EDSGN 100
Design Project #2
FINAL REPORT

CATA Bus Redesign

Introduction to Engineering Design
EDSGN 100 Sec 24

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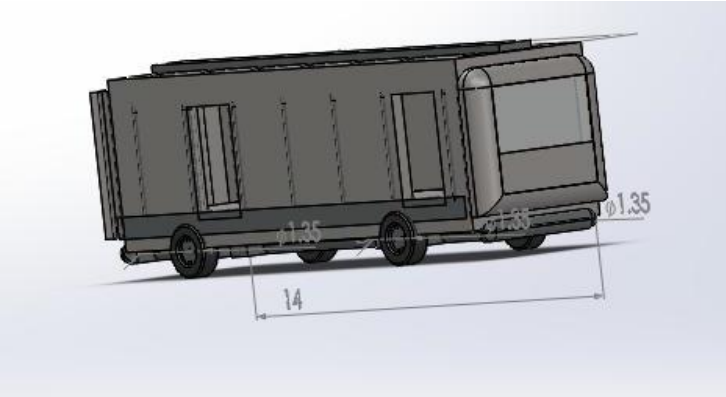

Submitted to: Prof. Bilen
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Executive Summary

This report discusses the project to incorporate aluminum into something on the Penn State campus to make it more sustainable and efficient. We examined the CATA bus system on campus and looked at a way we could use aluminum in the bus. To perform tests to determine the effectiveness of aluminum, we created a SolidWorks model and researched the use of aluminum in the automotive industry. We used the sustainability tool on SolidWorks to model certain components of our bus with aluminum to help us collect data on pollution and energy usage. After analyzing the data, we came up with a final design that best incorporated aluminum and allowed us to create the most efficient and clean bus for the environment and for State College.

CATA Bus Redesign

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A. Introduction and Problem Statement

The project we were given was sponsored by Alcoa and they tasked us with engineering a solution to make something more sustainable on campus using aluminum. The open-endedness of this question allowed our team to come up with many ideas as possible solutions to the original problem. After coming up with our design idea, redesigning the CATA bus system in State College, we gathered customer needs and performed a customer needs analysis, which can be found in Section B. The customer needs analysis gave us feedback on which concepts to focus on when redesigning the CATA bus. To help come up with ideas, we created concept generation maps that focus on different bus components that could change the efficiency of the bus using aluminum. After creating the maps we came up with possible redesigns for the bus, and using a screening matrix we looked at which options to give up on and which options to continue. This info can be found in Section C. The best design we came up with was chosen based on data we collected on SolidWorks which can be found in Section E. This data allowed us to assess the effectiveness of aluminum in the redesign as well its effectiveness in the long term, which will be discussed in Section G.

A.1 Initial Problem Statement

The goal of this project is to find something on the Penn State campus that can be better engineered using aluminum to make the product more sustainable and efficient. Our team hopes to meet these requirements by creating a solution that will utilize the intrinsic properties of aluminum and create a better environment for Penn State and the surrounding areas.

A.2 Mission Statement

We chose to redesign the CATA bus at State College to improve environmental sustainability and the efficiency of the transportation system. By utilizing aluminum to redesign the buses, we are able to create a more efficient bus that will succeed in the long run compared to steel buses.

B. Concept Generation

Our redesign is going to focus on the CATA bus and the internal components that can be changed from steel to aluminum to help make it more sustainable. Using data from customer needs assessment, we were able to generate a few different redesigns of the CATA bus model that could help increase efficiency and sustainability. These models were generated from external research of the automobile industry and the way aluminum has been incorporated into cars and buses to increase efficiency.

B.1 Customer Needs Analysis

To help our team focus on what problems there are with the CATA bus system on campus, we informally asked students that rode the bus for their opinions on the system. There were two main groups of students that we focused on: those riding the loops around campus, and those that commute to campus. The students that commute to campus have to pay a fare of $1.50 to ride, making their opinion more significant to our data collection. The customer needs that we gathered were then made into a list of interpreted needs to help us come up with solutions that we can engineer using aluminum.

Table 1. Customer Needs List and Interpreted Needs Created From Information Gathered by CATA Bus Riders On and Off Campus

Recorded Need	Interpreted Need
The buses are too crowded	Need less crowded buses
The buses aren't environmentally friendly	Need green buses
There aren't enough buses per route	Need more buses per route
The bus doesn't stop long enough	Need longer stops
Buses are too small	Need bigger buses
The bus fare is too expensive	Need cheaper buses
The bus stop information is bad	Need accurate bus stop information
The buses are too slow	Need quicker buses
The buses aren't comfortable	Need comfortable seats
The bus drivers are unfriendly	Need friendly bus drivers
The bus isn't safe	Need safe buses

Table 1 shows the customer needs that were gathered from the CATA riders. Many of the issues common amongst the riders was the crowded nature of the bus, the lack of certain buses compared to ones used less frequently, and the environmental impact of the bus. These are the main issues we focused on because the other issues could not be feasibly solved using aluminum. To determine which issues were the most important, we weighed the concerns and listed them in order of importance in our redesign process.

Table 2. Customer Needs Weighing and Importance of Interpreted Needs

Customer Needs	Weight	Overall Importance
Need less crowded buses	4	2

Need green buses	4	4
Need more buses per route	5	1
Need longer stops	3	8
Need bigger buses	3	7
Need cheaper buses	4	5
Need accurate bus stop information	2	9
Need quicker buses	3	6
Need comfortable seats	2	10
Need friendly bus drivers	1	11
Need safe buses	4	3

Table 2 shows us the importance of each interpreted need to our redesign process. The four needs that we are going to focus on the most are:

- The environmental impact of building and operating a bus
- The safety of the buses
- The cost to build a bus*
- The cost to operate a bus*

*We assumed that adding more buses and having less crowded buses were dependent on the cost of buses. CATA can only afford to produce a certain number of buses due to limited funds.

These needs are useful to us in the design process, but with a limited knowledge of automobiles and aluminum in the automobile industry, we had to research aluminum and ways we could use it in our redesigns.

B.2 External Research

In the automobile industry, steel is the most commonly used material, stainless steel being the alloy used in vehicles. The reason for the use of steel compared to aluminum is because of the sturdiness of steel, as well as the price of steel compared to aluminum. Using stock prices from November 2013, the price of steel is about $.38/lb, whereas aluminum is about $.80/lb, about 50% greater in price. Using numbers from 2011, the amount of steel used is about 87 million metric tons, and the amount of aluminum used is 12.5 million metric tons (Guy Matthews, 2011). Even though the use of aluminum is small compared to steel, its light weight can make it an excellent way for vehicles to increase fuel efficiency, usually between 7% and 20%. The lighter vehicles are more fuel efficient, and when looking to decrease the weight of vehicles, the frame

