Abstract

The goal of this thesis was to investigate possible ways to improve the current transportation system in regards to sustainability. This paper took a close look at alternative green energy technologies that can be a replacement to fossil fuel along with the AFVs (alternative fueled vehicles) as a part of the literature review.

It concluded that electric cars have the highest potential when compared to all other possibilities with the current technological advancements. However, it was also determined that the resource of the energy is more critical than the type of engine that is used. The only way to achieve a zero emission goal is by replacing the fossil fuel addiction with wind turbines, solar, wave and geothermal plants.

Two stages of design research were executed in this study. Stage-1 was a survey/open ended conversation that was conducted among potential end-users. The purpose of this survey was to understand participants’ opinions on a variety of existing vehicles and to collect ideas for the conceptual design.

The concept vehicle (OSU Car) was designed to visualize suggestions for improving sustainability in urban areas. This design was the outcome of initial design research and literature review.
The second part of the research was interviews with people who were selected from Stage-1 to evaluate the final design and ideas. The main goal of Stage-2 was the evaluation of the OSU Car and to gather data on end-user ideas, suggestions and/or critiques of the product. The secondary objective was the value comparison of information presented in 2D print outs vs. 3D projection in a design research process.

The solution is more complex than just improving the cars. Therefore, a concept called Next Generation Self-Sustaining Transportation Infrastructure was presented to show possible alternatives to eliminate commuting related environmental problems and increase the overall quality of daily transportation.
Dedicated to my family
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Vita

April 8 1984 .................................................. Born - Ankara, Turkey

2007 ............................................................. B.A. Industrial Design, METU

2006- 2008 ................................................... Balikcioglu Office Furniture, Ankara, Turkey

2008-2011 ................................................... Graduate Teaching Associate, Department

of Industrial, Interior, and Visual

Communication Design, The Ohio State

University, Columbus, OH

Fields of Study

Major Field: Industrial, Interior and Visual Communication Design
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Chapter 1: Introduction

The planet has been through a lot worse than us: earthquakes, volcanoes, plate tectonics, continental drift, solar flares, sun spots, magnetic storms, the magnetic reversal of the poles...hundreds of thousands of years of bombardment by comets and asteroids and meteors, worldwide floods, tidal waves, worldwide fires, erosion, cosmic rays, recurring ice ages...And we think some plastic bags, and some aluminum cans are going to make a difference? The planet...the planet...the planet isn't going anywhere. WE ARE!

George Carlin

Saving the planet is a rising concern worldwide. Global warming, carbon emissions and footprint, climate change, greenhouse effects, extinction of species, amongst other issues have already become a part of daily life. Governments, corporations and individuals have acutely diverse approaches to environmental problems. However, is it really the world that needs to be saved? George Carlin, an American writer and comedian, believed that the real issue is our survival, not the planet Earth's.

Nature is a self-sustaining organism. Humans were once a part of this harmony, although as they became more civilized, they have fallen apart from their origins. The Industrial Revolution was the turning point. With the invention of mass production and
the consumer economy, mankind completely isolated themselves from nature (McDonough and Braungart, 2002, 24-26). Nations that think they have more control over nature are characterized as “developed countries”. It is not a coincidence that they are also known as “industrialized countries”.

Consumer based economy has a linear path, which is not a self-sustaining system, while nature has a circular and sustainable pattern (Leonard, 2009). The "Take, make and waste" approach of the early Industrial Revolution has been shifting to "reduce, reuse, recycle”, which is less harmful to the environment, but not the complete solution (McDonough and Braungart, 2002, 45-67). It is every individual’s responsibility to step up for a green revolution and make a contribution to convert this linear flow into a full cycle that will prevent the extinction of mankind.

1.1 Problem

_The earth provides enough to satisfy every man's needs, but not every man's greed._

_Mahatma Gandhi_

1.1.1 What is Global Warming?

Global warming is the consummation of a phenomena called the “Greenhouse Effect” which has been a part of the earth’s workings since its earliest days. Without the Greenhouse Effect, the planet would never have warmed enough to sustain any life form. Gases such as carbon dioxide and methane allow sunlight to reach the earth, but prevent some of the resulting heat from radiating back into space. As ever increasing
amounts of carbon dioxide have been released, along with the development of industrial economies, the atmosphere has grown warmer at an accelerating rate (Layton and Grabianowski, 2008).

Al Gore, the 2007 Nobel Peace Prize winner for his efforts to increase awareness of environmental issues, reports that the planets Venus and Earth have approximately the same size and carbon amounts, but their average temperatures vary greatly. It is 59°F on Earth, while temperatures on Venus reach as high as 855°F. This is because carbon is stored in Venus's atmosphere, whereas it is deposited in the Earth's ground as oil, coal and natural gas. Venus is closer to the Sun than Earth, accounting for an increase in its temperature. However, this is still a relevant example because Venus is three times warmer than the planet Mercury, which is next to the Sun (Gore, 2008).

Briefly, modern industry is taking the carbon that is stored in the ground, converting it to a gas form, carbon dioxide, and releasing it into the atmosphere. Consequently, this increases the temperatures to a level that threatens life on Earth.

1.1.2 Transportation Related Environmental Problems

Transportation is one of principal causes of this carbon exchange process. There are approximately a billion fuel based transportation vehicles throughout the world and this number is expected to increase to 2 billion in 2030, primarily the result of economic boom in China and India (Sperling and Gordon, 2009). One car emits 4 tons of CO2 per year; today there are 700 million cars on the road creating 2.8 billion tons of CO2, and amounting to 25 percent of the world’s carbon dioxide emissions (Agassi, 2009). CO2
emissions have to be reduced in ten to fifteen years by 80 percent to avert catastrophic effects; by starting today, 10 years from now, fuel-efficient cars will reduce fossil fuel needs by only four percent (Chase, 2007).

Low self-awareness at the individual level is a significant problem. According to the Census Bureau Releases: 2008 American Community Survey, the percentage of workers that drove alone to work decreased slightly between 2007 and 2008, from 76.1 percent in 2007 to 75.5 percent in 2008. Moreover, the average American spends 19 percent of their income on their car (Chase, 2007). Therefore, the efficiency of one person spending nearly 20 percent of their income on a five-passenger car that is used for daily commuting becomes increasingly questionable.

1.1.3 Transportation and Urbanization

Cities are the veins of the global economy. There have been four significant transformations in cities since the 1900’s: industrial revolution; commuting and telecommunication technologies; democracy; creation of jobs and wealth in product and service sectors (Banister, 2005, 15). Today, there are 6.2 billion people in the world and half of this population is living in urban areas, whereas only 14 percent were living in cities in the 1900’s (United Nations, 2007). It is estimated this number will increase to 70 percent by 2050 and this growth will predominately occur in less developed countries (Population Reference Bureau, 2010).

Population increase and car ownership are correlated because transportation is a vital component of daily life in urban areas. Car ownership provides transportation liberty;
owners can go wherever they want, when they want (Mitchell, Bird and Burns, 2010, 12). This escalation has resulted in arduous consequences. Congestion, air pollution, noise, safety, degradation of urban landscapes, the use of space, and global warming are the foremost problems generated by city transportation (Banister, 2005).

1.2 Scope of the Study

Cars have always had sentimental value; they have been the iconic representation of their era. They represent a life style, personality and freedom (to commute) (Fink, 1990, 22-23). The current market place (car companies) understands these values and spends considerable effort identifying consumer needs and answering these needs. However, variation of the products is limited to size, the exterior appearance of the vehicles and some other basic functions. Although remarkable innovations have been made in power, safety, ease of driving and fuel efficiency, the basic design principles have scarcely changed since the first mass manufactured cars (Mitchell, Bird and Burns, 2010, 12-13).

This study seeks opportunities to integrate merging technologies and traditional car design, and to bring fresh and environmentally friendly perspectives for urban commuting. There are two main topics to cover for achieving this goal.

The first part of the study focuses on adapting new technologies and ideas to enhance the traditional car design, and creating a conceptual city vehicle to offer an alternative user experience. The well-known design quote "Form follows function" has transformed into "Form and function must fulfill fantasy (human experience)" (Cagan and Vogel,
Dr. Noel Mayo has raised the same question during this study: "What would Apple and Google do if they design a car?". The purpose of this thesis is not to design a single sustainable car. Rather the intention is to create guidelines for clean urban transportation. There will be a conceptual vehicle design to visualize these key points, but this vehicle should not be considered to be the only and final solution.

