank of 30mL, 100mL, or 250mL. The team is also limited to certain clear no expansive fuel lines. With all of these constraints in place, there is only a few different concepts related to the fuel system the team considered. These concepts are the use of carburetor, use of fuel injection, and the use of a forced induction fuel injected system.

The first concept is the method of using a carburetor to deliver the fuel in the engine. This is how most small engines are designed. It is a simple delivery system that does not require the need for computer processor or modules. It utilizes the mechanical appendances to deliver fuel. A big problem with carburetors is that they cannot precisely tune a vehicle to the absolute best fuel efficiency. Another disadvantage with carburetors is that they commonly are in need of adjustment. This means decreased reliability and increased maintenance. Figure 2.6 shows how a carburetor works.

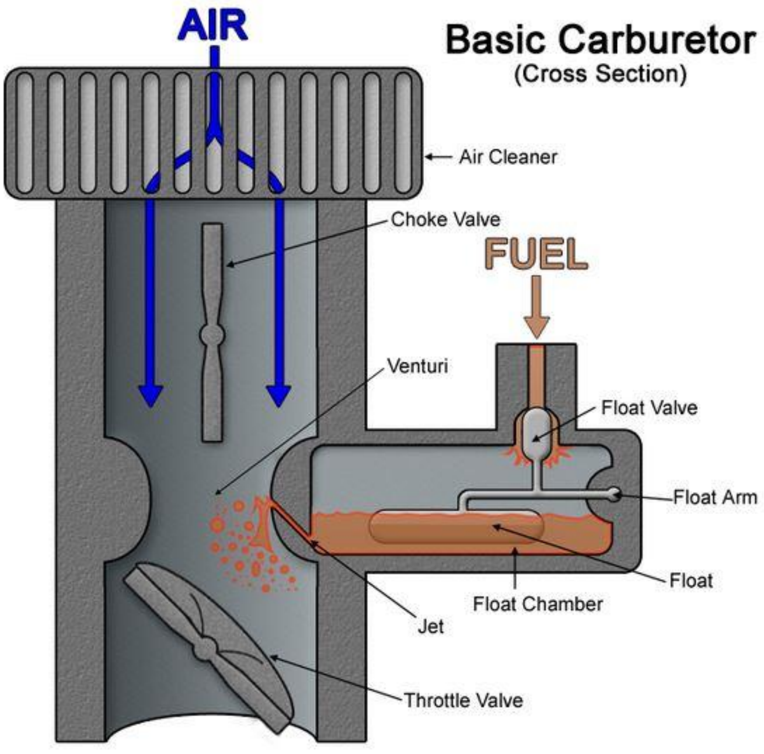


Figure 2.6: Carburetor Diagram

The second concept is the method of fuel injection. Fuel injection sprays fuel directly into the throttle body or into the cylinder depending on the system. This increases fuel efficiency because the spray is localized where combustion occurs. The system is very reliable once the team integrates it into the engine. Fuel injection also allows for very accurate tuning with the assistance of software and electronics. It does take some time to set up the system and get the system producing the best fuel efficiency results. Figure 2.7 shows how fuel injection works.

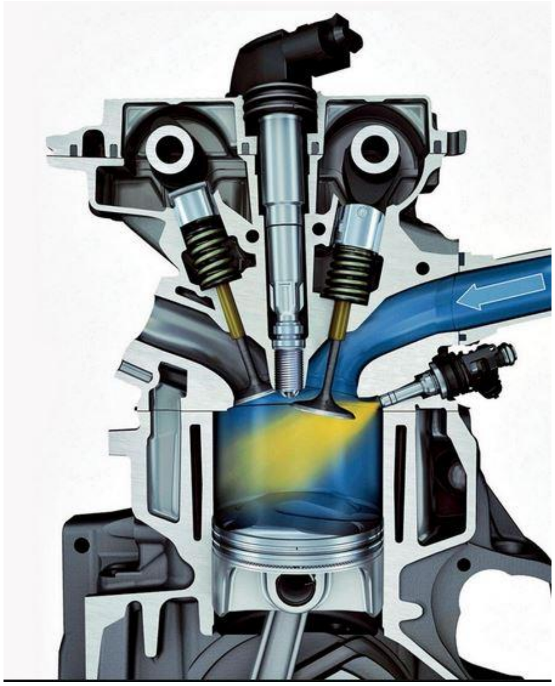


Figure 2.7: Fuel Injection Diagram

The third concept is the method of having a fuel injected system with the addition of a forced induction system. This is beneficial because it gives massive power increases and fuel efficiency by increasing the compression ratio. The common forced induction methods are turbochargers and superchargers. These forced induction methods require atop of fine tuning to obtain the best results, a compression too high can lead to engine damage. Forced induction methods also require additional integration with the engine atop the fuel injection. Figure 2.8 shows how forced induction works.