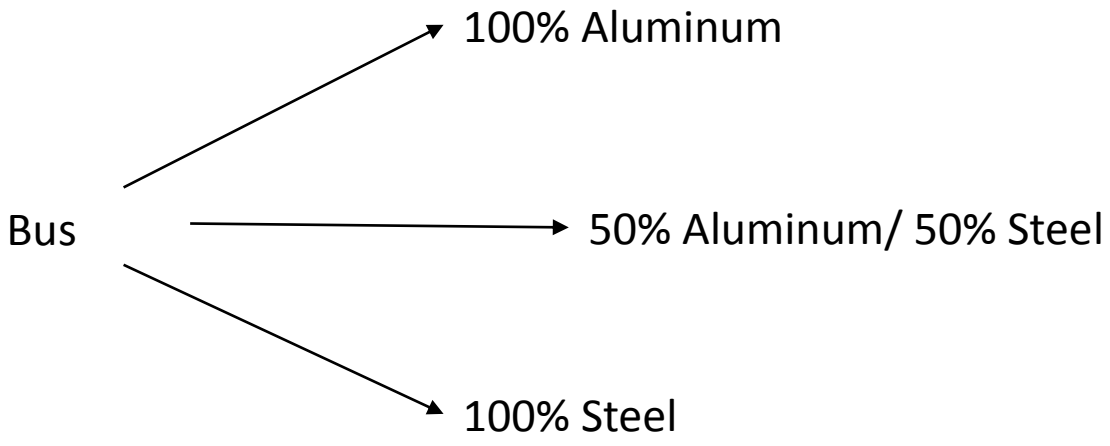
and chassis are the best options, accounting for almost 50% of the vehicles weight (Guy Matthews, 2011). This increase in fuel efficiency makes up for the increased price of aluminum compared to steel, and can make the cost of the bus worth it in the long term. The use of aluminum in our bus though would provide us with benefits and consequences.

Although lightweight in nature, aluminum is not as sturdy as steel, which can make a vehicle unsafe if it gets into a collision. Steel is the better option for crash safety. Another benefit of aluminum is that it is better for the environment because it requires less energy to manufacture and doesn't rust easily like steel, and it is also highly recyclable. This research helped our team look at what would be best in our redesign when trying to incorporate aluminum in the bus model.

C. Concept Selection

After collecting data and looking at research on aluminums use in the automotive industry, our team came up with a few ideas on how to redesign the bus by using concept generation maps. The maps helped us in the design process to compare different models of the bus using aluminum and steel. Which parts would be what material were determined by examining data that is found in Section E of this report.

Chart 1. Steel/Aluminum Comparison in the CATA Bus Model



This chart looks at how we want to handle the redesign of the bus: if we want to focus on a bus that is 100% steel, a bus that is 100% aluminum, or a bus that is some mix of aluminum and steel. After using the research from Section B. We decided the best way to focus on our redesign was to work on the internal components of the bus focusing on the frame, chassis, and the outside shell of the bus. Each of these contributes a fair amount of weight to the bus, but if the steel components of the bus are replaced with aluminum, then the weight of the bus

will decrease dramatically, increasing the fuel efficiency which will hopefully increase the number of CATA buses that are on the road.

Chart 2. Steel/Aluminum Comparison in the Bus Shell

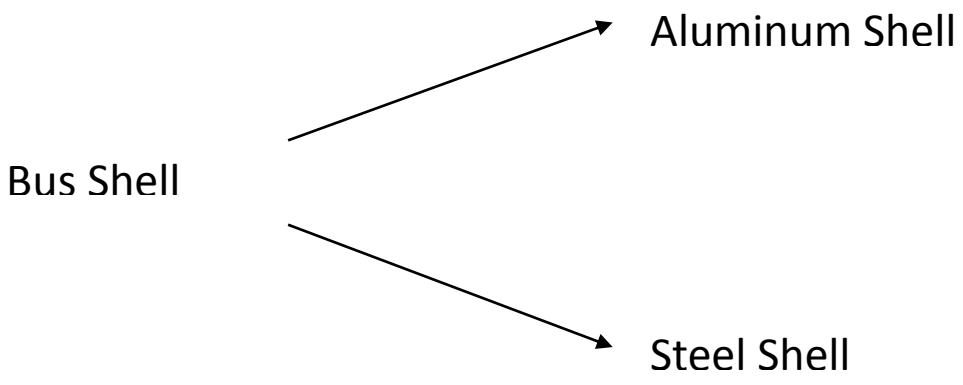


Chart 3. Steel/Aluminum Comparison in the Bus Frame

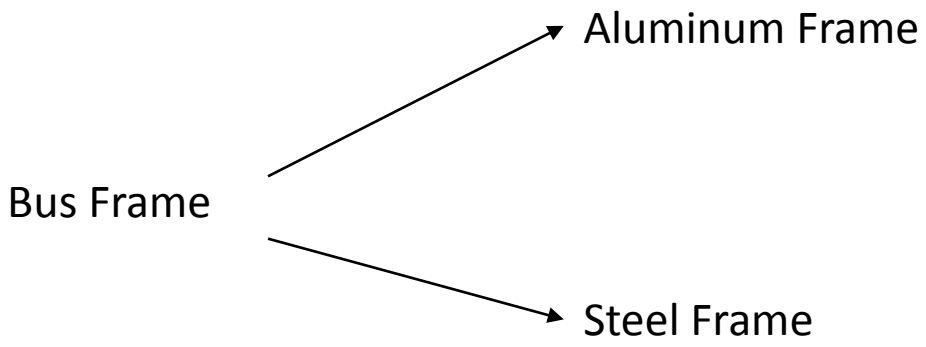
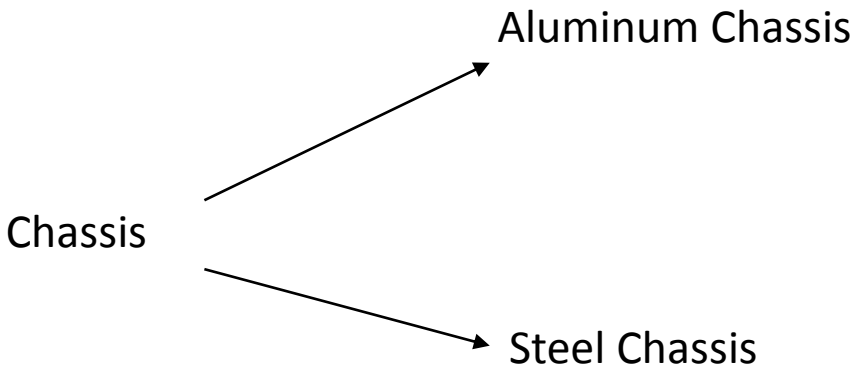