Secondly, this study focuses on transportation infrastructure. Focusing on commuting infrastructure is a more comprehensive solution to global warming than enhancing cars individually (Agassi, 2009). Currently there are two major players in this market, car companies and energy (fuel) providers. With the implementation of developing technologies, the number of the players could increase, and more competition would lead to improved green designs and creative system solutions.

Throughout the all the steps on this study, "Ten question for the Green Designer" is taken into great consideration:

1- Is there a risk of disastrous failure?
2- Could the product be cleaner?
3- Is it energy efficient?
4- Could it be quieter?
5- Should it be more intelligent?
6- Is it over-designed?
7- How long will it last?
8- What happens when its useful life ends?
9- Could it find an environmental market?
10- Will it appeal to the Green consumer? (Elkington et al, 2008, 23)

William McDonough and Michael Braungart say, "Environmentalists often characterize business as bad and industry itself (and the growth it demands) as inevitably destructive. On the other hand, industrialists often view environmentalism as an obstacle to production and growth" (McDonough and Braungart, 2002, 6). Overall, this study is a contribution to bridge-building activities between these two polar opposite schools of thought.

1.3 So What?

What if humans designed products and systems that celebrate an abundance of human creativity, culture, and productivity? That are so intelligent and safe, our species leaves an ecological footprint to delight in, not lament?

William McDonough and Michael Braungart

The main propose of this study is to not only make a contribution to green transportation design, but also to seek ways to create sustainable breakthroughs in commuting products. We are in a unique period of transforming traditional businesses, such as transportation, into completely new models which is imperative to creating successful businesses (Kim and Mauborgne, 2005, 16). This project is an attempt to show that consumer products can be both profitable and highly sustainable, and it is possible to create new businesses without harming our habitat.
As previously mentioned, fuel-efficient cars will reduce fossil fuel needs by only four percent in the next ten years (Chase, 2007). Is it really worth it to invest all this effort for only four percent? The answer is simply yes. This could be viewed as a small percentage but scientists, companies and individuals worldwide are working in various fields to decrease CO2 emissions. As these efforts combine, it is hopeful that there will be significant progress for a solution to the current environmental crisis.

1.4 Summary of the Study

After the topic was decided, this study started with a literature review and interviews with people. The main struggle in the early stage was green transportation always been a popular problem and companies and entrepreneurs have been working on this topic for years across the world. However, the patterns on these continuing projects has been able to be categorized and potential design opportunities be identified with the guidance of design research.

The first design research that has been taken in this study was an interview/survey with twenty participants. This was an user centered research. Many ideas were generated and became an important input to the conceptual vehicle design.

The next step was the visualization of the conceptual vehicle. This was a traditional industrial design process. It started with sketching ideas and narrowing down to one direction. After the main design decisions were made and the rough form was designed, all inputs were taken to Maya (a computer software) for 3d modeling and rendering.
These 3D models were imported to another software called Unity to add interactivity and features that enable 3D projection for the final part of the design research. The goal of the final research was to evaluate the design success of the conceptual vehicle.

Current transportation vehicles are not the only reason of problems, it also an infrastructure problem. Therefore, some suggestions were introduced for the final part of this paper.
Chapter 2: Alternative Fueled Vehicles

AFVs (alternative fuel vehicles) are a promising solution for decreasing commuting related carbon dioxide emissions. According to the Annual Energy Outlook 2010, transportation related CO2 emissions in the USA will increase from 1.9 to 2.1 million cubic tons and continue to be 33 percent of the all emissions from 2008 to 2035 (Figure 2.1) (U.S. Energy Information Administration).

Figure 2.1: U.S. energy-related carbon dioxide emissions, 2008 and 2035 U.S. Energy Information Administration, Annual Energy Review 2008

(Washington, DC, June 2009)
It is certain that car companies have a conservative approach to AFVs. However, there have always been limitations for the development of these technologies. Joseph Romm, former Acting Assistant Secretary at the US Department of Energy’s Office of Energy Efficiency and Renewable Energy, in his article “The Car and Fuel of the Future”, presents constraints in the growth of the AFVs: “There have historically been six major barriers to AFV success:

1. High first cost for vehicle
2. On-board fuel storage issues (i.e. limited range)
3. Safety and liability concerns
4. High fueling cost (compared to gasoline)
5. Limited fuel stations: chicken and egg problem
6. Improvements in the competition (better, cleaner gasoline vehicles)” (Romm, 2005, 2).

Leading alternative fuel vehicle technologies will be introduced in this chapter. The advantages and disadvantages of these fuels/vehicles will be compared to gasoline powered vehicles and current infrastructure, and their possibility to be the primary fuel in transportation will be evaluated in terms of these six major barriers.

### 2.1 Compressed Natural Gas and Liquefied Petroleum Gas

#### 2.1.1 Compressed Natural Gas

Compressed natural gas (CNG) is a fossil fuel that is in a gas form. Internal combustion engines running with natural gas have considerably lower Greenhouse Emissions
compared to gasoline powered engines: 20 to 30 percent decrease in carbon dioxide emissions, 70 to 90 percent decrease in carbon monoxide emissions and 75 to 95 percent decrease in nitrogen oxides emissions (Natural Gas Vehicles for America). The natural gas-powered Honda Civic GX is ranked as the cleanest internal-combustion vehicle in the market by US Environmental Protection Agency and it is certified as an Advanced Technology Partial Zero-Emission Vehicle by California Air Resources Board (CARB) (Honda.com).

Although they offer better emissions, these vehicles have half the range compared to regular cars because there is not enough room to store natural gas, and storage tanks utilize considerable space in the trunk (Harris, 2005). Compressed natural gas is widely used in public buses that do not have space problems because tanks can be placed on top of the vehicle: 71 percent of all heavy-duty CNG vehicles are transit buses in Southern California (Harte, 2009, 12).

2.1.2 Liquefied Petroleum Gas

Liquefied petroleum gas (also known as propane, LPG or Autogas) is a fossil gas that can be stored in liquid form and it is mainly used as residential heating and cooking fuel in the USA. In contrast, LPG requires less cargo space than compressed natural gas because it has a higher energy density per liter. Inigo Palacio Prada, Chairman of Global Automotive Industry Network (GAIN) and World LP Gas Association (WLPGA) informs that "Last year 14.6 million road vehicles worldwide used Autogas, making LP Gas the third fuel of choice for motorists. Autogas stands between compressed natural gas and gasoline and diesel in terms of carbon content." (Knox, 2009, 10).
The Ford, General Motors and Daimler-Chrysler companies offer propane-powered options on some models, but this modification increases the initial cost (Fueleconomy.gov). There are also far less fuelling stations available for LPG as compared to gasoline and diesel.

### 2.2 Hydrogen

Hydrogen has been promoted as a key green transportation solution for years, but it is not expected to have a significant technological development for its feasibility before 2020 to 2050. Joseph Romm states that: "Of all AFVs and alternative fuels, fuel cell vehicles running on hydrogen are probably the least likely to be a cost-effective solution to global warming, which is why the other pathways deserve at least equal policy attention and funding" (Romm, 2005, 4).

AFVs powered by hydrogen fuel cell need four times more electricity per mile compared to EVs (electric vehicles) with equally sized batteries (Brooks, 2004). Ulf Bossel, founder of the European Fuel Cell Forum, introduces a parallel result, “The daily drive to work in a hydrogen fuel cell car will cost four times more than in an electric or hybrid vehicle” (Bossel, 2004).

Other than these drawbacks, the cost of building an entirely new hydrogen energy infrastructure is the greatest barrier. In their article "A Cost Comparison of Fuel-Cell and Battery Electric Vehicles", Stephen Eaves and James Eaves came to this conclusion: "We find that government studies indicate that it would be far cheaper, in terms of production and refueling costs, to develop an EV, even if we do not consider the
substantial cost of building and maintaining the hydrogen infrastructure on which the FCV (Fuel-Cell Vehicle) would depend.” (Eaves and Eaves)

2.3 Compressed Air

French company Motor Development International (MDI) is the developer of compressed air technology. High pressured compressed air passes through the engine's cylinders to create the power. This air is stored in a tank made of carbon fiber and thermoplastics. The company claims that it is safe to operate: for instance, these tanks are commonly used as vehicles running on natural gas (MDI.lu).