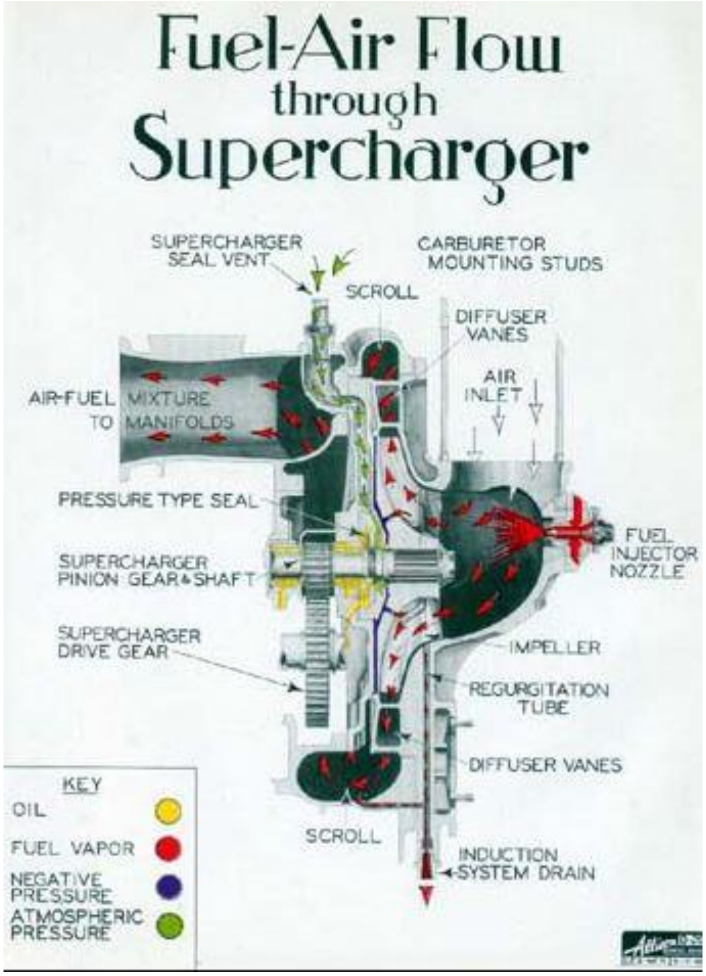


Figure 2.8: Supercharger Diagram

The team needed to decide which fuel system was best for the Eco-Marathon competition application. The team determined criteria that would be divided into six sections for the fuel system: fuel efficiency, ease of implementation, precise tuning, reliability, maintenance, and cost. The team defined each of these criterion and gave them a respective weighted percentage based upon importance.

The team defines fuel efficiency as a percentage of fuel that is converted into propulsion energy. This is measured in a percentage. This is the most important to the team because the more fuel efficient the fuel system is the less amount of fuel used to propel the vehicle and overall a lower vehicle fuel efficiency. The team gave fuel efficiency a weighted percentage of 40%.

The team defines ease of implementation as the amount of time it would take to install the fuel system. This is important to the team because the simpler the system is to integrate the more time the team has to test and tune. A simpler system is also easier to find potential problems and fix them. The team assigned ease of implementation with a weighted percentage of 10%

The team defines precise tuning as how accurate the fuel system can be tuned to. This is very important to the team because the more precise the fuel system tuning is, the better the fuel efficiency that can be obtained. The team assigned precise tuning with a weighted percentage of 20%.

The team defines reliability as the time it takes before the system has a problem and needs maintenance. This is important because the team wants a fuel system that will hold true to the tuned characterizes. The team does not want to have to worry about if the fuel system is going to fail during test runs or competition runs. For this reason the team gave reliability a weighted percentage of 15%.

The team defines maintenance as the amount of time spent maintain fluids and retuning to keep best fuel efficiency. This quantity will be measured in minutes. This is important to the team because the team does not want to spend a lot of time in between runs checking and retuning the vehicle at the competition. The team assigned maintenance with a weighted percentage of 10%.

The team defines fuel system cost to be the amount to purchase the fuel system, measured in dollars. This is not as important to the team because the whole objective of this competition is to be as fuel efficient as possible. This means that a good amount of the budget will go into a fuel system. The team assigned fuel system cost to have a weighted percentage of 5%.

The team picked three different fuel system concepts. These fuel system concepts were compared to each other based on the criteria set by the team. The fuel system concepts are displayed in **Table 2.3.** Each battery was given a score of score of 10, 50, or 100 based on the performance for each different criteria, 10 being the worst and 100 being the best. The scores were then multiplied by the respective criteria weighted importance percentage to give the final score.

Table 2.3: Fuel System Concept Decision Matrix

	Carburetor	**Carburetor with Weighted Percentages**	Fuel Injection	**Fuel Injection with Weighted Percentages**	Forced Induction	**Forced Induction with Weighted Percentages**
Fuel Efficiency (%)	10	**4**	50	**20**	100	**40**
Ease of Implementation (mins)	100	**10**	50	**5**	10	**1**
Precise Tuning	10	**2**	100	**20**	50	**10**
Reliability (days)	10	**1.5**	100	**15**	50	**7.5**
Maintenance (mins)	50	**5**	100	**10**	10	**1**
Cost ($)	100	**5**	50	**2.5**	10	**.5**
Total		**27.5**		**72.5**		**60**

After completing the decision matrix, it was clear to the team that the best fuel system for the vehicle was the fuel injection system. The reason behind this is that the fuel injection system is the most fuel efficient, has the best tuning precision, best reliability, and requires the least amount of maintenance.