Chart 4. Steel/Aluminum Comparison in the Bus Chassis



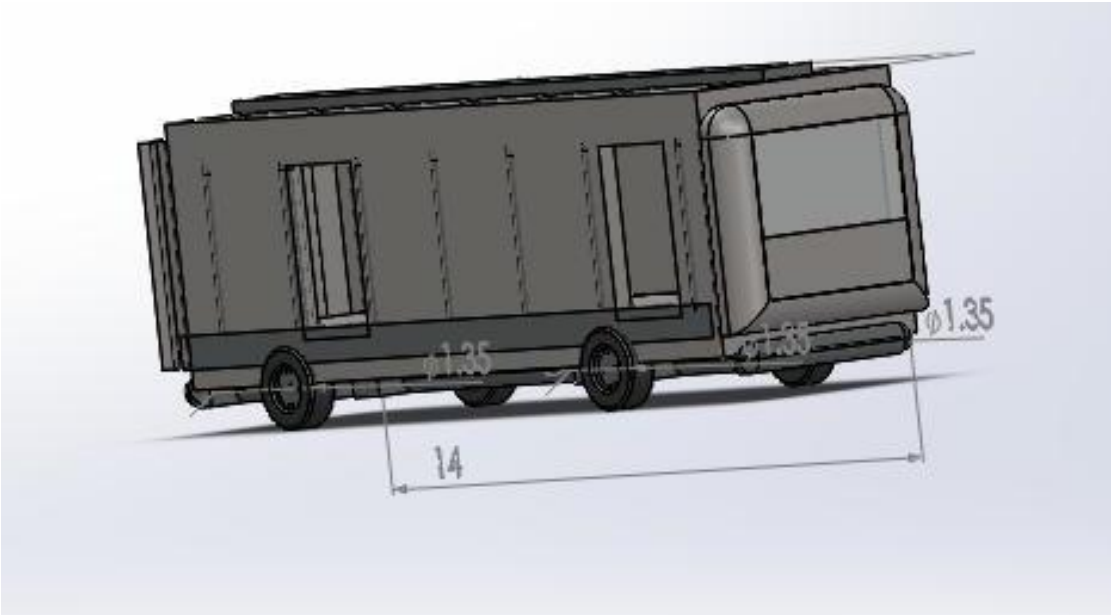
Each of the parts that we are focusing on in our redesign will either be incorporated into aluminum or steel. The three main components are all big factors in the weight of the design, so changing from steel to aluminum could be beneficial in the efficiency of the redesign. The concept generation maps helped us create five different designs for the CATA Bus. The redesigns are:

- A bus made completely out of aluminum
- A bus made from steel with an aluminum frame
- A bus made from steel with an aluminum chassis
- A bus made from aluminum with a steel frame
- A bus made from aluminum with a steel chassis

C.1 Concept Screening

After creating five possible redesigns, our team had to create a way to test the effectiveness of the redesigns against each other. To create measurements to compare, we modeled our design on SolidWorks and used the sustainability tool. This allows us to gather data on energy used and amount of pollution done to the environment with the different parts of the bus being different materials. Data on the sustainability of the different redesigns will be in Section E.

Image 1. SolidWorks Design of CATA Bus



The completed design of the bus in SolidWorks is 14 meters long. The design includes models of the frame, shell, and chassis, which allows us to collect data on each concept that we generated.

Image 2. SolidWorks Design of CATA Bus Frame

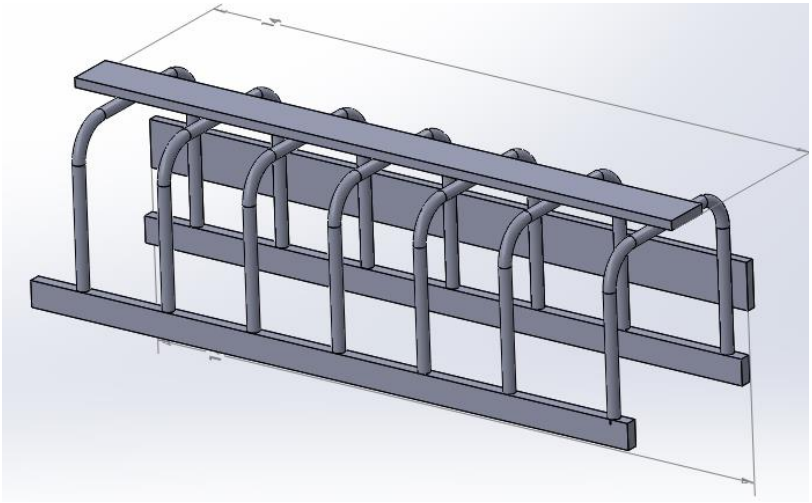


Image 3. SolidWorks Design of CATA Bus Shell

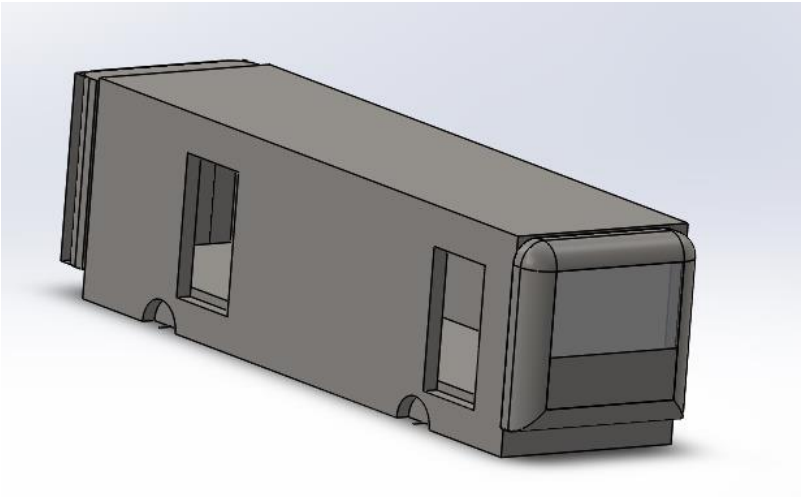
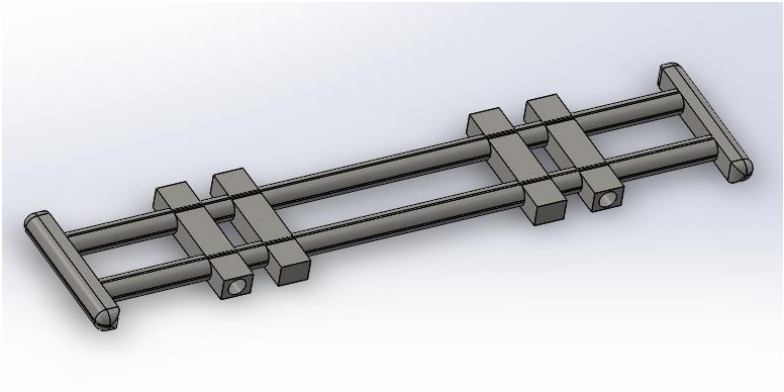


Image 4. SolidWorks Design of CATA Bus Chassis



Using the data gathered by the sustainability tool in SolidWorks, we judged the different concepts we came up with and decided whether or not we should keep the design or throw it out. To keep the comparison between steel and aluminum consistent, we set a baseline in the sustainability tool as a bus made completely from steel. The numbers generated by the sustainability report can be found in Section E.

Table 3. Concept Screening Matrix Detailing the Different Design Concepts

Model	Environmental Impact	Safety	Cost to Build	Cost to Operate	Total	Continue
All Steel	-	+	+	-	0	No(baseline)
All Alum.	+	-	-	+	0	No
Steel w/ Alum. Frame	+	0	+	0	2	Combine
Steel w/ Alum Chassis	+	+	0	0	2	Combine
Alum. w/ Steel Frame	+	0	-	+	1	Yes
Alum w/ Steel Chassis	+	0	-	+	1	Yes

When assessing the design concepts, it was important that we ranked our concepts based on the four needs that we generated in Section B. If we felt the concept positively affected the need, we scored it a +, if we felt it negatively affected the need, we scored it a -, and if the concept had no real effect then it was given a 0. The all steel bus and all aluminum bus both scored a total of 0, and because of this we decided not to use their designs in our redesign. The bus with the aluminum shell and steel frame, as well as the steel chassis both scored 1. The aluminum shell does not provide much in terms of safety, but the steel parts give the designs some rigidity. The buses with the steel shell and aluminum frame, as well as the aluminum chassis, both scored 2 which is the highest score out of all of our concepts. To move forward with our design and ensure that it is the most sustainable and efficient vehicle, we combined the aluminum frame and aluminum chassis onto a steel shell.