Although the company has released promising information, these cars are still not on the road to substantiate their argument and there are studies questioning this technology. Research prepared by The University of California, Berkeley concluded that: "The life-cycle analysis of the compressed-air car, however, showed that the CAC (Compressed Air Car) fared worse than the EV in primary energy required, GHG (Greenhouse Gases) emissions, and life-cycle costs, even under our very optimistic assumptions about performance. Uncertainty in technology specifications is considerably higher for CACs than for EVs, adding a risk premium" (Creutzig et al, 2009, 8).

2.4 Biofuels

Ethanol, the most common biofuel, is produced by fermentation that is similar to wine and beer production (Biofuelguide.net). Biofuels do not create any additional
Greenhouse Gasses because plants that are used for the production take the carbon
dioxide from the atmosphere, which will be released again by combustion engines.

Biofuels are already mixed with commercial fuel in approximately 10 percent of the USA
(Nytimes.com).

Research shows that the replacement of gasoline needs with bio fuels is not the correct
solution to decrease emissions. In the article "Use of U.S. Croplands for Biofuels
Increases Greenhouse Gases Through Emissions from Land Use Change" the authors
inform that: "Most prior studies have found that substituting bio fuels for gasoline will
reduce greenhouse gases because bio fuels sequester carbon through the growth of the
feedstock. These analyses have failed to count the carbon emissions that occur as
farmers worldwide respond to higher prices and convert forest and grassland to new
cropland to replace the grain (or cropland) diverted to biofuels." Furthermore, this report
states that corn-based ethanol will double greenhouse emissions in the next 30 years
and biofuels from switch grass, that will be produced on U.S. corn fields, will increase
emissions by 50 percent (Searchinger et al, 2008, 1).

Shai Agassi, the Founder and CEO of Better Place (a green energy company that has
one of the largest start-up financings in history), visualizes required farming land for the
bio fuels: "First, I thought ethanol is the solution, then it turns out every country has to
have an Amazon forest in their backyard to produce enough fuel."(Agassi, 2009).

Mass production of bio fuels has other drawbacks. Edwin Kessler, former Director of the
National Oceanic and Atmospheric Administration’s National Severe Storms Laboratory,
reports that "The alternative fuels programs damage the agricultural economy by
causing increases in the price of corn and other human foods and livestock feeds, losses
of already diminished habitat including tropical rainforests and wildlife, and losses of

"Stress on water supplies " needs to be explained with numbers: three gallons of water
are required to produce one gallon of ethanol, 12.5 billion gallons of ethanol (this is the
amount of the 2009 production rate in the USA) requires the water supply of a mid-size
city that has a population of 625,000 people (Nytimes.com).

Although it is not certain that massive production of biofuels would make a contribution
to green transportation, it would be useful if biofuels were produced from bio waste and
unused/recovered lands. Additionally, it is an easy way for individuals wanting to take
more responsibility for environment because biofuels production only requires a
backyard and low-tech equipment. Under current conditions, biofuels mixed with
petroleum fuels could decrease transportation related carbon emissions by 2 percent in
2015 and 7 percent in 2030 (Greene and Schafer, 2003, 9).

2.5 Hybrid Electric Vehicles and Plug-in Electric Vehicles

Each alternative fueled vehicle mentioned above could not pass two or more of the
barriers introduced in the beginning of this chapter. In addition to the previously
explained causes for their failure, they are also behind the competition with two other
alternatively fueled vehicles. Plug-in Electric Vehicles (also known as PEVs, electric
vehicles or EVs) and especially Hybrid Electric Vehicles (HEVs) are becoming the
leading green transportation vehicles.
Gasoline fueled vehicles use non-renewable energy (oil) and convert the energy to the movement through a combustion engine, while Plug-in Electric Vehicles store the electric power and use it as needed, thus the source of the electricity could be a renewable energy (Wolkin, 2009). Alternatively, hybrid cars have dual engine technology, which is a combination of both electric and internal combustion engine (Nice and Layton, 2010). Hybrids are the translation technology between internal combustion engines and plug-in electric cars.

Hybrids do not have the range and charging time (four to eight hours) limitations compared to EVs, making them ideal for long distance commuting. They consume 30 to 50 percent less fuel compared to regular vehicles. There are nine hybrids in the top ten Fuel Economy Leaders: 2010 Model Year (Environmental Protection Agency), proving that they are the dominant AFV in the market. Alternatively, Plug-in Electric Vehicles have zero emissions and operate silently which makes them ideal for cities where air pollution and noise are serious problems. Hybrid's long range ability over EVs is not always essential because the commuting distance is shorter in these areas. In addition, cities have dense populations allowing a profitable investment for the recharging or battery swapping stations that will be discussed in Chapter 7.

2.5.1 Resource Energy of The AFVs

Resource of the electrical power is critical to achieving the goal of zero emission. Stanton W. Hadley and Alexandra Tsvetkova came to the conclusion in their report "Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation" that "CO2 emissions are slightly higher with Plug-in Electric Vehicles than gas-fueled
Hybrid Electric Vehicles in most scenarios because of more carbon-intensive coal and oil (than gasoline), and/or the use of less efficient gas turbines and gas-fired steam turbines to meet the added generation needs." (Hadley and Tsvetkova, 2008, 68). The only way to eliminate transportation related Greenhouse Gas emissions is to convert the world’s fossil fuel dependence to renewable clean energy resources.

However, projections show that progress in creating green energies is not at the level it should be in USA. The U.S. Energy Information Administration reports in the Executive Summary 2010 that fossil fuel energy usage will reduce from 84 percent in 2008 to 78 percent in 2035, as a result of 45 percent of the increase in renewable energy generation (Figure 2.2). This report makes another assumption that increases for the green energy sources could be improved between 61 and 65 percent with the extension of the PTC (Energy Production Tax Credit) that is provided by the government (U.S. Energy Information Administration).
Figure 2.2: U.S. primary energy consumption, 1980-2035 U.S. Energy Information Administration, Annual Energy Review 2008
(Washington, DC, June 2009)

Although these numbers are not promising in the USA, it is certain that the rest of the world has started to take more responsibility. The United Nations Environment Programme states in their report "Global Trends In Sustainable Energy Investment 2008" that renewable energy investment bloomed to $148.4 billion, a 60 percent increase compared to 2006 and is anticipated to attain $450 billion per year by 2012, $600 billion per year by 2020 (United Nations Environment Programme, 2008, 1).
2.5.2 Environmental Concerns Related to Hybrid Electric Vehicles and Plug-in Electric Vehicles

Lithium ion batteries are the common technology for on board energy storage. Disposal/recycling of the ion batteries increases public concerns because they can be extremely toxic for the land and water supplies. However, small scale transportation companies, such as Tesla Motors and Solar Taxi (these vehicles will be introduced in Chapter 3), claim to have 100 percent recyclable- non toxic batteries.

Toxco, the leading battery recycling company in the USA, claims that they can recycle lithium ion batteries of any size. Lithium, which is explosive at room temperature, is frozen to -325°F to stabilize it. Thereafter, the batteries are processed and the materials are recycled (Toxco.com).

The range of the electric vehicles depend on their batteries. If a battery loses its 20 percent capacity, it is considered at its end of life cycle (Wolkin, 2009). However, lithium ion batteries have considerable potential for a second life span as a part of the electricity infrastructure, where they can store energy generated from wind and solar farms (Sherman, 2010).

Companies should design these batteries to be fully recyclable. Every step has to be taken into consideration and well calculated. The "take, use, waste" approach is the cause for the current environmental crisis and it is critical to change this mind set with Hybrid Electric Vehicles and Plug-in Electric Vehicles.
2.5.3 Health Concerns Related to Hybrid Electric Vehicles and Plug-in Electric Vehicles

Electromagnetic fields that are produced by battery packs are an unknown for human health. There is no specific research focusing on lithium batteries and human health, but there are related case studies on telecommunication technologies such as mobile phones and base stations. A number of studies, for instance: "Mobile phone base stations and adverse health effects: phase 2 of a cross-sectional study with measured radio frequency electromagnetic fields", could not identify any health hazards (Berg-Beckhoff et al). Alternatively, there is other research showing that electromagnetic fields have a negative effect on human health. In their article," Setting Prudent Public Health Policy for Electromagnetic Field Exposures," David O. Carpenter and Cindy Sage conclude that: "The evidence for hazards to human health from both electromagnetic fields and radio frequencies is sufficiently strong as to merit immediate steps to reduce exposure." (Carpenter and Sage, 2008).