Electrical System

The electrical system for the vehicle will be a very simple electrical circuit. The electrical system will be split up into two sub systems. The first sub system will focus on starting the vehicle up and running the vehicle as long as the key ignition switch is in the start or run position. This system will include all of the required kill switches, safety fuses, relays, wiring to the electric starter, and various other components related to the specific chosen engine and fuel injection system. The second sub system will focus on all of the other accessory components such as the horn, speedometer, GPS system, and possible interior lighting for door handle location. The main power source for the electrical system will be generated from a 12V battery.

The reason for the 12V battery is because all of the parts incorporated in the vehicle will be rated for 12V. This battery must have enough power and storage capacity to run the vehicle electrical systems for repeated long periods of time. The team needed to decide which battery was best for the Eco-Marathon competition application. The team determined criteria that would be divided into four sections for the battery: weight, scale, capacity, and cost. The team defined each of these criterion and gave them a respective weighted percentage based upon importance.

The team defines battery weight to be the overall weight of the battery in kilograms (kg). The reason this is important to the team is because the lighter the battery is, the lighter the overall weight of the vehicle is. For this reason the team assigned battery weight with a weighted percentage of 20%.

The team defines battery scale of the battery to be how much space the battery takes up, measured in cubic centimeters (cm^3). This is important because the team is limited to a certain amount of space on- board the vehicle. The smaller amount of space that is taken up by components will yield a slimmer and lighter vehicle which produces a more fuel efficient vehicle. The team assigned a weighted percentage of 15% to battery scale.

The team defines battery capacity as the amount of power that the battery can provide at the rated voltage. The battery capacity was measured in ampere-hours (Ahr). This is crucial to the electrical system because the vehicle battery must be able to last through several completions of start-up and run the vehicle electrical system for the entire run. The team assigned the battery capacity with a weighted percentage of 40%.

The team defines battery cost to be the amount to purchase the battery, measured in dollars. This is important to the team because the team has limited funds. A battery costing $1000 is just not reasonable. The team assigned battery cost to be a weighted percentage of 25%.

The team picked three different possible battery choices. These battery choices were compared to each other based on the criteria set by the team. The battery choices are displayed in **Table 2.4.** Each battery was given a score of 10, 50, or 100 based on the performance for each different criteria, 10 being the worst and 100 being the best. The scores were then multiplied by the respective criteria weighted importance percentage to give the final score.

Table 2.4: Battery Selection Decision Matrix

	Deka ETX-9	**Choice 1 with Weighted Percentages**	Duralast Lawn & Garden	**Choice 2 with Weighted Percentages**	Optima Yellow Top	**Choice 3 with Weighted Percentages**
Weight (kg)	100	**20**	50	**10**	10	**2**
Scale (cm^3)	100	**15**	50	**7.5**	10	**1.5**
Capacity (A-hr)	50	**20**	10	**4**	100	**40**
Cost ($)	50	**12.5**	100	**25**	10	**2.5**
Total		**67.5**		**46.5**		**46**

After completing the decision matrix, it was clear to the team that the best battery for the vehicle was Deka ETX-9. The reason behind this is that the Deka ETX-9 is the lightest, the smallest and still has good capacity and isn't too expensive.

Chapter 3: Engineering Analysis

Engine Analysis

Honda engines were selected for comparison because they offer superior power curves among small engines. 3 engines with different displacements were analyzed: GX25, GX35, and GY6 50cc. 2 different measures of efficiency were used: air standard Otto cycle efficiency and brake specific fuel economy (BSFC).

Engine properties were taken from manufacturers catalogues [1,2,3] and can be found in Table 3.1.

Table 3.1: Engine Properties

-	(units measured)	Honda GX25	Honda GX35	Honda GY6-QMB
Displacement	cc	25	35	50
Compression Ratio	unitless	8	8	10.5
Power Output	kW	0.72	1	2.1
Torque Output	N-m	1	1.6	3.1
Intial Fuel Consumption	L/hr	0.54	0.71	1.04
Intial Fuel Consumption	gram/s	0.5243049	0.68936385	1.0097724
Fuel Consumption engine speed	RPM	7000	7000	6500
Fuel Consumption engine speed	Radians/s	732.6666667	732.6666667	680.3333333

Since all engines are 4 stroke, the air standard Otto cycle can be used to analyze their efficiencies. The Otto cycle efficiency analysis calculates the maximum possible efficiency for the engine considering its compression ratio. Equation _ for the thermodynamic efficiency is:

$$\eta = 1 - \frac{1}{r^{k-1}}$$

Equation 3.1: Otto Cycle Efficiency

Where r is the compression ratio for the engine, and k is the specific heat ratio. For ambient air, k is equal to ~1.4 [4]. Using this equation, the calculated engine efficiencies can be found in Table 3.2.

Table 3.2: Otto Cycle Engine Efficiencies

η(GX25)	57%
η(GX35)	57%
η(GY6-QMB)	62%

As shown in Table 3.2, the GY6-QMB produces the highest efficiency among compared engines.