C.2 Concept Selection

To effectively rank all of our designs, we created a design selection matrix which scored the two models that were screened through, as well as our new combined model, a steel shelled bus with an aluminum frame and chassis. These three designs and the steel baseline were scored based on the same four needs used in the screening matrix, now weighed to show that the cost of building and operating the bus is more important than safety and environmental impact.

Table 4. Concept Selection Matrix Detailing the Design Concepts

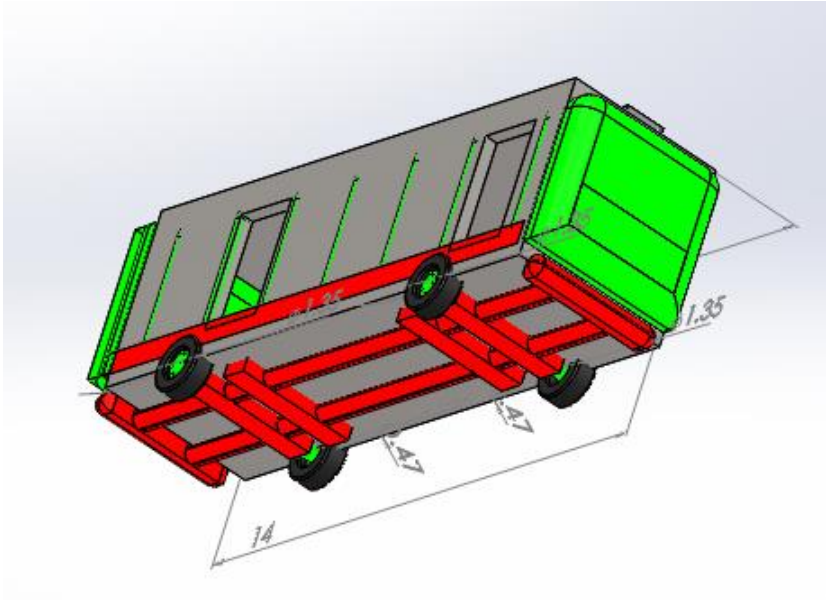
Model	Environmental Impact		Safety		Cost to Build		Cost to Operate		Total		Continue
Criteria	Rank	20%	Rank	20%	Rank	30%	Rank	30%	R	W	
All Steel (baseline)	1	.2	5	1	5	1.5	2	.6	13	3.3	No
Steel w/ Alum chassis and frame	4	.8	4	.8	3	.9	4	1.2	15	3.7	Develop
Alum w/ steel frame	5	1	1	.2	1	.3	5	1.5	12	3.0	No
Alum w/ steel chassis	5	1	2	.4	1	.3	5	1.5	13	3.2	No

The concept selection matrix shows that the best design incorporating aluminum is the steel shell bus with the aluminum frame and chassis. This design was picked over the other designs because of its steel-to-aluminum ratio. Overall, the use of aluminum in the frame and the chassis make the vehicle lightweight, which lowers the cost to operate. The aluminum also has a low environmental impact which gives it a long life cycle. The other designs did not sacrifice enough aluminum to make them feasible options. Even though an aluminum bus with a steel chassis or a steel frame would be good for the environment and sustainable in the long run, it costs too much money in the short term and would also give little protection in the case of a crash. The design we chose would allow CATA to produce a bus that would be very sustainable and efficient, making it possible to produce a larger bus fleet that would be a great long term investment.

D. Review of Design Features

The bus that we designed is assumed to be the same as the current CATA bus design, with the only difference being the use of aluminum in the design. Our bus design is like most other bus designs, with a frame that is placed in the interior of the shell, and a chassis that is placed in the undercarriage of the bus. Our design also includes rubber tires and a window in the front of the bus. Most of our measurements for our design are accurate and match the measurements of other transit buses. Our redesign is not special in any way, but what makes our design special is the use of aluminum in the model and the way it's incorporated into different pieces of the model. The weaknesses about our model are that there are many smaller details and components that we did not include in our design, as well as not including the engine, which is one of the most important parts of the bus. Without these specifics, our calculations may have been a bit skewed in the favor of steel due to its small price compared to aluminum's.

Image 5. SolidWorks Design of CATA Bus Model with Highlighted Chassis



Even though this model is the all steel bus, it shows off all the components of the bus that are important to the design, such as the chassis, shell, and a tiny bit of the frame. These components are what allowed us to complete the calculations necessary for the designs.

The link to download the CAD files of our bus is:
http://www.personal.psu.edu/ayv5135/ALCOA.rar

E. Analysis and Testing

Most of the data that allowed us to assess our design came from the sustainability tool on SolidWorks, which shows the energy consumed and environmental impact of both steel and aluminum. To make sure that our data was consistent and could be compared to each other, we created another model of the CATA bus as our baseline, which was a bus made completely out of steel. We made the assumption when looking at a solution to the bus design that the current CATA bus is made completely out of steel. When put into SolidWorks, the sustainability tool gave us our baseline figures.

Figure 1. Sustainability Report for All Steel Bus Design

Model Name:	All Steel Bus	Weight:	8.9E+5 kg
BASELINE		Built to last:	10 year
		Duration of use:	10 year