It is certain that this subject should be searched until solid results are achieved. Although Tesla Motors proposes to keep these electromagnetic fields in legal requirements with a shielding technology (Teslamotors.com), these legal requirements also should be verified with serious studies.

2.6 Conclusion

All AFVs mentioned above could not pass two or more of the barriers introduced in the beginning of this chapter:
1. High first cost for vehicle
2. On-board fuel storage issues (i.e. limited range)
3. Safety and liability concerns
4. High fueling cost (compared to gasoline)
5. Limited fuel stations: chicken and egg problem
6. Improvements in the competition (better, cleaner gasoline vehicles)” (Romm, 2005, 2).

Figure 2.3 shows the weaknesses and comparison of the alternative fuels in a relation to these six barriers. Moreover, an additional barrier ,"Is it really green?", was added because it is certain that some alternative fuels are not the solution to decrease greenhouse gasses.
As a conclusion, the electric car has a better chance to be the future green vehicle than the others. It could be generated from renewable energies, and it has the potential to be a zero emission vehicle. It has a better on board energy storage and most importantly infrastructure is already built and ready to use.
Chapter 3: Review of Existing Sustainable Vehicles

Chapter Three is an overview of the existing sustainable vehicles. These commuting vehicles are either in mass production or in the development process, but they are all real life examples. There are many conceptual designs that could definitely be in this paper such as MIT City Car. However, to limit the numbers and to be objective in the selection, only on road vehicles are discussed.

Sustainable vehicles can be classified under different topics: type of engine, type of energy resource to operate, number of wheels, range, entrepreneur vs. corporations... In chapter two, there is a comprehensive review of available engines and energy resources. Therefore, the number of wheels has been selected to group the vehicles in this part.
3.1 Two Wheel

3.1.1 Zero Motorcycles

Figure 3.1: Zero Motorcycles
(Zeromotorcycles.com)

Zero Motorcycle is an electrical street/sport bike manufacturer. Although there is a carbon emission to produce electricity, the company states that their bikes release less than one-eighth of the CO2 pollution per mile than a gas powered motorcycle. Moreover, their power packs do not have any toxic metals such as cobalt, nickel, lead or mercury and they are completely recyclable. Light weight is an important design criteria for these bikes; each frame is made using 100 percent aircraft grade aluminum (Zeromotorcycles.com).
3.1.2 PUMA

Figure 3.2: PUMA
(Segway.com/puma)

P.U.M.A. (Personal Urban Mobility & Accessibility) is a prototype developed by Segway. It uses Dynamic Stabilization to operate it on two wheels. This device is for 2 passengers with a range of 25-35 miles. It costs 0.60 dollars to recharge in 6-8 hours. This model offers new technologies, such as the ability to recharge while decelerating and transferring system information to the user through mobile devices (Segway.com/puma).
3.2 Three Wheels

3.2.1 Aptera

Figure 3.3: Aptera
(Aptera.com)

Aptera is a 100 miles per gallon vehicle that differentiates itself from other green transportation vehicles because of its light weight and advanced aerodynamics. R&D team reports that 50 percent of a regular car's energy is used by forcing air out of the way at 55 miles per hour. They were inspired by nature, a bird gliding in the air, to decrease this impact and designed with an aerodynamic exterior. Moreover, they decreased the total weight to almost half of a standard vehicle, so that it requires considerably less engine power and energy for acceleration and maintaining a stable speed.

They also state that Aptera is a really safe vehicle. The composite body structure-used in this vehicle is not only lighter than steel but also three times stronger. They take advantage of race car technologies to absorb and deflect energy from the cabin in the event of an accident (Aptera.com).
3.2.2 Air Pod

Figure 3.4: Air Pod

(MDI.lu)

This vehicle uses a controversial Compressed Air Engine which was developed by MDI (Motor Development International). High pressured compressed air passes through the engines’ cylinders to create the power. There are also dual engine options, a second fuel based engine (petrol, diesel, oil, alcohol or gas) to assist the main air engine in order to increase the range. It has three times less CO2 emissions in comparison to classic engines (MDI.lu).

It costs 3 dollars to drive 125 miles (Simon, 2008). Tanks can be filled with air from a compressor in just three minutes or plugged in for four hours and an on-board compressor can fill the tank as well (Harrabin, 2008).
3.2.3 Solartaxi

Figure 3.5: Solartaxi
(Solartaxi.com)

The Solartaxi is an electric vehicle with a 16 foot solar trailer that has 64.5 square feet of solar cells. The electricity is stored in a battery made from common salt, ceramics and nickel. The company claims that it is 100% recyclable. The solar cells on the trailer produce enough electricity to run the car up to 62 miles a day and the vehicle can operate at night with the harvested energy. Batteries can be charged about 1,000 times which is equal 125,000 to 250,000 miles (Solartaxi.com).
3.2.4 Twike

The Twike is a human-electric powered hybrid vehicle, designed to carry two passengers. This vehicle combines an electric motor with a pedal drive. Its engine converts muscle power into motion, while electric power assists the drive. There are approximately 900 owners of this bicycle/ EV experience worldwide.

Similar to PUMA, the braking system gathers the energy that is produced by the friction from deceleration and recharges the battery. It has a joystick steering system. This vehicle provides the electric equivalent of 250 to 500 miles per gallon with up to 93 miles range (Twike.us).
3.3 Four Wheels

3.3.1 Smart Car

This is a two person car that has 33 city/ 41 highway mpg. This vehicle is manufactured by Mercedes Benz and has a fuel based engine. The company claims that the Smart Fortwo meets or exceeds all federal government crash test standards; including a 5-star side crash rating and the highest scores for front and side crash, and roof strength from the Insurance Institute for Highway Safety (Smartusa.com).

The smart car is half the length of an average car and a third of the weight of a typical SUV in USA which makes it a parking friendly city car. Thanks to its small size, it requires less material to build and the company claims that 95% of the vehicle is recyclable (Smartusa.com).
Smart Car is ranked at the eighth position for 2010 Fuel Economy Leaders and it is the only non-hybrid vehicle in the top ten (Environmental Protection Agency).

### 3.3.2 Tesla Roadster

![Tesla Roadster](Teslamotors.com)

**Figure 3.8:** Tesla Roadster

(Teslamotors.com)

The Tesla Roaster is an electrical sport car. Tesla Motors have a different business model than other EV manufacturers; they manufacture high end sustainable cars and believe that EV technology should go from up to down (price wise) like any other new technology.
The company states that the tires and the battery of every Tesla Motors vehicle are recyclable. It has a range of 244 miles per charge in normal conditions. The battery pack in the Tesla Roadster is expected to maintain good driving performance for about 100,000 miles or five years. This car has filtering and shielding technologies to meet all legal requirements and minimize the effects of electromagnetic fields.

Tesla Motors states that lithium-ion batteries will lose 30 percent of their initial performance over five years. It costs 2 cents per mile or $5 to fully recharge the Roadster. They claim that depending on exact prices of electricity and gasoline, owners could save up to $131 per month compared to other premium sports cars (Teslamotors.com).
3.3.3 Volkswagen 1 Liter

Figure 3.9: Volkswagen 1 Liter
(Seriouswheels.com)

One Liter is a Volkswagen concept car for two passengers that claims to have 63 mpg. Its 6.5-litre tank gives a range of 400 miles without refueling. Similar to Aptera, its lightweight and advanced aerodynamics are the main focus to maximize efficiency. It does not have side mirrors to reduce the drag forces. It has special tires made of extremely lightweight composite material to allow optimal rolling resistance (Seriouswheels.com).
3.3.4 Toyota Prius

Figure 3.10: Toyota Prius  
(Toyota.com)

The Toyota Prius is the leading/ iconic hybrid car that uses dual engine technology which is a combination of electric and internal combustion engine (Nice and Layton, 2010). They offer features such as Solar Roof and LED headlamps to increase the sustainability of the vehicle (Toyota.com).

Toyota Prius is the top ranked car model at 2010 Fuel Economy Leaders with 48 city/ 51 highway mpg, whereas Lamborghini Murcielago is the lowest ranked car with 8 city/ 13 highway mpg (Environmental Protection Agency).
Chapter 4: The User-Centered Research Process

In the previous three chapters the problem definition and literature review were introduced. This chapter describes a user-centered research approach to explore and understand user needs related to daily commuting. These findings are used to inform and inspire a conceptual design that will be presented in Chapter 5. The evaluation of this concept, which is the final step of the research, will be introduced in Chapter 7.