Brake specific fuel economy is a measure of an engine's fuel consumption as a ratio with the amount of power reduced. BSFC is used as a measure of fuel efficiency while removing driving habits from consideration. Similarly to the air standard Otto cycle, BSFC does not provide real-world efficiency for the engine, but it does provide ratio's between the 3 engines to compare their max possible efficiencies.

BSFC is calculated using equation _ where r is fuel consumption in g/s, T is the torque produced by the engine in N-m, and ω is the engine speed in radians/s.

$$BSFC = \frac{r}{T \times \omega}$$

Equation 3.2: BSFC Equation

Using the properties from Table 3.1, the BSFC calculations can be found in Table 3.3. For BSFC, the lower the value, the less fuel consumed per power produced.

Table 3.3: BSFC Calculations

BSFC(GX25)	0.00072
BSFC(GX35)	0.00059
BSFC(GY6-QMB)	0.00048

While the GY6 consumes the most fuel initially, it has superior fuel consumption considering the power produced.

The GY6 produces the highest possible efficiency in the Otto cycle using air standard analysis and consumes the least amount of fuel with the BSFC equation. Consequently, the GY6-QMB is the engine that will be used in our design.

Using the BSFC calculations, and estimates for coefficient of drag, frontal area, and rolling resistance, an estimation of fuel efficiencies for the 3 motors was produced. The formula is displayed below:

$$Fuel\,Efficiency(mpg) = \frac{2.351215\,\frac{mpg}{km/_{L}} * 1000\,\frac{g}{L} * BSFC\left({}^{g}/_{J}\right)}{M_{car} * \left(A_f * C_D + C_{rr} * M_{Car} * 9.81\,{}^{m}/_{s^2}\right) * 1000m}$$

Equation 3.3: BSFC Equation

See Appendix C for the tabulated values. Figure 3.1 shows the three fuel efficiencies plotted as a function of mass of the car.

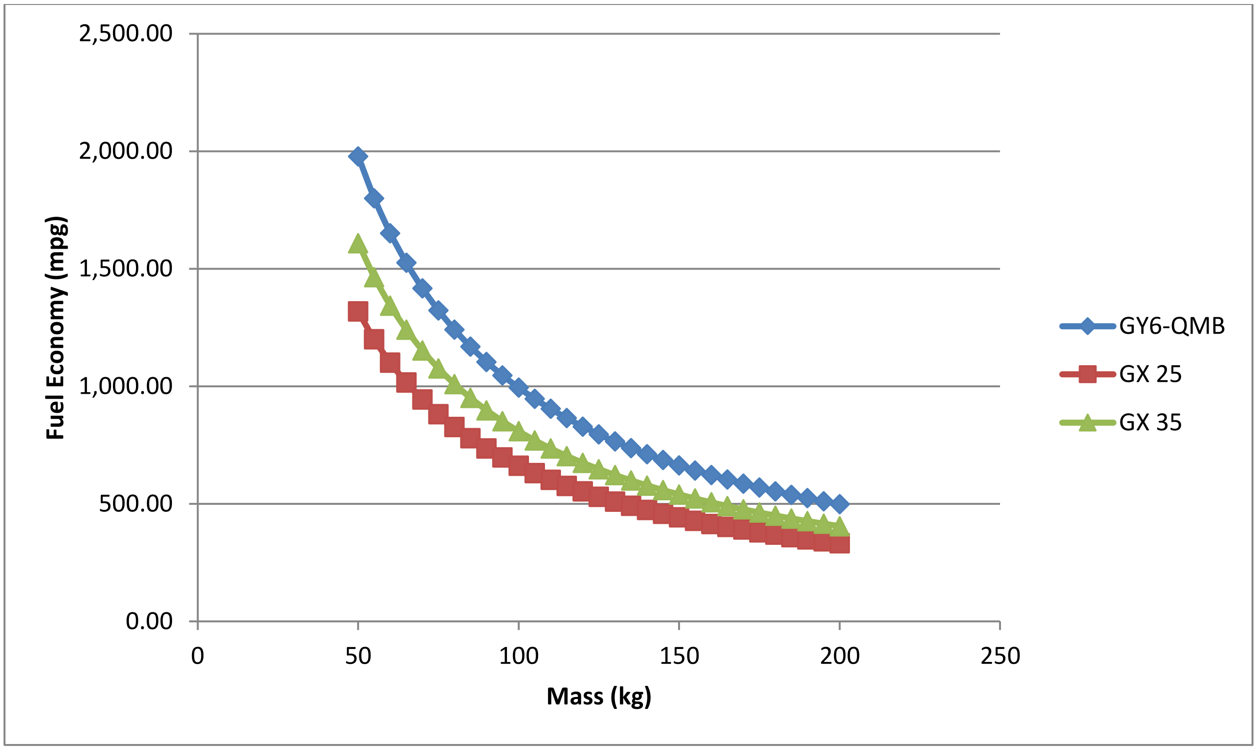


Figure 3.1: Fuel Efficiency Plot

Drivetrain

The drivetrain for our vehicle has four reduction gears, the first two are meshed together and connected to a clutch. The second two gears are connected together by a chain. The clutch is to disconnect the second gear from the first gear. The third and second gears are on the same shaft. Therefore, the clutch will disconnect second, third and last gears from the first gear. See Appendix A for an engineering drawing of the clutch system. As for our selected engine, it has a torque of 3.1 N-m @ 5500 RPM, produces a 2.1 KW @ 6500 RPM and has a 2.8 HP @ 6500 RPM. We can get the torque of the engine @ 6500 RPM by using the following equation:

$$T = \frac{(HP)(33{,}000)}{(2\,\pi)(RPM)}$$

Equation 3.4: BSFC Equation

However, the units of the torque will be (lb-ft) as for the above equation. Therefore the torque at 6500 RPM is = 2.262 lb-ft = 3.067 N-m. The gear ratio can be calculated using the following equation:

$$Gear\ Ratio = \frac{\left(\frac{RPM}{60\frac{sec.}{min.}}\right)(Wheel\ Diameter\ (meter) * \pi)}{\left(wanted\ speed\left(\frac{meters}{sec.}\right)\right)}$$

Equation 3.5: BSFC Equation

Where:

Used RPM = 6500 RPM

Wheel Diameter = 20 in. = 0.508 m.

Wanted Speed = 17 mph = 7.6 m/s

Therefore, the gear ratio will be about $22.75 : 1 \approx 23 : 1$, and this gear ratio is valid only if we used 20 in back wheel for our vehicle for a speed of 17 mph. However, this gear ratio will make it hard on our team to get the perfect numbers of teeth for our used gears, therefore we will use 24:1 as for our gear ratio. To calculate the torque output from the drivetrain to the rear wheel we will use the following equation:

$$Gear\ Ratio = \frac{T_B}{T_A} = \frac{N_B}{N_A}$$

Equation 3.6: Torque Output

Where:

B = Output, A = Input

T_B = Output torque of the drivetrain

T_A = Input torque to the drivetrain

$\frac{N_B}{N_A}$ = Gear ratio

As we calculated the gear ratio, which is 23:1 but we will use 24:1 as our gear ratio, and the input torque to the drivetrain "T_A" is = 2.262 lb-ft = 3.067 N-m. Now, we can get the output torque of the drivetrain "T_B" going to the rear wheel as following:

$$Gear\ Ratio = \frac{T_B}{T_A} = \frac{24}{1}$$

$$T_B = 24 * T_A = 24 * 2.262\ lb.ft = 54.288\ lb.ft = 73.608\ N.m$$

The first two gears in our drivetrain can have a gear ratio of 4:1, and the second two gears, the two gears connected to each other with a chain, can have a gear ratio of 6:1. Therefore, the total gear ratio for our drivetrain will be 24:1. To check if our gear ratio 24:1 is good enough to give us a speed close to 17 mph, we can use the output torque,

$$T_B = 54.288\ lb.ft = 73.608\ N.m,$$

to get the RMP at this torque,

$$RPM = \frac{(HP)(33{,}000)}{(2\,\pi)(T)} = 270.9$$

Equation 3.7: BSFC Equation

then use the following equation to get to the velocity of our vehicle:

$$V = (RPM) * \frac{(Wheel\ Diameter\ (meter) * \pi)}{60\left(\frac{sec.}{min.}\right)}$$

Equation 3.8: BSFC Equation

Therefore the velocity of our vehicle will be = 7.21 m/s = 16.13 mph, which is close enough to our assumed needed velocity of our vehicle. If we wanted to increase the velocity more than that, we can go with 22:1 or 20:1 as for our gear ratio.

Fuel System

The team is limited to very specific rules and guidelines for the design vehicle in regards to the fuel system. Through the concept generation and concept selection the team feels that the fuel injection concept does not need to be analyzed at this time. This is because the chosen fuel injection system is compatible with the GY6 engine. Also, the fuel injection software will allow the team to precisely tune the fuel flow rate once the final vehicle is designed. The reason behind waiting until the vehicle is finalized is because fuel efficiency is based on power to weight ratio. This means the lighter the vehicle, the less fuel that is consumed.

The method of analysis that the team will perform on the fuel system is an experimental process that involves performing many trial runs at different fuel injection flow rates and then measuring the consumed fuel. The team will also use a small scaled dyno to look at the different power curves of associated engine speeds. Through various research and these experiment trials, the team will obtain the best fuel efficiency for the design vehicle. The fuel injection system used is Ecotrons electronic fuel injection given in Figure 3.2.

Figure 3.2: Ecotrons Fuel Injection Kit

Electrical System

The design vehicle has so many different systems that are being incorporated together that the team has decided that as long as the selected battery can maintain power for the entire competition that, all other components (i.e. kill switches, push buttons, relays, and fuses will not need to be analyzed in an engineering matter. The reason behind this thinking is because the team is utilizing electrical components that have already been tested and proven reliable and appropriate and are prevalent in the common vehicle. Another reason is because of the fact that the GY6 engine has an electrical generator integrated into the engine. This means that the battery and electrical system will be charged as long as the vehicle is running. The battery will only need to be discharged when the engine is not running, and be responsible for starting the GY6 engine. The overall proposed circuit diagram layout is given in Figure 3.3.