Environmental Impact Comparison

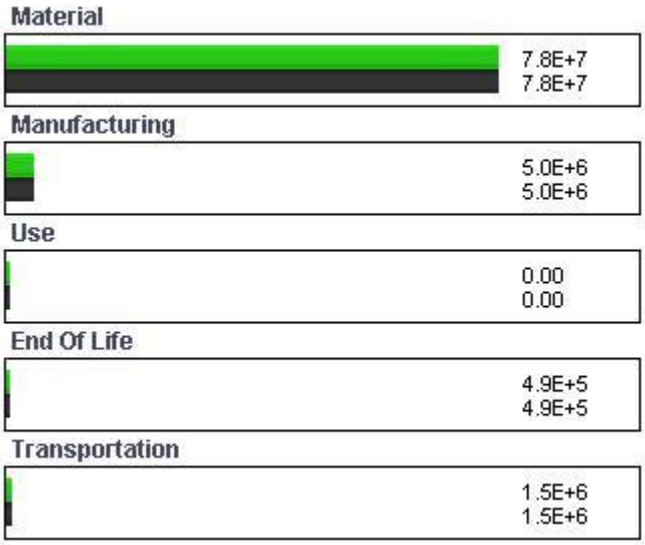
New Design: Better, Worse

Original Design: Baseline

Carbon Footprint - Comparison

Total : 8.4E+7 kg CO_2e

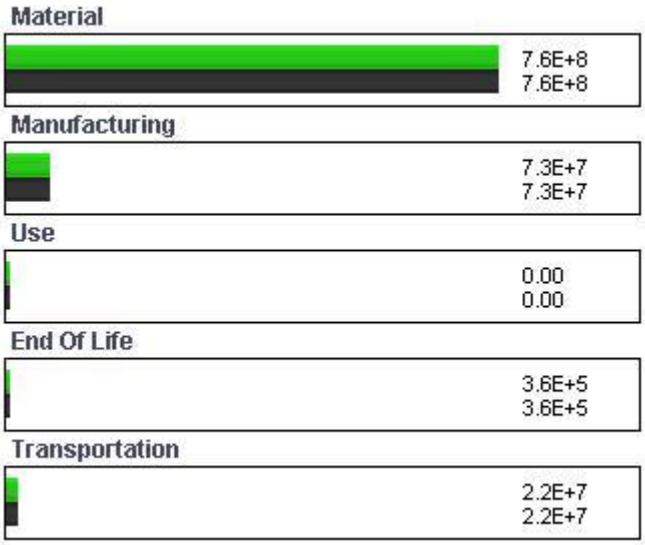
: 8.3E+7 kg CO_2e



Total Energy Consumed - Comparison

Total : 8.6E+8 MJ

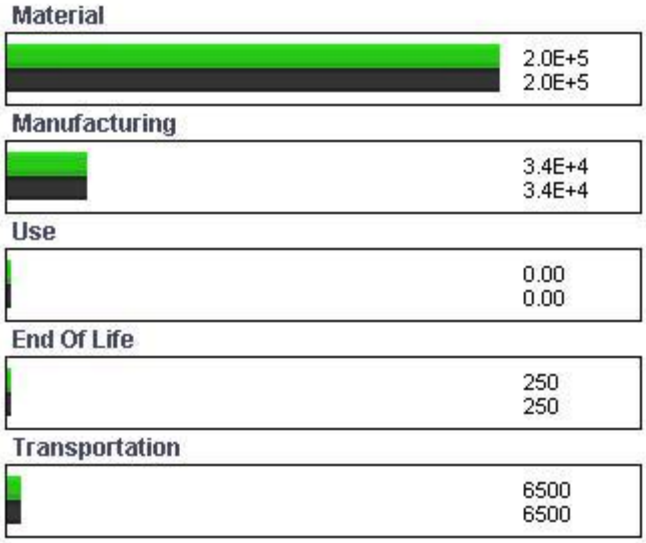
: 8.4E+8 MJ



Air Acidification - Comparison

Total : 2.4E+5 kg SO_2e

: 2.3E+5 kg SO_2e



Water Eutrophication - Comparison

Total : 2.1E+5 kg PO_4e

: 2.1E+5 kg PO_4e

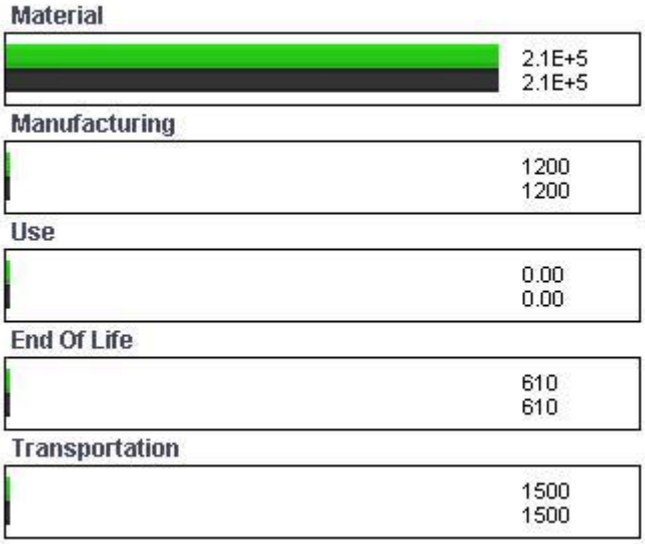


Figure 2. Sustainability Report for All Aluminum Bus Design

Model Name:	All Aluminum Bus	Weight:	8.9E+5 kg
BASELINE		Built to last:	10 year
		Duration of use:	10 year