As mentioned above, two stages of design research were executed:

Stage-1 is a survey/open ended conversation that is conducted among potential end-users. The purpose of this survey is to understand participants’ opinions on a variety of existing vehicles and to collect ideas for the conceptual design. This portion of the research will be introduced in this chapter.

Stage-2 is a focus group with people who were selected from Stage-1 as well as new participants to evaluate the final design and ideas. This portion of the research will be introduced in Chapter 7.
4.1 Objectives

In their design research and innovation book "Creating Breakthrough Products," Cagan and Vogel introduce "SET Factors" (Social Trends, Economic Forces and Technological Advances) to identify market gaps (Figure 4.1). Changes in these factors create "Product Opportunity Gaps" and it is important to indentify these gaps before developing new products to achieve successful results (Cagan and Vogel, 2001).

Figure 4.1: SET Factors (Social Trends, Economic Forces and Technological Advances)

(Cagan and Vogel, 2001)

Application of this theory to the topic of this study gives some guidelines for the research process. From a economic stand point, fossil fuel prices are becoming more unstable and this situation greatly concerns the public and many governments. Socially, the
awareness levels of people concerning environmental issues are accelerating, and individuals like Al Gore make sincere efforts to educate the public as mentioned in Chapter 1. And thanks to increasing investments, green technologies are becoming cheaper and more reliable as presented in Chapter 2. All these changes create a new design gap and there are many companies focusing on variety of solutions (Chapter 3). The objective of this research was to determine how successful existing sustainable vehicles are in answering user needs, and identify their weakness and strengths from the potential user point of view. Moreover, gathering ideas for the concept vehicle, which will be an alternative to these vehicles, is another goal.

4.2. Research Procedure

Participants were first asked to list the advantages/disadvantages of their current transportation vehicle and what features they would like to customize in their vehicles other than the features that are offered in the existing market. Sample of the survey can be found in Appendix A.

Then, participants ranked thirteen different types of vehicles relative to their safety, sustainability, size and aesthetics. These vehicles were picked after a comprehensive literature review. Five of these vehicles were sustainable vehicles that are locally developed and manufactured, whereas eight of them were from general market segments that are well known to the public (such as SUVs, sedans, sport cars). A brief verbal explanation was given for each vehicle on their engine type, storage capacity, and mileage per gallon to help participants to be relatively well informed.
Participants were also able to make comments on these vehicles as well as on transportation related topics. These comments were where most of the useful data was collected. Even though this research was designed to gather quantitative data, comments made a significant contribution. The survey served as a conversation starter and participants shared their ideas on transportation related issues freely.

4.3. Participants

The researcher's personal social network was used to recruit participants. The main reason for this approach was the convenience to find volunteers. The diversity (in regards to age, professional background and commuting preference) of participants was carefully addressed. Participants were between the ages of 22 to 35, they were either urban drivers or public transportation commuters and they all had at least one college degree.

There were nineteen people included in the interview/open ended conversation. Data were collected in individual or couple meetings with the researcher in Hopkins Hall. Participants’ ideas/comments were documented by note taking, voice records, as well as their written comments.

4.3.1 Observations

There were three couples and thirteen individuals. Couples showed different behaviors compare to each other. The first couple gave opposite answers, while the second couple
partially agreed, and the third one mostly approved each other’s opinion. Couples were more confident and open to share their thoughts compared to individual participants.

Some of the participants preferred to check their previous rankings as they proceeded to give more accurate rankings. The duration of each interview was between 15 and 48 minutes. This difference in duration of the sessions was a result of some of the participants’ willingness to share their opinions and their interests with respect to the subject matter.

Four of nineteen subjects were interested in the direction taken in this study and they have been identified as potential end users. They will be asked to continue with Stage-2 of the research for the evaluation of conceptual design.

4.4. Results

To analyze the data, participants’ rankings were converted to numerical values to create charts. This is the score sheet:

Very poor: 1 point
Poor: 2 points
Average: 3 points
Good: 4 points
Very good: 5 points
After that all vehicles' total scores in each category were divided by nineteen to create average values. Finally, these average numbers are ranked. Figure 4.2 is the final rankings and their visual representation.

![Figure 4.2: Final rankings](image)

Figure 4.3 is the visualization of the quantitative data that was collected during the surveys. Sustainable vehicles are written in green. As evidenced from the chart, these environmentally friendly vehicles have high scores on sustainability, whereas they have lower rankings on all other criteria. They have good intentions to achieve zero emission goals. However, they do not completely answer consumer needs and provide successful aesthetics.
Figure 4.3: Analysis of the survey data
Figure 4.4 is the conversion of some of the visual data to a line chart to demonstrate the relationship between aesthetics and user's overall opinion on the vehicle (I love it).

These two criteria show a similar pattern of rankings. In other words, if the user does not like the visual language of the vehicle, they have a negative overall idea about it. This pattern might explain why sustainable vehicles on this survey have lower scores. Hybrid cars are the exceptions, but as presented in Chapter 2, this study does not consider hybrids as sustainable vehicles because of using fossil fuels as their main energy resource.
4.4.1 Common Themes

Below are the common themes that were identified from the discussions of participants in the research sessions. Each bullet point in this list was expressed by at least 4 out of 19 participants:

- Fourteen participants are car owners and they all think that car ownership provides freedom for the destination and the time schedule, while upkeep costs are a serious drawback.

- Six participants think that SUVs and Pick-ups are safe for the occupants, but not for everyone else and they block visibility of the other vehicles.

- Five respondents use only public transportation for their daily commuting and they think the ability to multitask and not having the responsibility/stress of driving is a considerable benefit. Biggest portion of the multitasking is using a smart phone to connect to digital world. Three of these participants told that it would be very good, if transportation vehicles could provide more usage of developing mobile technologies. Conversely, the disadvantages are relying on the bus schedule and being in a crowd with strangers.

- Five respondents believe that the Aptera’s big front window provides good visibility and this is a feature they would like to have for driving in city.
- Five of the participants think that sustainable vehicles should be at least for two persons. They also believe that these cars could be wider because the main problem in cities is the length of the cars, not their width.

- Four of the participants think that it is not logical or efficient to have a big car all the time. They believe that it would be good to have a vehicle that can provide different size for variety of needs.

- Four of the participants have engineering backgrounds and they all are aware that batteries are a serious threat for the environment, so electric cars are not as sustainable as assumed by public. They also expressed their concerns for the resource of electricity. They believe that electric cars would not be good for the environment if the energy used for their power supply is generated from nuclear or coal plants instead of green energy resources.

- Three of the participants were concerned that entering current cars is difficult for people that have injuries and also for elderly citizens.

- The visual language/exterior design of the sustainable vehicles got negative responses. These are some of the comments (name of the vehicles are not specified in order to show respect for all the effort put in these vehicles): "It looks like cheese; it looks like a death trap; sustainable vehicles should look like regular cars; I don't want to be ashamed of what I am driving; it looks unstable because of having only one wheel in the back; it looks like a duck; it has high blind frequency and it look like a bubble; it doesn't
look rigid; it looks like a shopping cart; it looks like a bug; it looks like it is going to flip easily; it has a very awkward aesthetic; it is ugly but practical; it is goofy looking."

4.5. Design Decisions

These design decisions were picked by the researcher of this thesis from ideas that were generated by the participants during the research meetings and carried to the conceptual vehicle design that will be presented in the next chapter. These ideas were chosen because they could be used together to design a creative transportation vehicle that will enhance the user experience:

- Big front window to provide good vision for driver
- Different size options for different needs
- Rubber material on bumpers and rims to minimize damage, costs and material waste
- Enhanced ergonomics to enter/exit the vehicle
- Two seating and larger width for storage compared to existing sustainable vehicles
- Visual language that is familiar to current car designs but still has its own character
- More intuitive interface and features that will enable usage of mobile technologies in the vehicle
4.6. Lessons Learned about Conducting Research

The number of participants was too low to get accurate statistical analysis. To increase the numbers, this research could have been done as an online survey. However, an online survey method was used in the pilot study of this research and it showed that participants are less likely to make comments and share their ideas.

A better solution would be having a hybrid methodology: using interviews to obtain insights of the participants, and an online version to have a larger statistical sample.