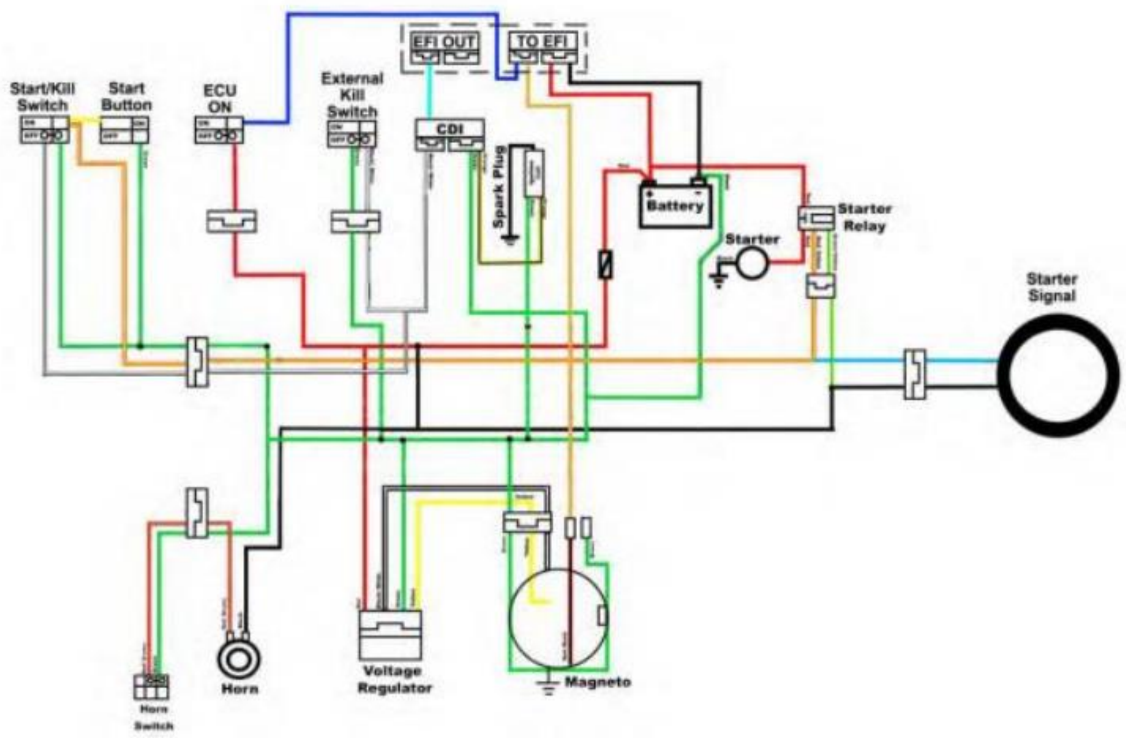


Figure 3.3: Approximate Circuit Diagram

Chapter 4: Cost Analysis

Bill of Materials

Table 4.1 shows the bill of materials for the final design. The bill of materials is broken into 4 sections: engine, drivetrain, fuel system, and electrical system. Prices were taken from market value. The total cost for the final design for the listed components is $1,622.94.

Table 4.1: Final Design Bill of Materials.

Name	Cost
Engine Bill of Materials	
GY6-QMB	$ 309.95
Drivetrain Bill of Materials	
Sprokets	$ 150.00
Chains	$ 30.00
Clutch System Assembly	$ 100.00
Shafts	$ 30.00
Bearings	$ 50.00
Rear Hub	$ 50.00
Fuel System Bill of Materials	
Ecotrons Fuel Injection System	$ 399.99
Shell Fuel Tank	$ 200.00
Fuel Lines	$ 10.00
Fuel Pressure System	$ 80.00
Fittings	$ 50.00
Electrical System Components	
Deka ETX-9	$ 64.00
Wires	$ 20.00
Fuses, connectors, etc	$ 20.00
Horn (from old car)	$ -
Kill Switches	$ 40.00
Depression Switches	$ 20.00
Total	$ 1,622.94

Chapter 5: Conclusions

The GY6 engine is the best fit for the application. Utilizing the GY6-QMB gives the vehicle the highest projected fuel economy compared to the other 2 engines considered. The strong after-market support allows the GY6 to be fuel injected with little part fabrication required. Fuel injection will be used because it provides better consistency during runs at different altitudes, and also allows for different tuning profiles to maximize fuel efficiency.

A final drive ratio of 20:1 is selected because it allows the car to reach a top speed higher than the 17mph average required. Reaching a higher top speed, then turning off the engine and coasting, then starting the engine again will maximize fuel economy. A chain and sprocket design is used with 2 gear reductions, as opposed to a single reduction, in order to reduce rotating weight at the rear wheel. A 2-stage custom clutch will be used to be able to run the starter without providing forward propulsion.