New Design: Better, Worse

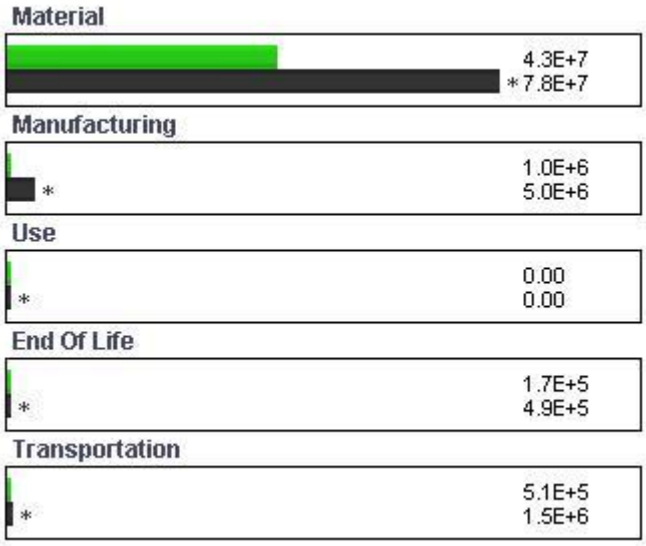
Original Design: Baseline

Environmental Impact Comparison

Carbon Footprint - Comparison

Total : 4.4E+7 kg CO_2e

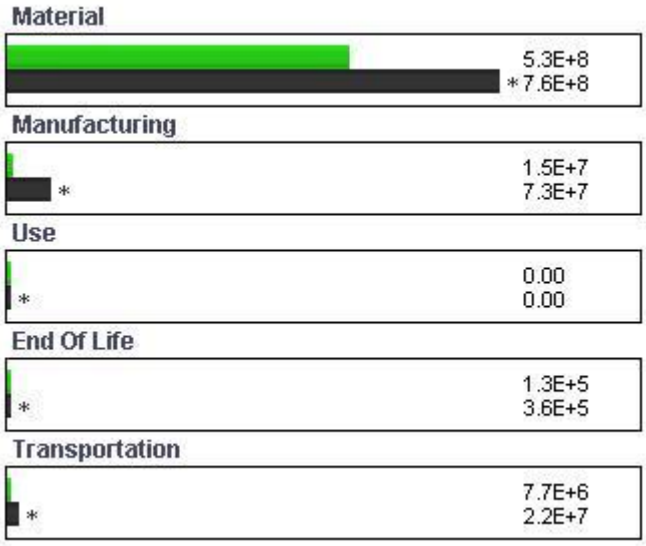
: 8.3E+7 kg CO_2e



Total Energy Consumed - Comparison

Total : 5.6E+8 MJ

: 8.4E+8 MJ



Air Acidification - Comparison

Total : 3.0E+5 kg SO_2e

: 2.3E+5 kg SO_2e

Water Eutrophication - Comparison

Total : 1.0E+4 kg PO_4e

: 2.1E+5 kg PO_4e

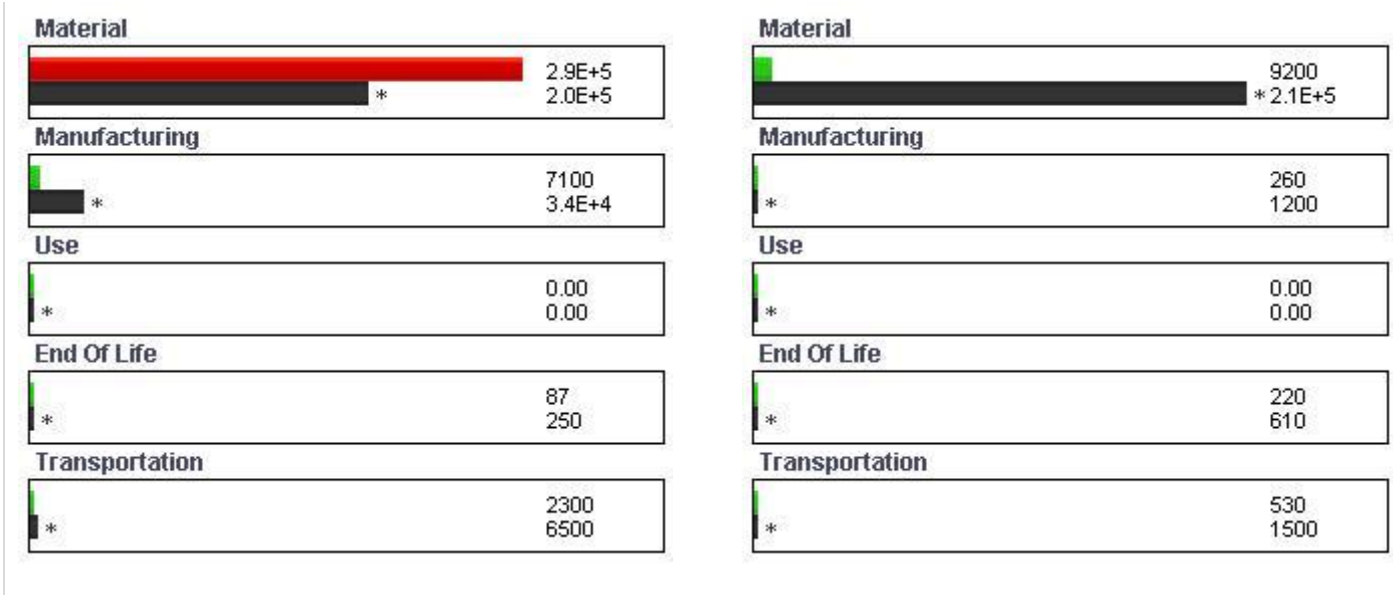


Figure 3. Sustainability Report for Steel with Aluminum Frame Bus Design

Model Name:	Steel with Aluminum Frame	Weight:	8.9E+5 kg
BASELINE		Built to last:	10 year
		Duration of use:	10 year

Environmental Impact Comparison

New Design: Better Worse

Original Design: Baseline

Carbon Footprint - Comparison

Total	: 8.0E+7 kg CO_2e
	: 8.3E+7 kg CO_2e

Total Energy Consumed - Comparison

Total	: 8.2E+8 MJ
	: 8.4E+8 MJ

Figure 4. Sustainability Report for Steel with Aluminum Chassis Bus Design

Model Name:	Steel with Aluminum Chassis	Weight:	8.9E+5 kg
BASELINE		Built to last:	10 year
		Duration of use:	10 year

Environmental Impact Comparison

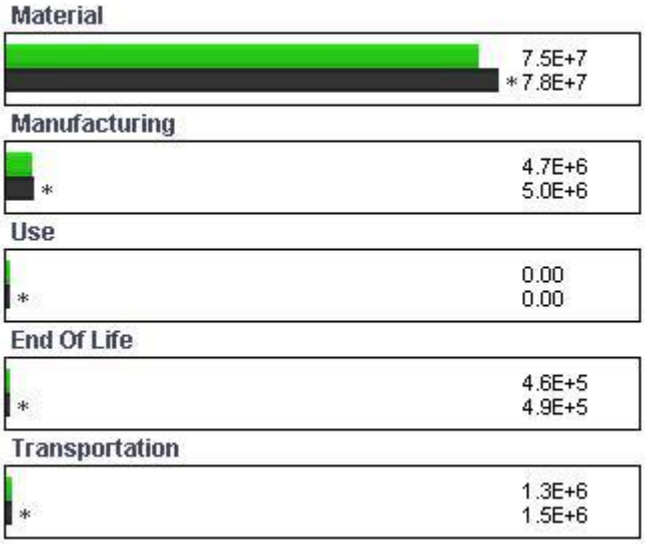
New Design: Better / Worse

Original Design: Baseline

Carbon Footprint - Comparison

Total : 8.1E+7 kg CO_2e

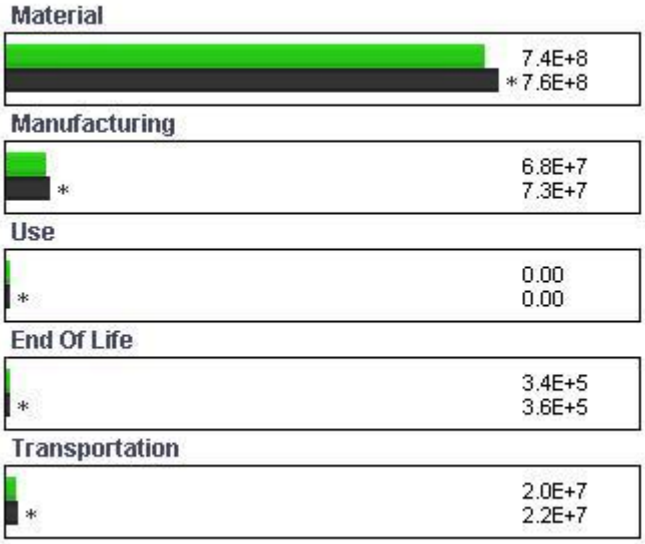
: 8.3E+7 kg CO_2e



Total Energy Consumed - Comparison

Total : 8.3E+8 MJ

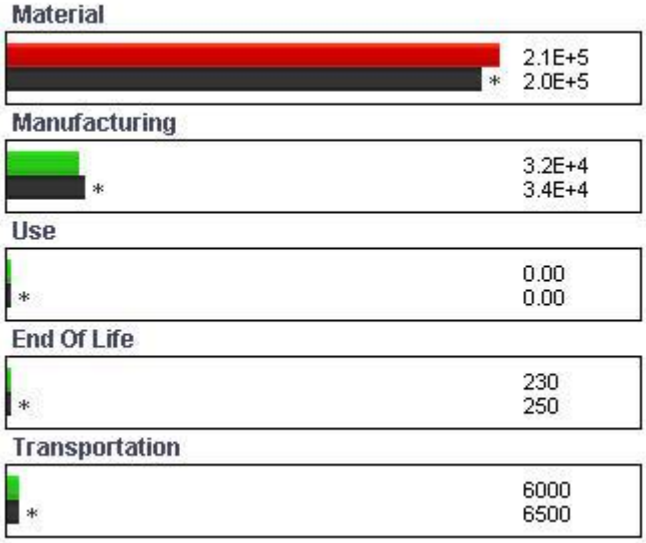
: 8.4E+8 MJ



Air Acidification - Comparison

Total : 2.5E+5 kg SO_2e

: 2.3E+5 kg SO_2e



Water Eutrophication - Comparison

Total : 2.0E+5 kg PO_4e

: 2.1E+5 kg PO_4e

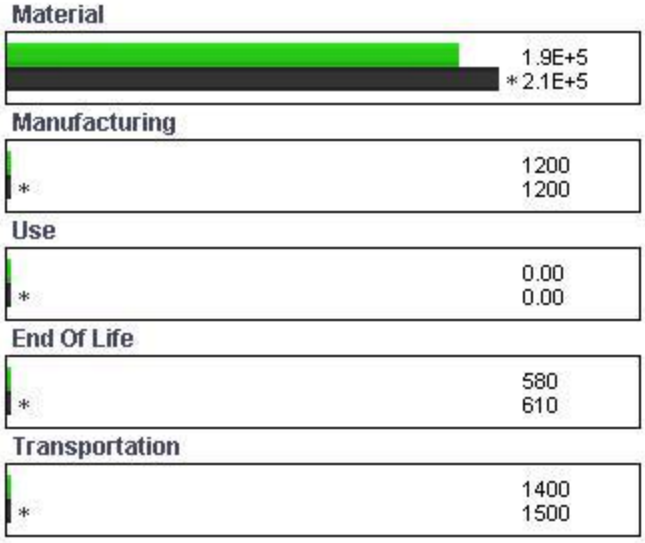


Figure 5. Sustainability Report for Aluminum with Steel Frame Bus Design

Model Name:	Aluminum with Steel Frame	Weight:	8.9E+5 kg
BASELINE		Built to last:	10 year
		Duration of use:	10 year

Environmental Impact Comparison

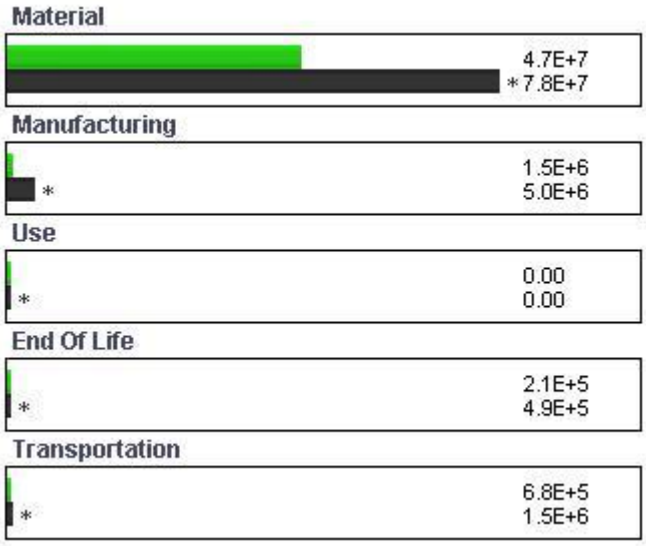
New Design: Better, Worse

Original Design: Baseline

Carbon Footprint - Comparison

Total : 4.9E+7 kg CO_2e

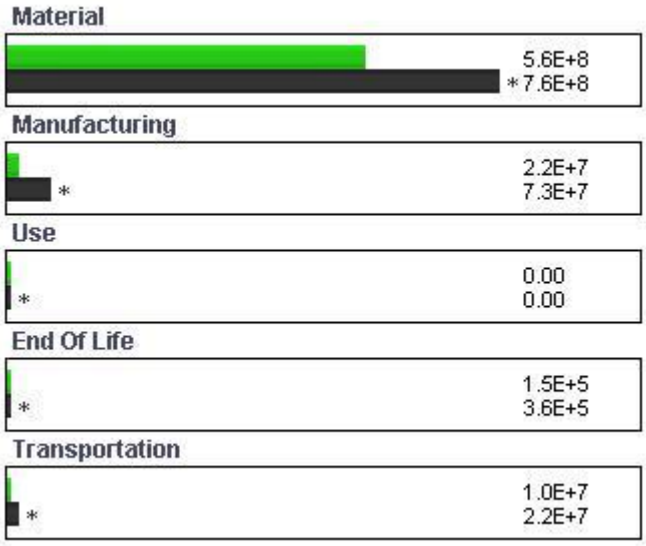
: 8.3E+7 kg CO_2e



Total Energy Consumed - Comparison

Total : 5.9E+8 MJ

: 8.4E+8 MJ



Air Acidification - Comparison

Total : 2.9E+5 kg SO_2e

: 2.3E+5 kg SO_2e

Water Eutrophication - Comparison

Total : 3.3E+4 kg PO_4e

: 2.1E+5 kg PO_4e

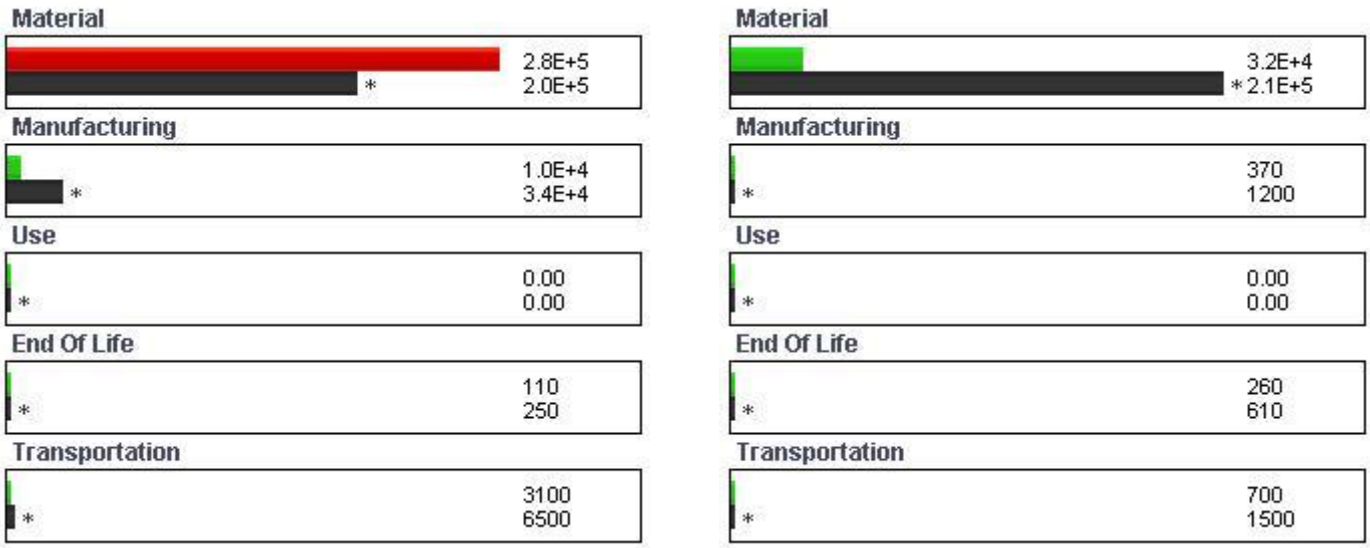


Figure 6. Sustainability Report Aluminum Bus with Steel Chassis Bus Design

Model Name:	Aluminum with Steel Chassis	Weight:	8.9E+5 kg
BASELINE		Built to last:	10 year
		Duration of use:	10 year

Environmental Impact Comparison

New Design: Better Worse

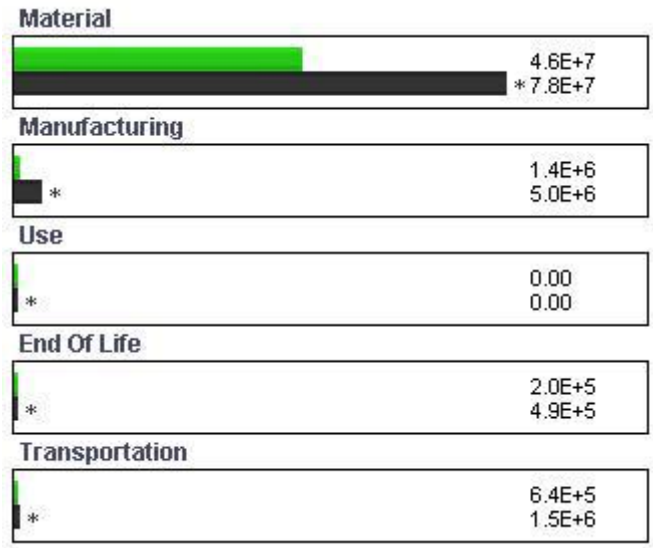
Original Design: Baseline

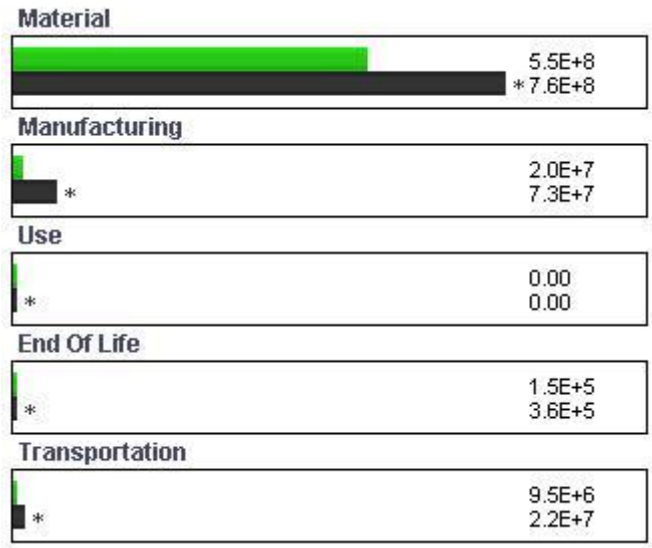
Carbon Footprint - Comparison

Total	: 4.8E+7 kg CO_2e
	: 8.3E+7 kg CO_2e

Total Energy Consumed - Comparison

Total	: 5.8E+8 MJ
	: 8.4E+8 MJ

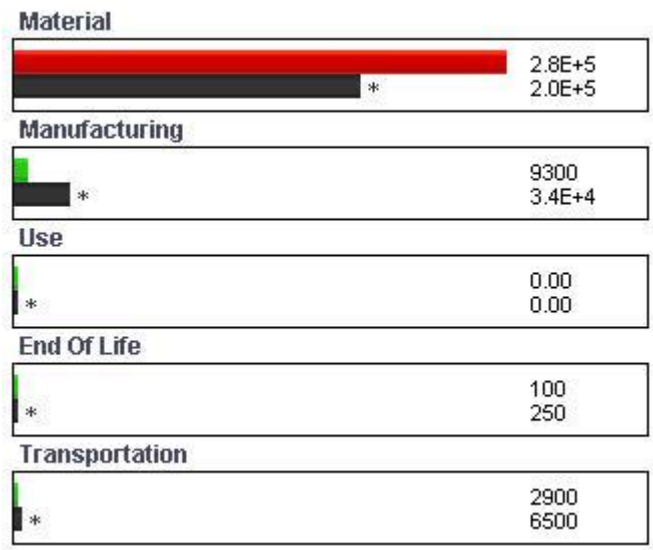




Air Acidification - Comparison

Total : 3.0E+5 kg SO_2e

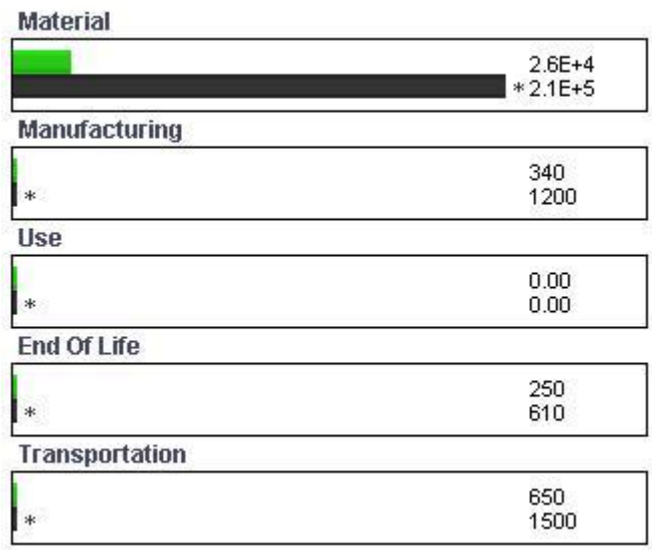
: 2.3E+5 kg SO_2e



Water Eutrophication - Comparison

Total : 2.7E+4 kg PO_4e

: 2.1E+5 kg PO_4e



Each design concept was put into the SolidWorks sustainability tool and the data shown in Figures 1-6 show their comparison to the baseline in Figure 1, which is the all steel bus. Some of these numbers are skewed and inaccurate, because when aluminum is compared to the all steel baseline, the weight of the bus does not change, which means the energy consumes and pollution to the environment shown are wrong, Aluminum is much lighter than steel, and because of this less aluminum will be used in the models of the CATA bus, making the designs less expensive as well. Despite the inaccuracy of SolidWorks in accounting for weight of the materials used, most of the data is used to help determine which of our models

will be best in using aluminum. It also helps reduce the cost of bus manufacturing and maintenance which can allow CATA to put more buses on the roads and increase efficiency.

F. Description of Design Operation

The user of our new redesign will be CATA because they will be using our design to help increase their sustainability and their efficiency. With the use of steel in certain parts of the bus design, the current model is highly unsustainable and will have to be replaced for a newer model in the future. With the redesign we worked on, we are able to deliver a CATA bus that will be sustainable and inexpensive in the long run. With these new buses made from aluminum, CATA will be able create a larger fleet that can service a larger number of students and State College residents, and save them money as well.

G. Life Cycle Analysis

The high recyclability of aluminum is one of the reasons why it is perfect for making something highly sustainable. When redesigning the CATA bus, using aluminum in the internal workings not only raises the fuel efficiency of the bus, but it also extends the lifetime of it. A bus made from aluminum is less like to rust and pollute the environment than a bus made from steel, which makes it perfect for long term use. The problem with using aluminum in the bus is that the cost to build the bus will be much greater than the cost to build it out of steel. This is an issue if CATA is afraid to pay a huge fee up front, but the fee provides a very good investment for the future savings made from maintaining an aluminum bus. When using an aluminum bus, the sustainability and efficiency will make it possible for there to be more buses along the loops and the other routes.

H. Project Summary

When looking at the redesign of the CATA bus using aluminum, it’s important to consider what aluminum can do for an automobile. The use of aluminum in a vehicle can increase the fuel efficiency, which will save on costs spent on fuel in the future. Even with aluminum being the more expensive metal than steel, the light weight means that the vehicle will also use less aluminum. The problem with aluminum currently is the price, but we can overcome this problem if we make use of the aluminum that we currently have and continue recycling it. A large percentage of aluminum in use today has been repeatedly recycled since the late 19th century, and if we continue to recycle this aluminum, the cost to mine new ore will be lower, which will hopefully make the price of aluminum a bit closer to the price of steel. With the improvements made to the CATA bus model, they can create more buses for use in the future and lower the fare for passengers, due to their future savings from investing in aluminum buses.

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