Moreover, the number of the vehicles could have been fewer because participants got bored and wanted to get done with it as soon as possible through the end of the session. This situation decreased the quality of the data.

Participants were asked if existing vehicles allowed enough possibilities for customization and what additional features they would like to customize, other than the features already offered in the existing market. Respondents could not give sufficient answers to these questions. Some of them stated that if there were guidelines, options, or visuals available they would get a better picture and would probably be able to answer these questions.
Chapter 5: Design of the Vehicle

We can’t solve problems by using the same kind of thinking we used when we created them.
Albert Einstein

This chapter is the presentation of a concept vehicle that is designed to visualize suggestions for improving sustainability in urban areas. OSU Car will be one of the many different models that will be locally manufactured and disassembled for recycling. This design is the outcome of initial design research and literature review that were introduced in the previous chapters. This vehicle is a proposal/brainstorming of what would be a creative approach to car design. It is not the perfect/final solution but an attempt to think on alternative ways of commuting in cities.

5.1 OSU Car

The OSU Car (Figure 5.1) is a two passenger electric vehicle for daily transportation needs in urban areas. This vehicle uses “Michelin Active Wheel” technology that is an integration of the steering wheel with an electric engine (Figure 5.2) (Michelin, 2008). All the required components can be compressed into a wheel because of the electric engine’s simplicity and minimal space requirements.
Figure 5.1: OSU Car
The OSU Car does not have a traditional dashboard. Instead, it uses head up display technology to project all the required information to the front window for the driver. Eliminating the dashboard and engine from the vehicle not only considerably decreases the space and weight that is needed for the hardware of a car, but also allows for a larger front window for better driver/passenger vision (Figure 5.3).
Figure 5.3: OSU Car’s interior space
The OSU Car has dimensions of 92 inches long, 80 inches wide and 67.5 inches high. It is shorter than a smart car (106 inches) making it ideal for city transportation (Figure 5.4).

Bumpers have a special structure that are coated with rubber material to absorb shocks and prevent damage that could happen in slow speed accidents. For example, if the driver hits a car in a parking lot, both cars will benefit from this smart design by minimizing/avoiding the damage. In this way, the need for changing a whole bumper for minor damage will be eliminated. Similar to this idea, rims are also made of rubber to help drivers that have trouble in parallel parking.
5.2 Head up Display

Head up display provides opportunities to improve the user experience, in addition to information such as: speedometer, fuel and engine power displays. Back view could be projected to screen from the night vision camera in the back of the vehicle. OSU Car could detect the speed limit and warn the driver. Sensors could consistently provide distance information about the vehicle in the front; even automatically decelerate the car to avoid an accident (Figure 5.5).

![Head up Display](image)

**Figure 5.5:** Head up Display

Navigation data would be projected in 3D to the screen so the driver would not need to take off his/her eyes of the road, which is a serious danger that could cause an accident
(Figure 5.6). The license plate could be projected on the front and back of the car and could be downloaded from web, therefore, physical plates would no longer be required.

Figure 5.6: Navigation Projection

5.3. Auto Controlled Trailer

Initial research showed that users have diverse needs and desires related to the size of their vehicle. Study also indicated that, even though they need/want a bigger size, they do not need it all the time. OSU Car offers a trailer sharing system that members can rent whenever they need extra space (Figure 5.7). These trailers have their own batteries and controls, and can be used as extra carrying capacity or to increase the number of passengers. Trailers are not physically attached to the vehicle; they will follow the vehicle at a safe distance. The driver's command is transmitted to the trailer
electronically and trailer does exactly the same maneuvers as the main vehicle. Trailers are parked in parking lots in dense areas, similar to Zip Car, and members can rent them online and physically activate them with a membership card.

Figure 5.7: OSU Car and Trailer

Trailers could be different sizes and have different functions (Figure 5.8). For example, in a FedEx branch, there could be different sizes and the delivery person can use the size he/she needs for that day (Figure 5.9). Or in an airport, one car could transport many trailers at the same time. There also could be customized trailers for contractors or business. There could be different designs for plumbers, cable people, car sharing, food delivery, etc (Figure 5.10).
Figure 5.8: Different trailer sizes

Figure 5.9: OSU Car for FedEx
Figure 5.10: OSU Car for different businesses
5.4. Hand Gesture and Voice Control

OSU Car uses hand gesture detection and voice control technology to provide advanced usability for its basic functions, for example, to start the engine, interact with user menu/navigation and open the door. This technology is already in the commercial market (Microsoft Kinect) and available for a gaming devices (Xbox.com).

5.5 Local Manufacturing and Diverse Models

OSU Car will be only one of the many designs that have similar approaches. The basic idea behind these cars will be keeping the material and production needs, costs and complexity to a minimum. Therefore smaller and local manufacturing would be started worldwide instead of having a single huge manufacturing center. Consequently, these vehicles will be more appealing to entrepreneurs, developing countries and local communities. Even big car companies might be interested in this green transportation project because of low risk/cost requirements.

Body parts, which are the 95% of the total weight, would be produced and assembled locally, whereas engine wheels and electrical components could still be produced in a central location. Each city or country could have their own design. Instead of having the same models all over the world, there could be huge diversity thanks to local design/manufacturing.
This idea has several benefits. First, it will decrease emissions by avoiding transferring the material and product from one side of the world to other and using local materials. Ray Anderson, previous CEO of Interface (a billion dollar surface carpeting corporation), criticizes this waste of energy by “….never made sense… Brazilian iron ore that gets turned into steel in a Chinese mill, then is used to manufacture appliances that are shipped to California, and then are trucked to a retail store in New York” (Anderson, 2009, 131).

Secondly, it will provide more local employment and democratic global wealth. Finally, there will be a variety of models that all consumers would appreciate because they would be able to express themselves better (Coates, 2003, p 43).

5.6 Disassembly and Recycling

In their sustainability awareness book, “Cradle to Cradle”, William McDonough and Michael Braungart introduce the idea of 100% recycled products that consumers could bring their old models and get the newer version without wasting any material (McDonough and Braungart, 2002, 123). This idea provides for consumer loyalty and keeps the assets of capitalism without harming the environment.

Similar to this idea, OSU Car and all other designs in the system could be disassembled in the same manufacturing center in which they were produced and enter the system again as a raw material. By this way, linear system of industry, the "take, make, waste", will be transformed to a circular/ self-sustaining system.
5.7. Socially Responsible Design

In his book, “Design for the Real World”, Victor Papanek talks about six design priorities for socially responsible design: design for Third World, teaching devices, disabled people, experimental research equipment, survival system and elderly citizens (Papanek, 1971, 352). This study tries to answer possible needs of three of these categories. The first is designing for Third World. Keeping the design of the vehicles as simple as possible with low costs is an attempt to encourage developing countries to produce their own local vehicles.

The second is elderly people. Electrical seats in the vehicle could help senior citizens to get in/out of the car by moving them to the front/entrance of the vehicle (Figure 5.11). The final is the disabled people. A change in the bumper allowing a similar height of the sidewalk, would provide easy wheel chair accessibility to the vehicle (Figure 5.12). The bumper could even have a lifting function, so the user can get in from the ground level. The locking system could secure the wheel chair while traveling.
Figure 5.11: Story board of how to exit/enter the car
Figure 5.12: Handicap Access
Figure 5.13: Orthographic views
Chapter 6: Design of the Infrastructure

This chapter is the presentation of the Next Generation Self-Sustaining Transportation Infrastructure, which is a framework that consists of suggestions to eliminate commuting related environmental problems and increase the overall quality of daily transportation.

6.1 Current Linear Transportation Infrastructure

Current transportation infrastructure, similar to the modern industrial system, has the "take, make, waste" approach that moves material and energy in one direction (Figure 6.1). There are two major players in this system.

Figure 6.1: Current linear transportation infrastructure
First, car manufacturers provide vehicles for commuting needs. They are responsible for material's waste as a result of not having solid recycling policies.

Next is the fuel corporations that supply the required energy to the system. They deliver non-renewable energies to the commercial market. Oil companies have resources and technology to make a significant investment on green energies. However, they prefer to maintain their enthusiasm for oil. The latest environmental disaster (2010) in Gulf of Mexico is evidence that oil companies have to invest in renewable energies rather than deep ocean drilling. Ray Anderson, a leading sustainability industrialist, thinks that these extreme oil production methods have considerable similarities with drug addiction (Anderson, 2009).