An Ecotrons fuel injection system specifically for the GY6 with a programmable ECU will be used. Since the fuel system cannot utilize an electric fuel pump, a pressurized bottle will drive the fuel to the injectors. Once the Ecotrons system is installed, the motor will be broken in and tested using a small scale engine dyno. Fuel injection profiles will be determined through tests on the small dyno.

The electrical system will use existing vehicle components, saving money and making wiring components easier. The GY6 provides on-board power generation, and a Deka ETX-9 battery will be used because of its sufficient power generation and light weight. Final circuit diagrams will be determined when the vehicle is more complete. Construction on the vehicle is scheduled to begin in January. Please see Appendix B for project planning.

References

[1] Acosta, B., Betancourt, M., Pinheiro, F., "Shell Eco-Marathon 25% of Final Report," B.S. thesis, Mechanical Engineering Department, Florida International University, Miami, 2012.

[2] Honda Engines, "GX25 Motor Specs," http://engines.honda.com/models/model-detail/gx25, Oct. 2013.

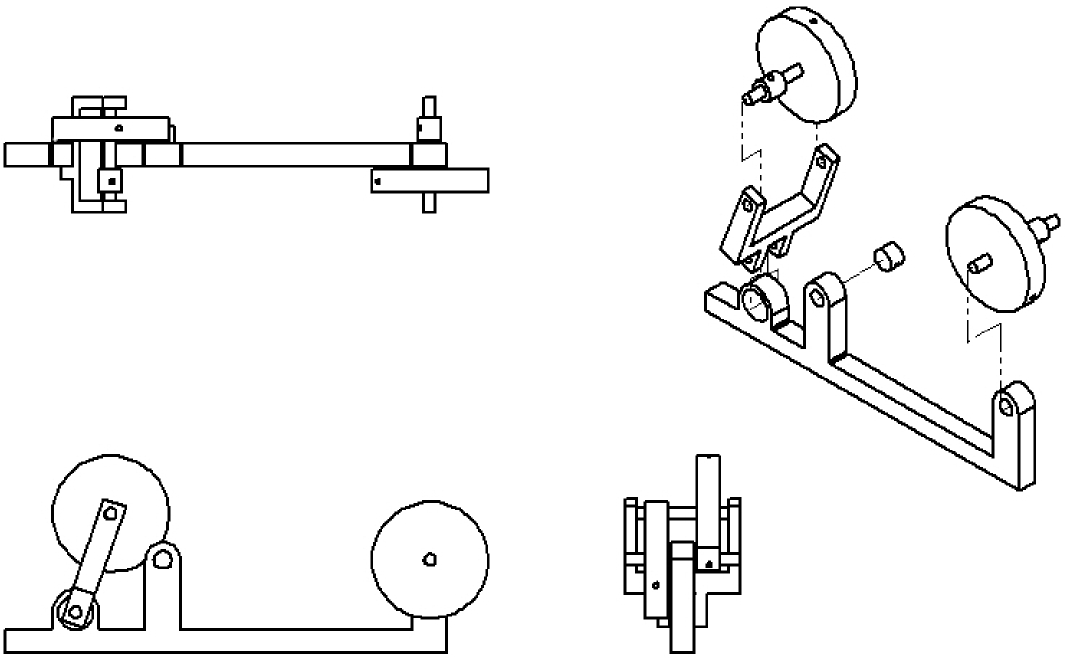
[3] Honda Engines, "GX35 Motor Specs," http://engines.honda.com/models/model-detail/gx35, Oct. 2013.

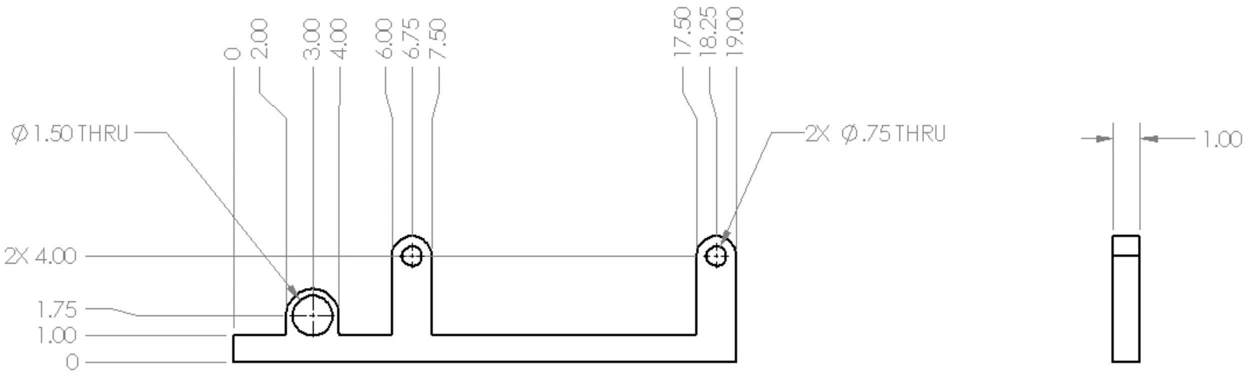
[4] AZ Power and Lawn. "NAU – SAE ENGINEERING, JOHN Price quote for 25CC ENGINE". 26 Oct 2013.

[5] AZ Power and Lawn. "NAU – SAE ENGINEERING, JOHN Price quote for 35CC ENGINE". 26 Oct 2013.

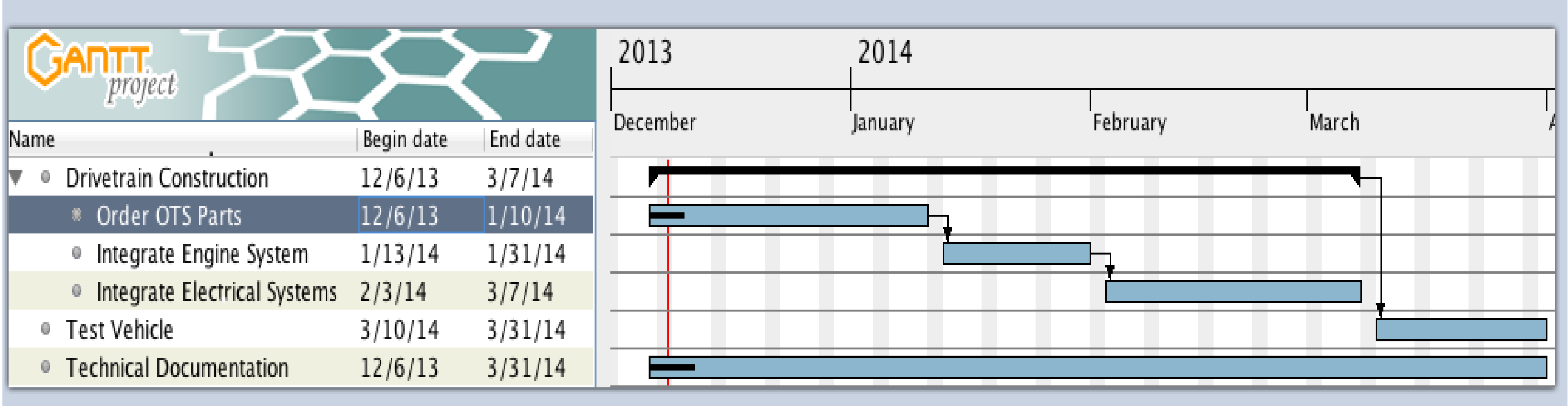
[6] ebay, "139QMB 50CC 4 STROKE GY6 SCOOTER ENGINE MOTOR AUTO CARB," http://www.ebay.com/itm/139QMB-50CC-4-STROKE-GY6-SCOOTER-ENGINE-MOTOR-AUTO-CARB-/360090949889?pt=Motors_ATV_Parts_Accessories&hash=item53d717d901&vxp=mtr, Oct. 2013.

Appendix A: Engineering Drawing of Clutch System





Appendix B: Project Planning



Name	Begin date	End date
Drivetrain Construction	12/6/13	3/7/14
Order OTS Parts	12/6/13	1/10/14
Integrate Engine System	1/13/14	1/31/14
Integrate Electrical Systems	2/3/14	3/7/14
Test Vehicle	3/10/14	3/31/14
Technical Documentation	12/6/13	3/31/14

Appendix C: Table of Fuel Economies Related to Mass of the Vehicle and Engines

Table C.1: GY6 Estimated Fuel Efficiency

Mass	Fuel Economy
50	1,977.93
55	1,799.77
60	1,651.05
65	1,525.03
70	1,416.89
75	1,323.07
80	1,240.90
85	1,168.34
90	1,103.80
95	1,046.01
100	993.98
105	946.87
110	904.03
115	864.90
120	829.02
125	795.99
130	765.49
135	737.25
140	711.01
145	686.58
150	663.77
155	642.43
160	622.42
165	603.62
170	585.92
175	569.22
180	553.46
185	538.54
190	524.41
195	510.99
200	498.25

Appendix C Cont.: Table of Fuel Economies Related to Mass of the Vehicle and Engines

Table C.2: GX25 Estimated Fuel Efficiency

Mass	Fuel economy
50	1,318.62
55	1,199.84
60	1,100.70
65	1,016.69
70	944.59
75	882.05
80	827.27
85	778.89
90	735.87
95	697.34
100	662.65
105	631.25
110	602.69
115	576.60
120	552.68
125	530.66
130	510.33
135	491.50
140	474.01
145	457.72
150	442.52
155	428.29
160	414.95
165	402.41
170	390.61
175	379.48
180	368.97
185	359.03
190	349.60
195	340.66
200	332.17

Appendix C Cont.: Table of Fuel Economies Related to Mass of the Vehicle and Engines

Table C.3: GX35 Estimated Fuel Efficiency

Mass	Fuel economy
50	1,318.62
55	1,199.84
60	1,100.70
65	1,016.69
70	944.59
75	882.05
80	827.27
85	778.89
90	735.87
95	697.34
100	662.65
105	631.25
110	602.69
115	576.60
120	552.68
125	530.66
130	510.33
135	491.50
140	474.01
145	457.72
150	442.52
155	428.29
160	414.95
165	402.41
170	390.61
175	379.48
180	368.97
185	359.03
190	349.60
195	340.66
200	332.17