6.2 Next Generation Self-Sustaining Transportation Infrastructure

"But the plain truth is, reengineering transportation systems to become resource-efficient is not going to be easy, fast or cheap. However, with leadership, it can be easier, faster, and less expensive than sitting on our collective status quos." (Anderson, 2009, 134)

In this part, a new infrastructure design will be introduced to show a possible closed loop system. This study only deals with individual transportation. Therefore, solutions will be focused on this topic.
The main goal is to increase the number of the major players, competition and flexibility, that will lead to creative solutions. Figure 6.2 is the visual presentation of the Next Generation Self-Sustaining Transportation Infrastructure.

Figure 6.2: Next Generation Self-Sustaining Transportation Infrastructure
6.2.1 Car Body Companies

Similar to the vehicle concept (OSU Car) that was presented in Chapter-5, there would be vehicles that are manufactured locally. Corporate or local companies only manufacture the body of the vehicle, not the engine or electronic parts. The benefits of this approach were introduced in chapter-5.

6.2.2 Tire/Engines

It is known that performance of a vehicle depends on tires, engine and their collaboration. Motor racing sports are a clear example of this relation. However, there is no direct connection in current vehicle design for the development of these parts together. Tire engines, similar to Michelin Active Wheel, give an opportunity to increase performance and efficiency of vehicles by enabling collective research on both parts by the same company.

6.2.3 Renewable Energies

Renewable energy is the heart of the system. It is critical to invest in green energies because it will not only eliminate the transportation related emission but also eradicate fossil fuel burning as a primary energy resources, which generates 78% of the greenhouse emissions in USA. (United States Government Accountability Office, 2008).
6.2.4 Transportation Services

Shai Agassi, a green energy entrepreneur, introduces a new business model which is called "Battery Swapping" (Agassi, 2009). He believes that consumers do not need to buy batteries for their vehicles. Similar to cell phone/wireless carrier business models, batteries could be leased and the users are charged for the miles they drive. Battery swapping stations would change the on board battery with a fully charged battery in less than 2 minutes.

These energy/service providers could also be responsible for the software and applications that will be used in these high tech vehicles such as navigation and road assistance. In addition, initial research from this study shows that participants who use public transportation (subway, buses) think that being able to multi task and not having the stress of driving during commuting is an advantage. Inspired from these findings, it is possible to update current highways making it possible to use auto pilot technologies. This will allow drivers to relax and focus on something else instead of controlling the car. This system also would help to prevent accidents and control traffic flow. Therefore energy efficiency will be minimized while the safety of commuters is maximized.

6.2.5 Individual Contribution

Current systems do not provide enough involvement of individuals and society at a required level. A person who wants to make a contribution to green transportation has limited options such as: buying a hybrid car or not driving more than she/he needs. But
what happens when a cleaner engine is developed next year or is it really a solution to drive less while fossil fuels are still the main energy resources?

It is important to increase the participation and help people to be a part of the solution. Three steps of the Next Generation Self-Sustaining Transportation Infrastructure is designed to encourage individual contribution. These are car sharing, locally powered fuel stations, and recycling/repair shops.

### 6.2.5.1 Car Sharing

In the USA, 90 percent of car trips to work and 58 percent of any other trips are done by a single person and vehicles are only used on average one hour per day (Shaheen et al, 1999). Car sharing would minimize this waste. There are already some successful car sharing businesses.

Robin Chase, founder and CEO of Zipcar, says “What ZipCar does is we park cars throughout dense urban areas for members to reserve by the hour and by the day, instead of using their own car. How does it feel to be a person using a ZipCar? It means that I pay only for what I need. All these hours for a car sitting idle, I’m not paying for it. It means that I can choose a car exactly for that particular trip. So here’s a woman that reserved Mini Cooper, and she had her day. I can take a BMW when I’m seeing clients. I can drive my Toyota Element when I’m going to go on that surfing trip. Are members happy? The company has been doubling in size every year since I founded it, or greater.” (Chase, 2007).
These programs could be established by corporations for employees, local governments as a part of public transportation, and small communities that want to take more responsibility. Car sharing has many benefits: great variety of vehicles, fewer ownership responsibilities, less cost to the users, less parking space and most importantly, considerable deduction in greenhouse emissions (Shaheen et al, 1999).

6.2.5.2 Locally Powered Fuel Stations

Solar and wind energy are the leading green resources, and it is important to use the right one in the right location. For instance, it is not wise to have a lot of solar panels in Ohio where there are not that many sunny days. Instead, wind would be a good way to harvest energy.

Local fuel stations, or in this scenario Battery Swap stations, could be more than energy delivery locations. They can also be a source of energy. Each of them could have a different set up to have maximum efficiency to gather energy. These stations could be leased to people by corporations or owned by local residents. Therefore, everyone in a community would have a chance to make a contribution. This is also a great way to give creative tools to people, so that they can find a way to gather their own energy and sell it, similar to organic farming. It is also great for research and development of green energies because these people will also be working as independent researchers/developers.
6.2.5.3 Local Recycling and Repair Shops

As previously mentioned, local manufacturing and recycling is critical to achieving zero emission goals. There are only a few highly efficient/effective recycling programs. For example, Volvo, the largest truck manufacturer on the globe, has launched a program so that they can recycle 90% of their trucks (Volvo Trucks Magazine.com, 2010). Local recycling centers would be located in the same factory where vehicles are produced or different facilities where used parts go back into the system as raw material to eliminate waste.
Chapter 7: Workshop for the Evaluation of Ideas

Two stages of design research were conducted for this thesis:

Stage-1 was a survey/open-ended conversation that was conducted among potential end-users. The purpose of this survey was to understand participants' opinions on a variety of existing vehicles and to collect ideas for the conceptual design. This portion of the research was described in Chapter 4.

The Stage-2 research was an evaluation of the conceptual vehicle that included the participants that are interested in small sustainable city cars from Stage-1, as well as some new participants. This portion of the research will be introduced in this chapter.

7.1 Research Objectives

The main goal of the Stage-2 research was to evaluate the electric car concept (OSU Car) and to gather data on end-user ideas, suggestions and/or issues with the product. The idea was to compare this vehicle with other similar cars to validate its design potential.

The secondary objective was to compare the value of presenting information via 2D print outs vs. 3D projection of a conceptual design during the design research process. Real
scale prototyping of a concept is a common method in transportation design. This approach is expensive, time consuming and limits the number of the concepts that could make it to next steps. The idea of using 3D projection to show concepts is to convert this method to a quicker and cheaper method, so that research quality will increase. 3D projection is a common technology that is used in 3D movies. It has a onetime cost for hardware of less than 1000 dollars. Hundreds of different concepts could be projected in 3D while researching opinions inexpensively, which would have required huge resources in time and energy with real prototyping.

7.2 Research Procedure

In this study, printed out surveys and 3D projection were compared as a means of obtaining input from people about design concepts. Participants were interviewed individually. Sample of the survey can be found in Appendix B. For the survey, two new cars were used (Nissan Leaf, MIT City Car) along with the OSU Car that was presented in Chapter 5. These new vehicles were preferred rather than the cars that were used in Stage-1 survey to provide new material for the repeat participants to consider. Moreover, these vehicles were introduced to the market/public after the first part of the study was completed and better represented the state of the art.

Participants were told to assume that these three cars have the same sustainability (in terms of millage, efficiency, battery performance, etc.) and were asked to rate them on four criteria: safety, size, aesthetics and how much they liked the car overall (e.g., I love it). The name of the maker/developer (Nissan, MIT, OSU) of these vehicles was not shown in order to eliminate brand perception on participants' ratings. The cars were
named City Car, Leaf and Electrical Car.

After rating the cars, more detailed information on OSU Car was given to participants in printed form. These images were presented in Chapter 5. After they had a chance to review the information, they were asked if they would like to change their initial ratings on the OSU Car. Then they were asked to score some new criteria: big front window, different size options, rubber material on bumpers and rims, ergonomics to enter/exit the vehicle, and heads up display. These criteria were determined to be important in the first research and were presented in Chapter 4.

The final part of the research was the 3D projection of the OSU Car (Figure 7.1). This concept was 3D modeled in Maya, then it brought into another software called Unity 3D, which is a game engine, to add interactivity and 3D effects. A 3D projector was used and participants wore special glasses called "shutter glasses" to see the virtual environment in 3D. Finally, they were given a wireless game controller (similar to the Playstation or Xbox joystick) to rotate the vehicle on the X axis. They were able to activate two animations, i.e., the visualization of opening the front windshield while the electrical seats come forward, and visualization of the folding/unfolding of the passenger seat and steering wheel. The final technology used in this process was Microsoft Kinect that provided head tracking to adjust the position of the car to the user's point of view in real scale.
Figure 7.1: 3D projection settings

7.3 Results

There were eight participants in this phase of the research, four from the target group selected from the first stage, and four new participants. Figure 7.2 shows the scores of each vehicle. This chart was created by converting participants’ rankings to numerical values and then averaging total numbers. This is the score sheet:

- Very poor: 1 point
- Poor: 2 points
- Average: 3 points
Good: 4 points
Very good: 5 points

Nissan Leaf had the highest rankings on safety and size, whereas it got the lowest scores on aesthetics and "I love it". MIT City Car and OSU Car had very similar scores, while MIT City Car was rated higher on aesthetics, and OSU Car had better scores on size and "I love it".

The accuracy of the data can only be considered to be directional due to the low number of participants. Moreover, Columbus, Ohio may not be the best place to conduct research for a small car because of the "bigger is better" ideology of Americans. However, this chart/research validates that overall design quality of the OSU Car is not behind compared to products that are available to the public in regards to criteria that were evaluated in this study.
Figure 7.2: Scores of each vehicle

After giving more detailed information about OSU Car, participants were asked if they wanted to change their ratings on that vehicle. All participants increased their score by one or two on different size options (automated trailer). Only one respondent also increased aesthetics and "I love it" by one.
Figure 7.3 shows the scores of the key features of OSU Car that were determined in the first stage of user-centered research. These key were features all contributed by the individuals in this target group. They have been told what part they have contributed after the interview session/conducting the data was completely over. None of them remember their comments, because they participated the initial research more than a year ago. However, they were all quite happy and proud of being part of this concept.

Unlike in the first set of ratings, the target group and new participants scored each criteria differently. Different size options (automated trailer) and big front window were scored highly by the target group, while these options had poor ratings from the new participants. Heads up display and ergonomics to enter and exit the vehicle had similar scores but were still rated higher by the target group.

An unexpected score came from rubber material (using rubber bumpers to minimize the damage on low speed accidents). This category had slightly higher ratings with new participants. During Stage-1 key features were proposed by more than one participant, while there was only one participant who suggested the rubber material. This might be the reason why this idea was not rated very high by the rest of the target group.
Figure 7.3: Scores of the key features
7.3.1 3D projection vs. Print outs

When participants were asked to compare the types of information they received in this study, the majority (6 participants) rated 3D projection higher than the printouts. One participant gave it the same score, and one person rated print outs higher than the 3D.

Participants agreed that these two methods of providing information worked well together. 3D projection provided them an interactive reality, whereas print outs gave a higher amount of information. One participant suggested that all the ideas presented in printouts could be used in 3D projection. This would considerably increase the production time, and may not be practical in some cases. In other worlds, putting more information in the 3D projection to have less printed material requires more resources.

In addition to this research, two OSU Design alumni, who have been working for Honda, were asked for their opinion about using 3D projection in the early stages of transportation design for the user feedback. They both agreed that this is a new approach and would be significantly useful.
Chapter 8: Conclusion

The goal of this thesis was to investigate the possible ways to improve the current transportation system in regards to sustainability. Evidence that is presented in Chapters 1 and 2 shows the danger and potential catastrophic results of releasing CO2 and other green house gasses into the atmosphere along with wasting and trashing the earths' resources.

This paper took a close look at alternative green energy technologies that can be a replacement to fossil fuel. It concluded that electric cars have the highest potential when compared to all other possibilities with the current technological advancements. However, it was also determined that the resource of energy is more critical than the type of engine that is used. The only way to achieve a zero emission goal is by replacing the fossil fuel addiction with wind turbines, solar, wave and geothermal plants. Nuclear energy was not considered in this study, and although it may seem like a good alternative, recent events in Japan (2011) and The Chernobyl disaster in 1986 show how dangerous and unstable this technology is.

The other issue that this study revealed is the importance of the collaboration and organization of all the green technologies with green businesses. There are a lot of brilliant minds solving a small portion of the big puzzle, but no one is really working on how to coordinate these efforts. The documentary entitled "A Convenient Truth: Urban
Solutions from Curitiba" (2007) show the possibility of creating a smart and diverse transportation infrastructure with almost no budget.

This is where the elements of the social triangle (individuals, industrialists and government) have to find a way to work together. All these elements have significant influences on each other. One of them should take the driver’s seat and lead the others to the right way of thinking and acting. Individuals should elect governments with a solid sustainability plan. Industrialists are the most important player in this equation. However, as evidenced from where humanity has come, they have no intention of being pioneers. Therefore, society and governments have to push them into the fast line of transformation to achieve zero emission polices or they will continue their practices that have not changed since the early days of the Industrial Revolution (Anderson, 2009).

Finally, this study presented a conceptual car (OSU Car) to show the possibility of creative and more efficient vehicles as a reaction to the sameness in the car market. Local product development and manufacturing is the key to diverse and efficient transportation vehicles. Designing cars in California for the rest of the world and having the "one size fits all" approach might be perfect solution for mass manufacturing, but it is deadly for our survival on planet earth (McDonough and Braungart). Moreover, the OSU Car was developed with the users in mind. Their ideas and suggestions are taken into consideration from the beginning of the design process. It was a small step in the move towards being local, diverse and creative in transportation design.
8.1 Future of the Work

The future applications of this research have the potential to follow different paths. The first step is to create a business plan to find investors and apply this concept to real life. As mentioned in Chapter 5, OSU Car is just one of the many other local designs. All these vehicles have low initial investment costs to encourage entrepreneurship, and all of them need a solid plan to find investors.

The second direction would be focusing on the interior design of the OSU Car. Eliminating the dashboard in vehicles and integrating heads up display would have a lot of potential that needs to be investigated more deeply. It would be a new expansion for interaction and graphic design. Moreover, the small interior space of this vehicle requires flexibility and multi functionality. Possibilities along with the ergonomics would be a good design research topic.

The final possible direction is looking at the big picture and designing a transportation infrastructure that will provide zero emission and waste. There were some suggestions presented in Chapter 6 showing that there are endless possibilities to improve the current system. This inquiry could be written as a guideline for the government, where it is needed the most.
Bibliography


# Appendix A: First Stage Research Materials

1. What is your current transportation vehicle?

2. What are the advantages of your current transportation vehicle?

3. What are the disadvantages of your current transportation vehicle?

4. Do you think current transportation devices give enough opportunity for customization?

5. What features would you like to customize besides the ones that offered in existing market?
**APTERA**: advanced aerodynamics, 100 mpg, 2 passengers

What is your opinion about this vehicle concerning each of the following criteria?

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Comments:

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**BICYCLE**

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**PUMA:** Electric engine, 35 miles on a single charge at a cost of 35 cents per charge

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**SCOOTERS AND MOTORBIKES**

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### LUXURY CARS

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Comments:

### TWIKE: human-electric hybrid vehicle, range 100 miles, 0 mpg, two passengers

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### COMPACT CARS

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### SOLAR CARS

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## HYBRID CARS

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## SUVS and PICK-UPS

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Comments:
**AIR CAR**: compressed air engine, 124 mpg, 3 passengers

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Please rank the following criteria according to their importance for you.

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Appendix B: Second Stage Research Materials
### City Car

What is your opinion about this vehicle concerning each of the following criteria?

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<tr>
<th>Criteria</th>
<th>Very poor</th>
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<th>Good</th>
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</thead>
<tbody>
<tr>
<td>Safety</td>
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</tr>
<tr>
<td>Size (passengers and storage)</td>
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Comments:

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### Leaf

What is your opinion about this vehicle concerning each of the following criteria?

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Comments:
### Electrical Car

What is your opinion about this vehicle concerning each of the following criteria?

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Comments:
### Electrical Car

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<tbody>
<tr>
<td>Big front window</td>
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<tr>
<td>Different size options</td>
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<tr>
<td>Rubber material on bumpers and rims</td>
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<tr>
<td>Ergonomics to enter/exit the vehicle</td>
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<tr>
<td>Heads up display</td>
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Comments:

Please rate your overall experience

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<tr>
<th>Print outs</th>
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Comments:

<table>
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Comments: