IPRO 322 Final Report
Spring 2010

Carbon Footprint of Automobiles

Advisors: Don Tijunelis and Edita Baltrenaite

1.0 Introduction

Global climate change caused by increasing concentrations of atmospheric carbon dioxide is one of the most significant threats facing our world today. Carbon dioxide is emitted into the atmosphere primarily by the burning of fossil fuels for energy. Although there are a number of greenhouse gases (GHGs) contributing to this warming effect, CO_2 emissions account for the vast majority of this warming effect), as it comprises of over 75% of the total GHGs emitted. We are already witnessing the effects of global warming in the melting of the polar ice caps and glaciers, and elevation of global sea levels. Negative impacts of such effects are already developing, and future consequences are predicted to be catastrophic. Further complicating this issue is that those less fortunate in the world are to feel the greatest impact from these changes. What is contributing to this climate change must be dissected further than the great industrial manufacturing processes and corporations that are primarily responsible for generating green house gas emission, namely CO_2. Each person as a consumer of goods, the production of which requires processes that disrupt natural lands and produce CO_2 emissions, can be held accountable for the CO_2 emissions that results from their consumption and activities. This is the basis of a carbon-footprint

A carbon footprint can be calculated for various activities including both production and consumption of goods. These calculations can become very complicated especially when variables such as extraction of raw materials and transportation of these goods are considered. This problem is further exacerbated if these activities occur on a global scale. However, to develop the carbon footprint concept is of primary importance to make each person responsible for their consumption and for the ecologically damaging impact of their behavior. In this way people will have a measurable means of determining their physical impact to the earth based on their behavior. Without such a system individuals do not have any quantitative method to positively change their behavior. For example, is a hybrid electric vehicle actually better for the environment than a regular vehicle? There are very different answers to this query made available to the public as there are many sources of information currently available to calculate a carbon footprint. A variety of calculators, specific product figures, etc, are actually offered. However, what do these numbers mean and how are they determined? How will the average consumer interpret the carbon footprint that is ultimately assigned or the emission of one ton of CO_2? First is to define the ultimate goal of seeking to reduce global greenhouse emissions, in particular CO_2. Next is to analyze available data to find any trends and then to brainstorm solutions based on available information. It is upon the analysis of the available information on greenhouse gas emissions and carbon foot printing that a focus on reducing the CO_2 emitted by automobiles would be a great place to start. In the United States, the major sources of CO_2 are power plants, heating systems of homes and factories and automobiles. When power plants and heating systems are combined, automobiles are the second leading source of CO_2 emissions.

There are over 250 million registered vehicles in the US which is more than all of the vehicles in the countries of the European Union combined. Hence, the US emits more CO_2 from automobiles than all of the countries in Europe, China, India and Japan combined thus presenting a significant problem with no easy solution. Therefore, at this point, the goal was to focus on the basics to first and foremost determine the actual carbon footprint of an automobile, and then to determine the best way to present this information to the average consumer. As the problem of global warming is universal and not specific to any country together with our Lithuanian counterparts we worked as an intercontinental team to address this issue.

This project is aimed at presenting a “user friendly” way of identifying vehicles with respect to the emission of greenhouse gases (GHG) throughout their life cycle. The overarching goal of this project would be to resolve some issues of what the actual life-time carbon emissions of a vehicle is, show examples of automobiles that are actually better for the environment, and then present this data in a standardized and meaningful way that can modify consumer behavior. Our objectives include:

- To find the best fuel efficient cars by observing the following fuel types: diesel and petrol.
- Research materials such as aluminum, steel, plastic, rubber and glass in respect to the amount of green house gasses are emitted throughout the production process.
- Examine and calculate the carbon footprint for chosen automobiles
- To work collaboratively and effectively to achieve the outlined tasks according to protocols.
- To prepare a final report and presentation of carbon footprint over life cycle for the chosen European and U.S automobiles.

Much information is provided regarding tail-pipe emissions that is the amount of CO_2 emitted while the car is in use; however, to find the actual footprint of the car there are many other factors that emit CO_2 to consider. These include material extraction, parts manufacturing, vehicle assembly, fuel extraction, fuel production, recycling, disposal, and transportation of materials between each phase to their next destination.

To obtain a rough estimate of carbon emission value per vehicle in Kilograms of CO_2 we focused on three categories, manufacturing, fuel-cycle, and recycling/disposal. These categories were not only established for the purposes of comparison but also in the hopes that when applied, would affect methods of manufacturing, automotive design and the starting materials that are used in addition to reducing the amount of fuel used. As examples, we calculated the carbon footprint of BMW 3 Series, Volkswagen Golf, Peugeot 407, Fiat Punto and Opel Astra, Audi A3, Mazda 5, Nissan Leaf, Hyundai Sonata, BMW X5d, and Chevrolet Imapala using Life Cycle Assessment which takes into account the amount of CO_2 emitted during automobile manufacture, use and recycling. In order to get the amount of energy used in the production phase of automobiles, materials such as steel, glass, rubber plastic used in the automobile were considered. In addition to our research, we also used the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model for analysis. GREET is a program or form designed by Argonne National Laboratory, which consists of an excel sheet that takes certain criterion of cars and solves for emissions output including CO_2 in grams/mile and energy requirements in Btu/mile; these CO_2 emissions were calculated with respect to the automobile's Curb weight in pounds of steel, plastic, and glass. The data and calculations of total CO_2 emissions during life cycle of cars would be presented in a simple, visible and understandable way for the customers and would show the impact of each car on the environment.

Tasks and responsibilities were assigned to sub teams within the groups. During the first half of the project sub teams focused on researching fuels and cars, while the latter half of the semester was dedicated to CO_2 emission calculations for the above named automobiles and working on deliverables.

2.0 Purpose and Objective

IPRO 322 is the first project of its kind. The original goal of this project was to find a user-friendly way to identify vehicles with respect to the carbon emissions emitted over its life-cycle. This project could potentially impact the entire car industry. Although we did not have a sponsor we worked with a researcher from Aragon University. This project was not limited to the just United States although it is one of the countries that have developed a way to let the customer know the emissions of their vehicles. Since burning fuel is one of the largest contributors to greenhouse gases then having the knowing the emissions of a vehicle is important to the average driver. By having this knowledge and understand it the consumer is conscious of their overall foot print and more likely to make a better decision with respect to a lower emissions vehicle when it choosing a vehicle to drive. This project was so broad that the team with more time would have endless way to show the emissions of a vehicle over its life time, so it leaves room to break this project into many parts and open it up into new IPRO projects.

The objectives were constantly changing as the course of the semester moved forward. There will be more detail in the organization and approach section of this report. The basic objectives that did stay constant were finding the emissions that took place during the manufacturing, use, and recycling process of a car, while keeping that in mind it was important to find a variety of vehicles that demonstrated the contrast in green house emissions in these cars. We research the materials steel, plastic and glass to find out if producing these materials were a big contributor to the total amount emitted. Another objective was meeting all of the deadlines of our project such as the project plan, the midterm presentation, the ethics paper and lastly the final report. In order to develop our goal we needed to do the research to gain the proper knowledge as a team to make informed decisions as to how we wanted to present our data to the audience so that it would be easily understood. One of the most important objectives was to work collaboratively and effectively to achieve the outlined tasks that we have set for ourselves in a timely manner.

3.0 Organization and Approach

With the goal of creating more awareness of Greenhouse Gas (GHG) Emissions for the public, the Illinois Institute of Technology Interprofessional Project (IPRO) Group 322 and the international IPRO group from Vilnius Gediminas Technical University (VGTU) agreed to address the problem of a lack of public awareness for the greenhouse gas (GHG) contribution made by cars and trucks.

The way of communicating with the VGTU students was via Internet and IITV communications, as both groups cooperated to research and report GHGs or carbon-footprint for vehicles in the USA and Lithuania using several current and emerging power source options. First the team decided that it wanted to use new cars as opposed used cars to conduct this research. By choosing new cars over used cars it eliminated the worry about where that car has been or the work that has been done. It also laid a clean slate for the groups to calculate

At first, the project was broken into three groups: Fuel, Car, and VGTU group. When starting, the Fuel Group was focused on the variety of fuels and their contributions and characteristics. The Car group focused on the emissions of the American cars that have been selected. The potential fuel types to be examined were electric, oil, propane, ethanol, gasoline, bio-diesel, and diesel. Both groups divided the work on materials and manufacturing into 5 cars then we assigned the fuel. Research was to be done on materials such as aluminum, plastic, steel, and glass with respect to the amount of GHG emissions throughout the production process. The VGTU division was led by Rūta Navickaitė as research was done on European vehicles.

In addition to these plans was the initiative to conduct research and surveys to determine which cars were the most popular and which fuels are more likely to be used. Another IIT task was to gather GHG emission and carbon footprint information from automakers at the 2010 Chicago Auto Show, but there was little to be found. This was one of the first cases that the IIT group realized that the information about green house gases was not as readily available as it was it was thought to be. At the Auto show we interviewed several dealers about the information that they had on the emissions of the new vehicles of 2010.The information that we received was insufficient to compare numbers. For more information about what took place at the auto show refer to the appendix for a full report on out findings. The VGTU students were finding overwhelmingly comprehensive data. The total amount of CO_2 emissions found by the VGTU students, in summation of the amounts of CO_2 emissions in regards to vehicle materials found during the pre-manufacturing and recycling phases were under the following: steel and iron, synthetic materials and plastic, rubber, gas oil and grease, glass, non-ferrous metal, aluminum, lead, and foam and cables.

One of the few standards that were regulated in the U.S. was the California standards. We classified the cars in groups such as the: low emissions, ultra-low emissions, super low emissions and, zero emissions. We researched these cars as a standard to compare carbon emissions to. The top 4 cars were the Hyundai Sonata, BMW X5d, Nissan leaf, and Mazda 5. After this the team was able to come up with a calculation formula in order to have a standard. Refer to the appendix for the calculation formulations. We employed the help of Andrew Burnham from Argonne. He explained the program GREET.

Afterwards, our group took our research in another direction as work was done on a selected number of vehicles, categorized by gasoline and diesel driven vehicles. In addition to our research, we also considered the possibility to implement the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model in our project. GREET is described as a program or form of calculation used by Argonne National Laboratory, which consists an excel sheet that takes certain criterion of cars and solves for emissions output including CO_2 in grams/mile and energy requirements in Btu/mile. Then we decided to calculate the all the car's CO_2 emissions with respect to the Curb Weight in lbs., steel, plastic, and glass after finding out that results from fueleconomy.gov were solved via GREET. By the data and calculations of total CO_2 emissions during life cycle of cars, it is shown, which automobile is the greenest and which car has the biggest impact on environment and human health. Furthermore, the analysis of emitted CO_2 is proposed in the simple, visible and understandable way for the customers.

This project was challenging because of the discrepancy in information that was available to our Lithuanian counterparts versus what was available to us in the United States. For instance, while the VGTU group was able to obtain carbon emission information for manufacturing and recycling of their vehicles, the I.I.T group could not access such data and hence had to use the GREET model as a guide for calculations. This difference could be associated with the fact that unlike Europe where the European Union requires that such information be made available, the United States doesn't require such information to be released by manufacturers. To have a common basis for the comparison of automobiles from both groups, we had to standardize calculations by using metric units. Our choice of automobiles was based on emission standards of California (Low Emission

Vehicle, Super Ultra low Emission Vehicle, Zero Electric Vehicle etc) as well as ratings of the European Union.

Our team made significant progress towards achieving our goal of presenting a user friendly way of identifying automobiles with respect to the emission of green house gases over their lifetime. The calculations and data for the amount of CO2 emitted during manufacturing, use and recycling are presented in tables and explained in the Analysis and Findings section of the paper.

4.0 Analysis and Findings

At the start of our IPRO we researched and took a look at greenhouse emissions and carbon footprint on different types of cars (trucks, sedans, SUVs, etc.) and the emissions coming from different available fuels (petrol, diesel, alternative). We tried to find a way to compare this different data that we found by sorting out and getting more specific and what cars exactly we were focusing on as well as fuels. At the same time the Chicago Auto show took place and it was decided it would be a good idea to attend it in order to gather additional information on CO_2 emissions from the different manufacturers. After the auto show our approach to the IPRO and data presentation changed by choosing five specific vehicles that run on gas and diesel, in order to look at their carbon footprint more specifically for direct comparison.

After synthesizing all the information found plus what happened at the auto show, we went on California's website on emission regulations and further researched vehicles with stickers indicating Low-Emission Vehicle (LEV), Ultra-Low-Emission Vehicle (ULEV), Super-Ultra-Low Emission Vehicle (SULEV), Zero-Emissions Vehicle (ZEV) and vehicles with no sticker. Two cars were chosen from each group with the intent of getting the CO_2 emissions from four categories: tailpipe emissions, fuel production, manufacturing and recycling. However, in the end six vehicles were chosen from these groups of vehicles. These four categories were all important factors that needed to be taken into account when thinking of the emission of a life cycle of a vehicle. For the manufacturing aspect it was chosen to only look at three main material used- steel, glass, and plastic as these materials appear in most vehicles and were the top materials used in cars.

While researching it was very difficult to get any information other than tailpipe emissions for the specific vehicles that were chosen. No vehicle manufacture had made any of the data available for specific vehicles. If the manufacturers had any information, they had general information about their factories overall which were not specific or very useful for what we were researching. Finding a way to directly compare carbon footprint between vehicles was also a challenge that became very quickly realized. It became very apparent from the beginning that the U.S. did not require manufacturers to release any specific information in terms of CO_2 emissions for the categories that were being researched as compared to our Lithuanian counterparts who were able to get this information easier for their specific cars as it is required in Europe to have this information available.

We decided to calculate the CO_2 emissions by hand. We would calculate the CO_2 emissions that came from fuel production and recycling and then from steel, glass, and plastic production which would make up manufacturing and then calculate the CO_2 emissions for the specific car by the weight of the vehicle. It would allow us to compare the vehicles in a more direct way. Since our Lithuanian team is based in Europe and they have the metric system and ere we use the Imperial system, we also had to take into consideration converting our data into metric units so that we would be able to compare the vehicles from both groups.

Half way into research we found Argonne's GREET model which is a full life-cycle model that evaluates energy and emission impacts of advanced vehicle technologies and new transportation fuels, the fuel cycle from well to wheel and the vehicle cycle through material recovery and vehicle disposal need to be considered. After we were introduced to the GREET model by Argonne, understanding how to use it was a challenge. As well as making it work with the data we had so far. Also after emailing fueleconomy.gov, we found out that the data that we thought for tailpipe emissions also included fuel production using the GREET model as well which meant that more hand calculations had to be done. With the help of Dr. Tijunelis, Andrew Burnham from Argonne National Laboratory was able to come to one of classes and discuss their GREET model more in depth and to give us a better understanding of the model so that we would be able to make sure that our calculations had been done correctly. At this point we were still unsure how to go about with recycling as no proper data was available. After speaking with Mr. Burnham, we decided to not make recycling a priority. Mr. Burnham had stated that they did not look at recycling in too much depth because the amount of CO_2 emissions was not as important. The benefits of recycling are far greater than that of the CO_2 emissions that are emitted because of it. He did however suggest that for manufacturing we take into account the use of "virgin" steel- steel that had never been used before for anything and recycled steel because the CO_2 emissions were quite different and virgin steel production emitted more CO_2 than recycled steel.

The formulas [1] that were used to calculate the CO_2 emissions were equations that were formulated by our team members through the use of various websites [2] and brainstorming. The equations were a matter of taking the kilograms of CO_2 emitted by the productions of steel and glass per tone and converting that number into pounds so that the weight of the vehicle could be put in to find as close of a specific number that we could get and then multiplying that number by the percentage of that material that was found in a car on average. For plastic there was an extra step of calculating the kilowatts per hour that it took to make a kilogram of plastic and then continuing with the same calculation foundation as steel and glass.

We stated that 150,000 miles is the life expectancy in terms of miles for an average car and we used this number in calculating the tailpipe emissions. We took the 150,000 miles as the life of a vehicle and converted it to the kilogram of CO_2 per gallon that was emitted by either gasoline or diesel, using the numbers that were found during research, and getting from that the kilograms of CO_2 emitted for the life of a vehicle. To calculate the CO_2 emitted from fuel production, we took the CO_2 emission number that was acquired through economy.gov and subtracted from it the CO_2 tailpipe emissions to get the CO_2 emissions from fuel production. With these equations, we plugged in the information of the vehicle into the equation to achieve the CO_2 emission for each vehicle. Since these numbers were calculated by hand, it should be known that there may be some slight differences by some percent due to normal human error and also due to estimation, etc.

Car Model	**Weight (lbs)**	**Steel(kg)**	**Plastic(kg)**	**Glass(kg)**	**Totals(kg)**
Audi A3	3423	2174	1677	28	3880
Mazda 5	3422	2174	1677	28	3878
Nissan Leaf	2800	1779	1372	23	3174
Hyundai Sonata	3309	2102	1621	27	3750
BMW X5D	5225	3319	2560	43	5922
Chevrolet Impala	3555	2258	1742	29	4029

Manufacturing based on energy required to produce

The table above shows the kilograms of CO_2 that are emitted by the different materials that were chosen for the manufacturing process. It shows the different emissions for each vehicle based on its weight which in the end shows the total manufacturing of the materials for each vehicle. Tables were calculated for the other criteria and also for the process of manufacturing and extraction as well. From the data tables, one can see the differences in the CO_2 emission by each vehicle. This shows the difference a car really makes when you look at the total life cycle of a vehicle and not just tailpipe emissions. It shows that the Nissan Leaf which is an electric vehicle (ZEV vehicle), does pollute through tailpipe emissions, but emits CO_2 through the recharging of the vehicle and through manufacturing as well.

Car Model	Cars (lbs)	V. Steel(kg)	Plastic(kg)	Glass(kg)	Total(kg)
Audi A3	3423	14133	7921	466	22520
Mazda 5	3422	14129	7918	466	22513
Nissan Leaf	2800	11561	6479	381	18421
Hyundai Sonata	3309	13662	7657	450	21770
BMW X5d	5225	21573	12091	711	34375
Chevrolet Impala	3555	14678	8226	484	23388

Materials Manufacturing and Extraction

Car	Manufacturing(kg)	Manufacturing + Extraction(kg)	Extraction only(kg)
Audi A3	3880	22520	18640
Mazda 5	3878	22513	18635
Nissan Leaf	3174	18421	15248
Hyundai Sonata	3750	21770	18019
BMW X5d	5922	34375	28453
Chevrolet Impala	4029	23388	19359

Extraction – Difference between manufacturing + extraction and manufacturing alone

The data tables were a major accomplishment for the team as we were able to finally compare the different types of cars in a more direct way such as an electric car with a diesel vehicle or a gasoline vehicle. It also enabled the opportunity to compare the data with the data that was accomplished and compiled by the Lithuanian team and their vehicles. The formulas that were derived by the team may be as close of a number in terms of CO_2 emission of the life cycle of a vehicle that can be normally understood by any consumer. A consumer can clearly see there are more CO_2 emissions from a car than just the tailpipe emission which in turn leads to more greenhouse gases and makes the carbon footprint of the consumer even bigger. This entire IPRO also shows the lack of data that is available on the CO_2 emissions of the vehicle from the manufactures particular in the United States. Hopefully with the accomplishments of this team in formulating the equations and coming up with the CO_2 emissions for different vehicles in a friendly approach, more can be done to include every vehicle or include more information available.

5.0 Conclusion and Recommendations

Global Climate change is not a new science and it is a global problem. Since atmospheric CO_2 emissions were recorded in the 1950's evidence shows increases in CO_2 emissions being a major contributor to the warming of the global average climate through the greenhouse effect. Carbon dioxide is emitted into the atmosphere primarily by the burning of fossil fuels for energy. Although there are a number of greenhouse gases (GHGs) contributing to this warming effect, CO_2 emissions account for the vast majority of this warming effect), as it comprises of over 75% of the total GHGs emitted. We are already witnessing the effects of global warming in the melting of the polar ice caps and glaciers, and elevation of global sea levels. Negative impacts of such effects are already developing, and future consequences are predicted to be catastrophic. Further complicating this issue is that those less fortunate in the world are to feel the greatest impact from these changes. What is contributing to this climate change must be dissected further than the great industrial manufacturing processes and corporations that are primarily responsible for generating green house gas emission, namely CO_2. Each person as a consumer of goods, the production of which requires processes that disrupt natural lands and produce CO_2 emissions, can be held accountable for the CO_2 emissions that results from their consumption and activities. This is the basis of a carbon-footprint. A carbon footprint can be calculated for various activities including both production and consumption of goods. These calculations can become very complicated especially when variables such as extraction of raw materials and transportation of these goods are considered. This problem is further exacerbated if these activities occur on a global scale. However, to develop the carbon footprint concept is of primary importance to make each person responsible for their consumption and for the ecologically damaging impact of their behavior. In this way people will have a measurable means of determining their physical impact to the earth based on their behavior. Without such a system individuals do not have any quantitative method to positively change their behavior. Moreover, individuals do not even know if their corrected behavior is actually a benefit. For example, is a hybrid electric vehicle actually better for the environment than a regular vehicle? There are very different answers to this query made available to the public as there are many sources of information currently available to calculate a carbon footprint. A variety of calculators, specific product figures, etc, are actually offered. However, what do these numbers mean and how are they determined? How does or how will the average consumer interpret the carbon footprint that is ultimately assigned or how will they even interpret the emission of one ton of CO_2? In many ways, this is only a small part of the larger problem that exists to reduce carbon emissions and halt global warming.

So where do we start to approach the problem. First is to define the ultimate goal of seeking to reduce global greenhouse emissions, in particular CO_2. Next is to analyze available data to find any trends and then to brainstorm solutions based on available information. It is upon the analysis of the available information on greenhouse gas emissions and carbon foot printing that a focus on reducing the CO_2 emitted by automobiles would be a great place to start.

Of all the GHGs, CO_2 is the predominant form, constituting over 75% of all the greenhouse gases present in our atmosphere. In the United States, the major sources of CO_2 are power plants, heating systems of homes and factories and automobiles. When power plants and heating systems are combined, automobiles are the second leading source of CO_2 emissions.

There are over 250 million registered vehicles in the US. This more than all of the vehicles in the countries of the European Union combined. All told, the US emits more CO_2 from automobiles than all of the countries in Europe, China, India and Japan combined. This is a significant problem with no easy solution.

It was determined that the technology to measure CO_2 emission, legislation and other means to regulate this problem are available. However, through the course of our research it was also determined that especially in the United States, there is a profound lack of reliable and 'official' data. For the fact that there is also much controversy surrounding this issue in the US, there is also a plethora of inconsistent data as well. Moreover, as many organizations from Argonne National Laboratories in the US, the European Union and other various governments have developed some sort of rating system for their automobiles, there is also much inconsistency between these systems, and a quantitative standard has yet to be set.

Therefore, at this point, the goal was to focus on the basics to first and foremost determine the actual carbon footprint of an automobile, and then to determine the best way to present this information to the average consumer. The overarching goal of this project would be to resolve some issues of what the actual life-time carbon emissions of a vehicle is to determine which cars are actually better for the environment, and then to present this data in a standardized and meaningful way that can modify consumer behavior.

Much information is provided regarding tail-pipe emissions, the actual burning of fuel while the car is in use. However, to find the actual footprint of the car there are many other factors that emit CO_2 to consider other than only fuel consumption such as material extraction, parts manufacturing, vehicle assembly, fuel extraction, fuel production, recycling, disposal, and transportation of materials between each phase to their next destination. So we reduced this to three categories, manufacturing, fuel-cycle, and recycling/disposal, for which we would determine a rough carbon emission value for specified in kilograms of CO_2 emitted per vehicle. These categories were not only established for the purposes of comparison but also in the hopes that when applied, would affect methods of manufacturing, automotive design and the starting materials that are used in addition to reducing the amount of fuel used.

From our calculated data and working alongside a subject matter expert and our better equipped Lithuanian counterparts, the severity of the lack of information, discrepancies in values, methods of calculating values, and presentation of data was brought to light. Nevertheless, even from this, solutions can be developed and the focus of our direction became clearer. By physically going through the exercise of actually seeking information and working with some of the available data to calculate a carbon footprint of an automobile rather than merely accepting unsubstantiated data, we were able to expose specific hurdles that must be approached and overcome to tackle this profound issue.

During the course of the IPRO we encountered various obstacles, both big and small, and we managed to successfully overcome most of them, but some of those aspects could be improved upon, and maybe taken with a different approach. Our main goal of producing a user-friendly way of showing the whole carbon emissions to the consumers was met, but due to time constrains, we weren't able to fully analyze our approach. It would be a better idea to see how user-friendly our approach actually is. This could be done by conducting surveys to the general public and showing them our findings to see if they believe that it is user-friendly enough or not.

Again, one of the biggest problems we had was during the collection of data. We had to find various amounts of information from different sources, but not all of the data we required was available. Having so many different sources also meant that we would sometimes get different values for one specific item. With our main goal being to find exact data for each one of the different car models we had chosen, this made it difficult and imprecise. A greater use of an advanced tool, such as Argonne's GREET model, could significantly help in increasing the accuracy of these values.

Seeing how our Lithuanian counterpart managed to find specific data, data which is given openly to the European market, while it isn't available here in the United States, it stands as a recommendation to see how the regulating laws change and see if this data is released openly to the public.

Our IPRO was composed by members of different cultures, with each one of us having a different way of communicating between us and our advisor. Our advisor tried to step back as much as possible, and let us work by ourselves the best we could, but a better plan would be to guide us a little longer at the beginning in order for these differences to not affect us as much.

Working with an international group was a new experience for us. We recommend having a strong communication with them, and try to pre-empt various inconveniences that might come up. We had such problems like religious holidays, or when the daylight savings time changed our time with respect to them, making us lose valuable meeting sessions.

This was the first semester in which this IPRO was offered, so there were certain things that made it have a better start. Having no previous background work it was more complicated to start working, but we hope that our work can help future IPROs get organized quicker and better.

This project was challenging because of the discrepancy in information that was available to our Lithuanian counterparts versus what was available to us in the United States. For instance, while the VGTU group was able to obtain carbon emission information for manufacturing and recycling of their vehicles, the IIT group could not access such data and hence had to use the GREET model as a guide for calculations. This difference could be associated with the fact that unlike Europe where the European Union requires that such information be made available, the United States doesn't require such information to be released by manufacturers. To have a common basis for the comparison of automobiles from both groups, we had to standardize calculations by using metric units. Our choice of automobiles was based on emission standards of California (Low Emission Vehicle, Super Ultra low Emission Vehicle, Zero Electric Vehicle etc) as well as ratings of the European Union.

Our team made significant progress towards achieving our goal of presenting a user friendly way of identifying automobiles with respect to the emission of green house gases over their lifetime. The calculations and data for the amount of CO_2 emitted during manufacturing, use and recycling are presented in tables and explained in the Analysis and Findings section of the paper.

6.0 Acknowledgements and References

Websites Used in Calculations for CO_2 emissions from fuels:
http://numero57.net/2008/03/20/carbon-dioxide-emissions-per-barrel-of-crude/
Steel production CO_2 emissions values
http://www1.eere.energy.gov/industry/steel/pdfs/theoretical_minimum_energies.pdf
Plastic types and production emission value numbers
http://www.ltu.se/polopoly_fs/1.5035!plastics%20-%20final.pdf
Breakdown of an average vehicle weight
http://msl1.mit.edu/esd123_2001/pdfs/class_materials/basecost.pdf
Basis for a lot of the calculations, it is based off of GREET
http://www.fueleconomy.gov/
Recycling and Manufacturing + Extraction CO_2 emissions data
http://www.greenmatrix.org/
GREET was used for a majority of the factors for CO_2 emissions
http://www.transportation.anl.gov/modeling_simulation/GREET/index.html

Appendix A: Calculations

Manufacturing

1. Steel

$$Car(lbs) \times (70\%) \times \left(\frac{1lb}{2.204kg}\right) \times \left(\frac{2kgCO_2}{kg\_steel}\right)$$

where : $\left(\frac{3.3kWh}{kg\_steel}\right) = \left(\frac{2kgCO_2}{kg\_steel}\right)$

2. Plastic

$$Car(lbs) \times (15\%) \times \left(\frac{1lb}{2.204kg}\right) \times \left(\frac{7.2kgCO_2}{kg\_plastic}\right)$$

where :

$$\left(\frac{12kWh}{kg\_plastic}\right) = \left(\frac{7.2kgCO_2}{kg\_plastic}\right)$$

3. Glass

$$Car(lbs) \times (3\%) \times \left(\frac{1lb}{2.204kg}\right) \times \left(\frac{0.6kgCO_2}{kg\_glass}\right)$$

where : $\left(\frac{0.985kWh}{kg\_glass}\right) = \left(\frac{0.6kgCO_2}{kg\_glass}\right)$

Manufacturing + Extraction of raw material used in car

1. Virgin Steel

$$\text{car weight(lbs)} \times 70\% \times \left(\frac{1\text{lb}}{2.204\text{kg}}\right) \times \left(\frac{13\text{kg } CO_2}{\text{kg\_steel}}\right)$$

where : $\left(\frac{3.3kWh}{kg\_steel}\right) = \left(\frac{2kgCO_2}{kg\_steel}\right)$

2. 25% Recycled Steel + 75% Virgin Steel

→ Conversion factor : 10kg CO_2/kg steel for virgin steel, 4kg CO_2/kg steel for recycled steel

$$\text{car weight(lbs)} \times 70\% \times \left(\frac{1\text{lb}}{2.204\text{kg}}\right) \times \left\{\left(75\% \times \left(\frac{10\text{kg } CO_2}{\text{kg\_virgin\_steel}}\right)\right) + \left(25\% \times \left(\frac{4\text{kg } CO_2}{\text{kg\_recycle\_steel}}\right)\right)\right\}$$

3. Plastic

→ Conversion factor : avg 34kg CO_2/kg plastic mix

$$\text{car weight(lbs)} \times 15\% \times \left(\frac{1\text{lb}}{2.204\text{kg}}\right) \times \left(\frac{34\text{kg } CO_2}{\text{kg\_plastic\_mix}}\right)$$

4. Glass

→ Conversion factor : tempered glass = 10kg CO_2/kg glass

$$\text{car weight(lbs)} \times 3\% \times \left(\frac{1\text{lb}}{2.204\text{kg}}\right) \times \left(\frac{10\text{kg } CO_2}{\text{kg\_tempered\_glass}}\right)$$

Assembly

1. UNESCO (United Nations)
- 20,000MJ per car
  - where : 1kWh/3,600J & 0.6kg $C0_2$/kWh

2. GREET (United States)
- 3.9 million Btu per car
  - where : 1kWh/3413Btu & 0.6kg CO_2/kWh

Tailpipe emissions

kg CO_2/lifetime: (150,000 mile/life)*(car petrol gal/mile)*(8.834 kg CO_2/gal)

→ Assumed 150,000 miles for vehicles life

$$\left(\frac{150{,}000 \text{ miles}}{\text{life}}\right) \times \left(\frac{1\text{gal\_gasoline}}{\text{mpg(mile)}}\right) \times \left(\frac{8.834 \text{ kg } CO_2}{1\text{gal\_gasoline}}\right)$$

kg CO_2/lifetime: (150,000 mile/life)*(car diesel gal/mile)*(10.493 kg CO2/gal)

→ Assumed 150,000 miles for vehicles life

$$\left(\frac{150{,}000 \text{ miles}}{\text{life}}\right) \times \left(\frac{1\text{gal\_diesel}}{\text{mpg(mile)}}\right) \times \left(\frac{10.493 \text{ kg } CO_2}{1\text{gal\_diesel}}\right)$$

Tailpipe emissions and fuel production

$$\frac{Car(TonsCO_2)}{1Year} \times \frac{907.185(Kg)}{1Ton} \times \frac{1Year}{15{,}000(Miles)}$$

→ Conversion factor: 907.185 kg/ton
Assumed car driven 15,000 miles/year

$$\frac{Car(KgCO_2)}{1Mile} \times \frac{150{,}000(Miles)}{Lifetime}$$

→ Assumed 150,000 miles for vehicles life

Fuel Production emissions

→ Fuel production kg CO_2

$$(\text{calculated tailpipe emission} + \text{fuel production emission}) - (\text{calculated tailpipe})$$

Appendix B: Budget

No money was spent during this IPRO.

Appendix C: Team Organization

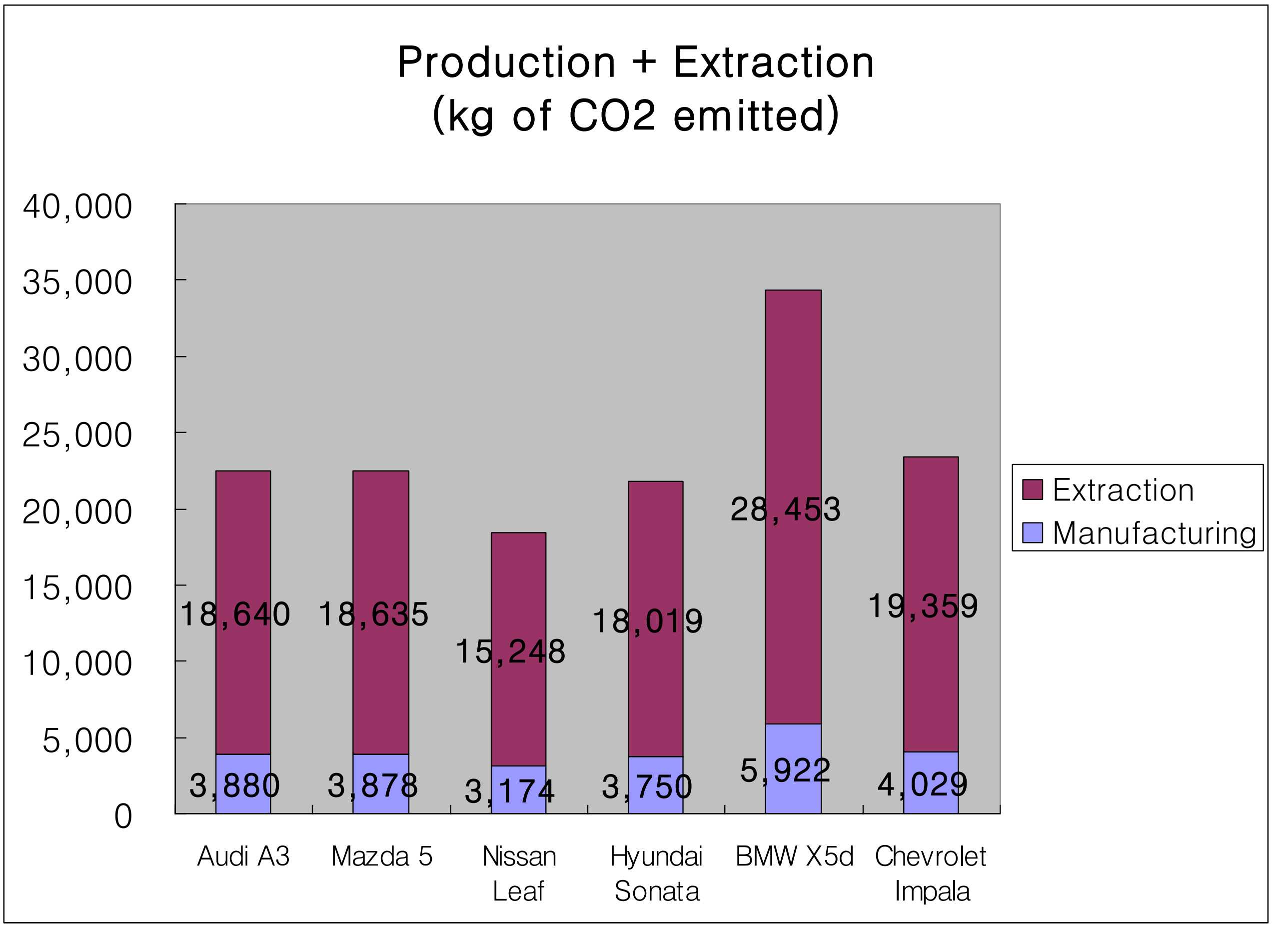
IPRO 322 Class Roster		
Bais, Rajiv	Political Science	rbais@iit.edu
Blagnytė, Rũta	Environmental Management and Clean Production	ruta.blagnyte@ymail.com
Burian, James	Mechanical Engineering	jburian@iit.edu
Choi, Lien	Molecular Biochemistry Biophysics	lchoi@iit.edu
Dũdaitė, Jolita	Environmental Management and Clean Production	joolitaa@gmail.com
Fournier, Andrew	Bioche Environmental Management and Clean Production mistry	afournie@iit.edu
Kalpokas, Vytautas	Environmental Management and Clean Production	wytukas@gmail.com
Kargis, Mindaugas	Environmental Management and Clean Production	kargis.mindaugas@gmail.com
Mora, Andres	Computer Engineering	amora2@iit.edu
Navickaitė, Rũta	Environmental Management and Clean Production	navickaite.ruta@gmail.com
Rafalko, Susan	Computer Engineering	srafalko@iit.edu
Savickas, Remigijus	Environmental Management and Clean Production	rsavickas@gmail.com

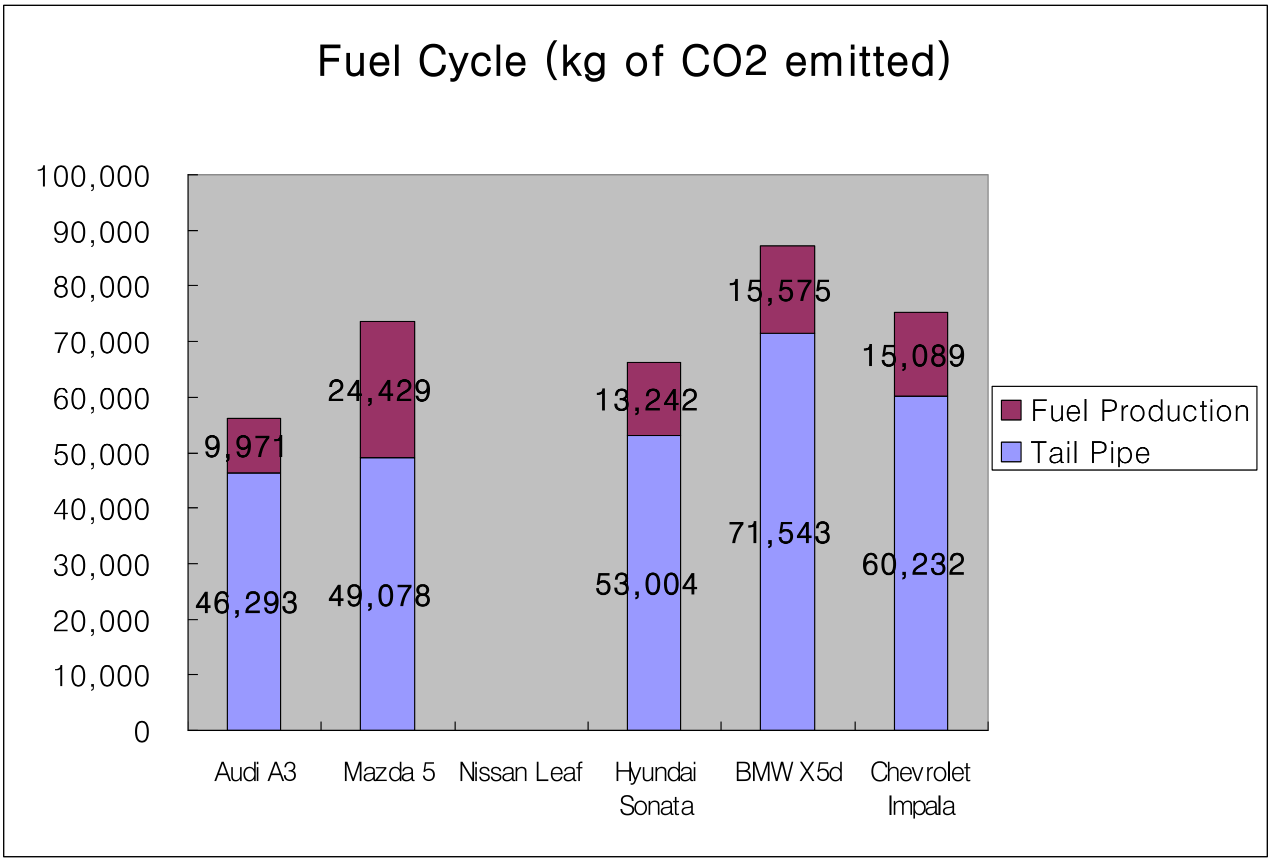
Shonekan, Morayomola	Electrical Engineering	mshoneka@iit.edu
Swanston, Seantoia	Political Science	sswansto@iit.edu
Vasilev, Teodora	Architecture	tvasilev@iit.edu
Yi, Won-Jae	Computer Engineering	wyi3@iit.edu
Yu, Mary	Biomedical Engineering	myu8@iit.edu

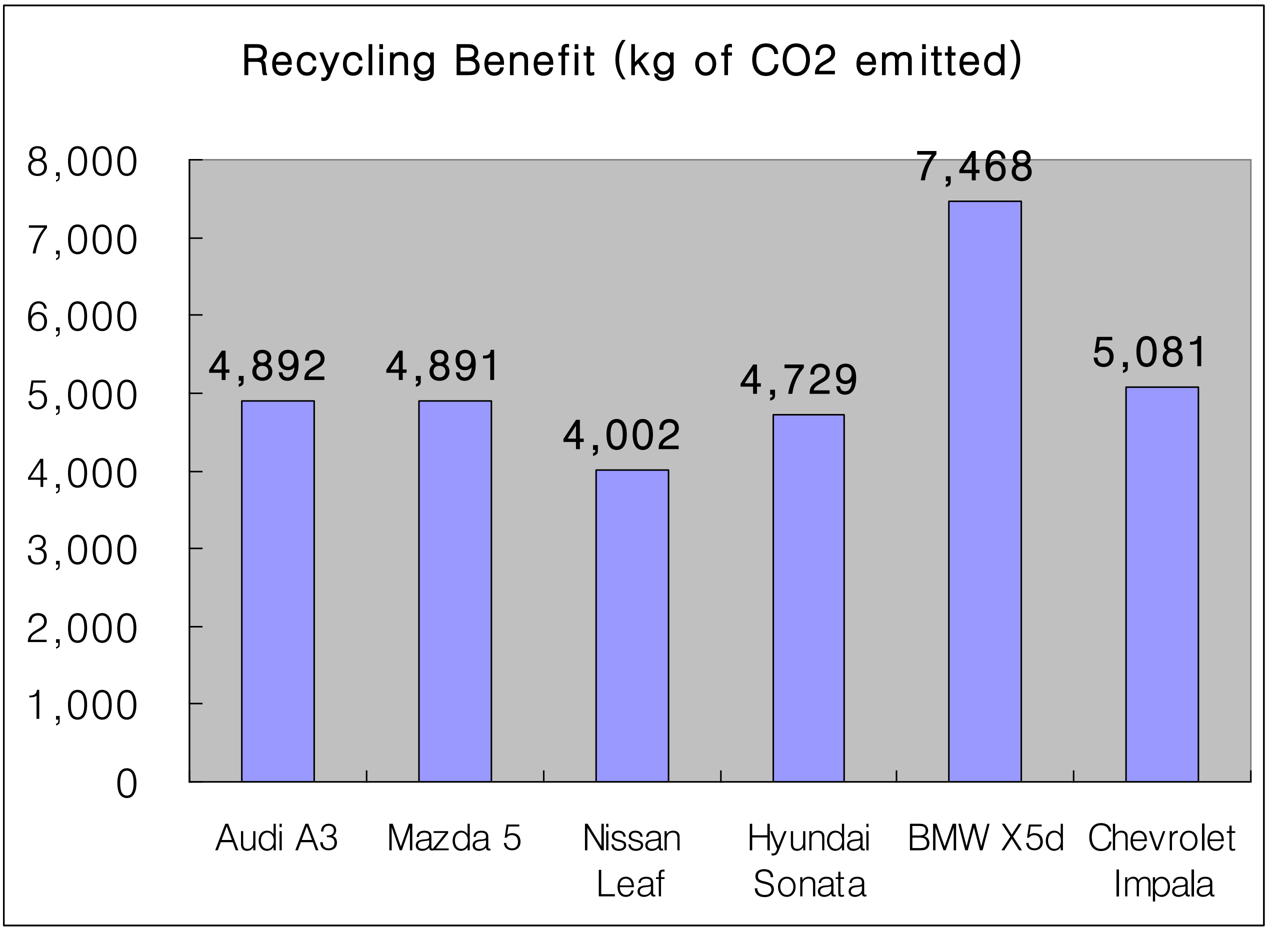
Appendix D: Graphs and Tables

Percentage Breakdown (%)			
Car	Production	Fuel-Cycle	Recycling
Audi A3	26	74	6
Mazda 5	21	79	5
Nissan Leaf	80	20	19
Hyundai Sonata	22	78	6
BMW X5d	25	75	6
Chevrolet Impala	21	79	5

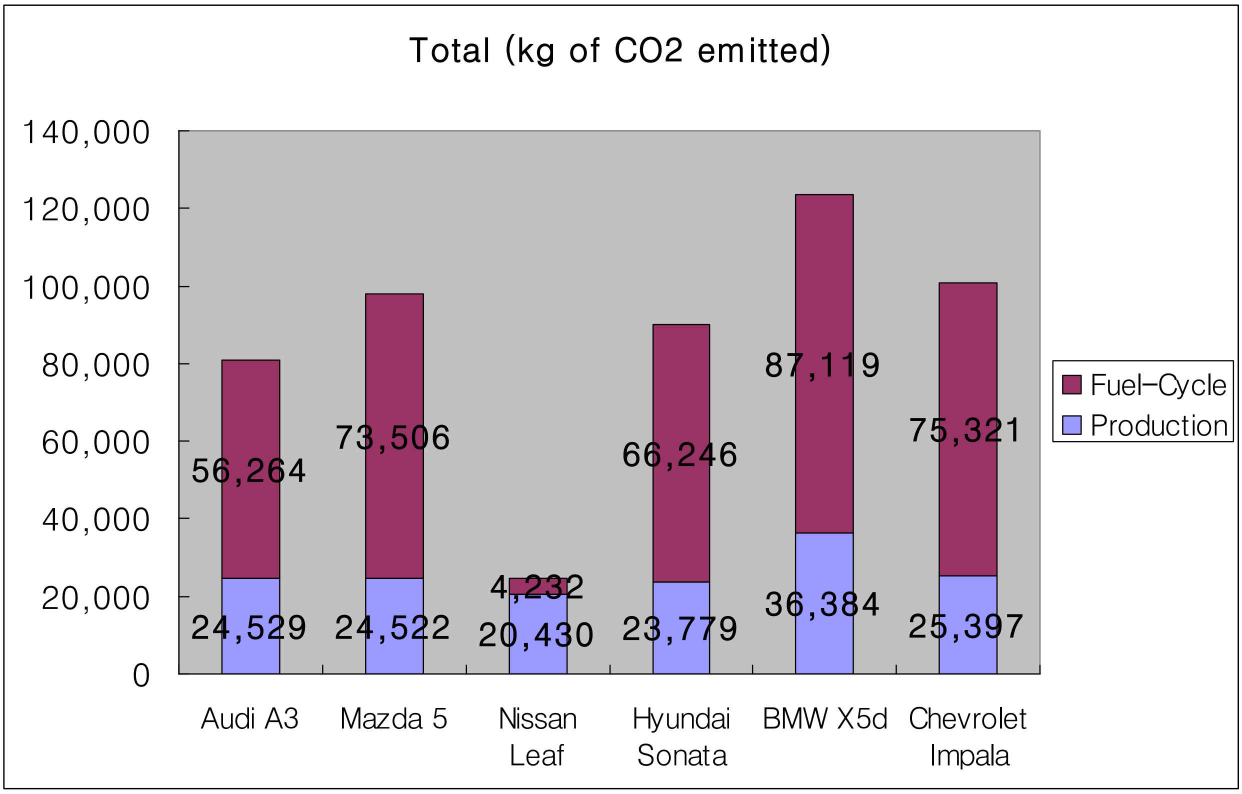
Car	Production(kg)	Fuel-Cycle(kg)	Total avg. Emission(kg)
Audi A3	24,529	56,264	75,900
Mazda 5	24,522	73,506	93,138
Nissan Leaf	20,430	4,232	20,661
Hyundai Sonata	23,779	66,246	85,296
BMW X5d	36,384	87,119	116,035
Chevrolet Impala	25,397	75,321	95,638


Production + Extraction
(kg of CO2 emitted)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
18,640
18,635
15,248
18,019
28,453
19,359
3,880
3,878
3,174
3,750
5,922
4,029
Audi A3
Mazda 5
Nissan Leaf
Hyundai Sonata
BMW X5d
Chevrolet Impala
Extraction
Manufacturing

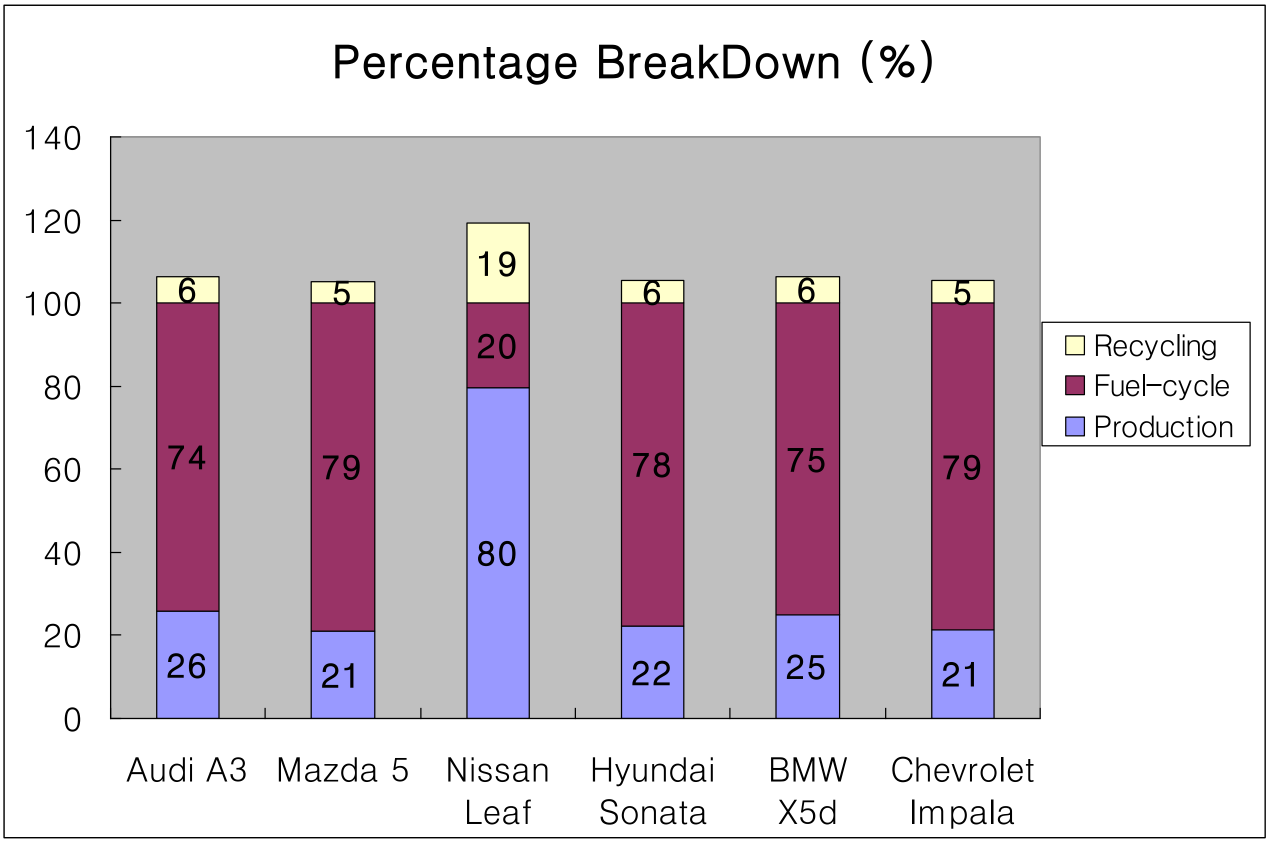

Fuel Cycle (kg of CO2 emitted)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
9,971
24,429
13,242
15,575
15,089
46,293
49,078
53,004
71,543
60,232
Audi A3
Mazda 5
Nissan Leaf
Hyundai Sonata
BMW X5d
Chevrolet Impala
Fuel Production
Tail Pipe



Recycling Benefit (kg of CO2 emitted)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
4,892
4,891
4,002
4,729
7,468
5,081
Audi A3
Mazda 5
Nissan Leaf
Hyundai Sonata
BMW X5d
Chevrolet Impala



Total (kg of CO2 emitted)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
56,264
24,529
73,506
24,522
4,232
20,430
66,246
23,779
87,119
36,384
75,321
25,397
Fuel-Cycle
Production
Audi A3
Mazda 5
Nissan Leaf
Hyundai Sonata
BMW X5d
Chevrolet Impala



Percentage BreakDown (%)
140
120
100
80
60
40
20
0
6
74
26
5
79
21
19
20
80
6
78
22
6
75
25
5
79
21
Audi A3
Mazda 5
Nissan Leaf
Hyundai Sonata
BMW X5d
Chevrolet Impala
Recycling
Fuel-cycle
Production

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Faculty of Environmental Engineering

Department of Environmental Protection

Carbon footprint of Automobiles

Prepared by: AVGmfu09 group students

ABSTRACT

Climate change is already happening and represents one of the greatest environmental, social and economic threats facing the planet. The basic source, which causes climate change are greenhouse gases (GHG). Therefore, GHG are emitted during life cycle of automobiles.

In this project it is chosen European automobiles such as Volkswagen Golf, BMW 3 series, Fiat Punto, Peugeot 407 and Opel Astra. Moreover, CO2 emissions are evaluated according to different phases, like raw material production, manufacturing, vehicle use and disposal and recycle of automobiles. By the data and calculations of total CO2 emissions during life cycle of cars, it is shown, which automobile is the greenest and which car has the biggest impact on environment and human health. Furthermore, the analyses of emitted CO2 are proposed in the simple, visible and understandable way for the customers.

CONTENT

INTRODUCTION

Global climate change caused by increasing concentrations of atmospheric carbon dioxide is one of the most significant threats facing our world today. Within transportation, light-duty vehicles produce the largest share of emissions, including 64% of carbon dioxide (CO2) and significant shares of other greenhouse gases (GHGs) (A study...2008).

Emissions from an individual car are generally low, relative to the smokestack image many people associate with air pollution. But in numerous cities across the country, the personal automobile is the single greatest polluter, as emissions from millions of vehicles on the road add up. Driving a private car is probably a typical citizen's most "polluting" daily activity (Automobiles and... 2010).

When many people think about automotive (GHGs), they tend to focus solely on tailpipe emissions or what vehicles emit during their driving or use phase. The power to move a car comes from burning fuel in an engine. Pollution from cars comes from by-products of this combustion process (exhaust) and from evaporation of the fuel itself. For a complete understanding of how a material affects the environment – from its initial production, use and end-of-life disposal or recyclability phases – many scientists are adopting a Life cycle assessment.

Team Objectives:

- To find the best fuel efficient cars by observing the following fuel types: diesel and petrol.
- Research materials such as aluminum, steel, plastic, rubber and glass in respect to the amount of green house gasses are emitted throughout the production process.
- Examine the Carbon foot print of the cars in use phase.
- To work collaboratively and effectively to achieve the outlined tasks according to protocols.
- To prepare final report and presentation of carbon footprint during life cycle of European automobiles (Volkswagen Golf, BMW 3 series, Opel Astra, Peugeot 407 and Fiat Punto).

1. Life cycle assessment

Life Cycle Assessment (LCA) models the complex interaction between a product and the environment from cradle to grave. It is also known as life cycle analysis or ecobalance (Life cycle... 2010).

LCA methodology provides auto manufactures with a road map for reducing the GHG emitted during the raw material and production phases and the lifetime GHG emissions of their products including end – of – life recycling credits. The research of Dr. Ronald Geyer of the University of California Santa Barbara confirms that to truly reduce vehicles total GHG output, every pase of the material must be considered.

Basic stages of automobile life cycle are:

- Materials production;
- Vehicle manufacturing;
- Vehicle use;
- Vehicle disposal/recycle.

Therefore, it is needed to make steps for life cycle assessments:

1. Planning. Statement of objectives, definition of the product and its alternatives, choice of system boundaries, choice of environmental parameters, choice of aggregation and evaluation method, strategy for data collection.

2. Screening. Preliminary execution of the LCA, adjustment of plan

3. Data collection and data treatment. Measurements, interviews, literature search, theoretical calculations, database search, qualified guessing, computation of the inventory table.

4. Evaluation. Classification of the inventory table into impact categories, aggregation within the category, normalization, weighting of different categories,

5. Improvement assessment. Sensitivity anglysis, improvement priority and feasibility assessment.

It is generally recognized that the first stage is extremely important. The result of the LCA is heavily dependent on the decisions taken in this phase. The screening LCA is a useful step to check the goal-definition phase. After screening it is much easier to plan the rest of the project (Life cycle... 2010).

2. Materials production

The car is a mix of materials: glass windows, rubber tires, lead batteries, copper wires, as well as traces of zinc, magnesium, tin, platinum and cobalt. However, steel is still the single most important material in cars. It is strong, durable and malleable. On the flip side, though, it is relatively heavy. For this reason, car manufacturers have been trimming down on its use.

In order to estimate the amount of energy used during vehicle production, we first had to identify the materials used in the vehicles. Energy use for material production can be estimated on the basis of information in the open literature or obtained from producers (Development application... 2010).

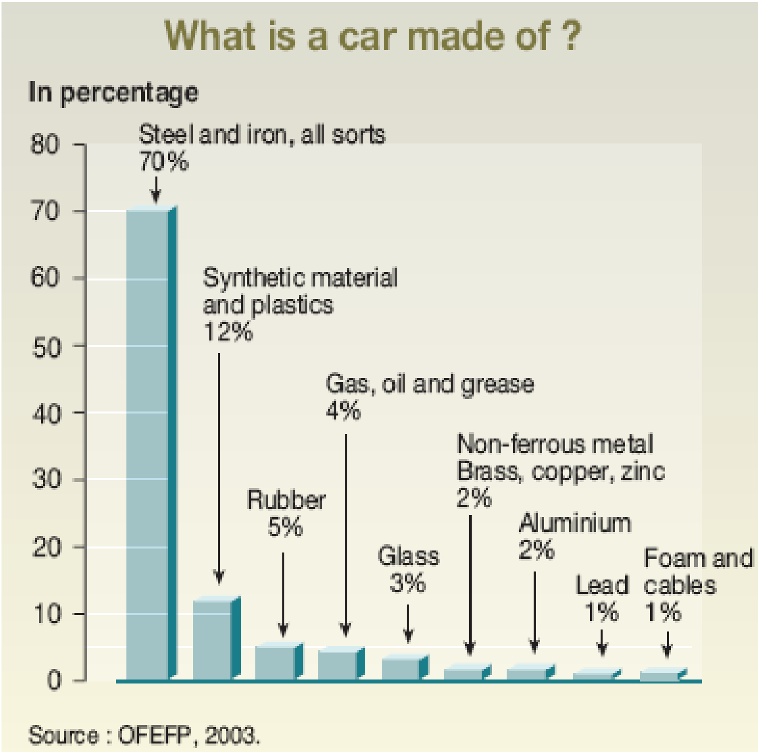


Figure 2.1 Material used in car production

Ecologic review for a 1,000 kilogram car produced in 1994; estimated over 10 years; assuming a total mileage of 150,000 kilometers and an average fuel consumption of 8.1 liters per hundred kilometers. (From production to disposal of the car).

It is chosen five kind of automobiles as follows: BMW, Volswagen Golf, Peugeot 407, Fiat Punto and Opel Astra. According to statistic data, the sales of Fiat Punto are 379 thousand cars in a year. Moreover, the sales of Opel Astra reach 402 thousand automobiles. Furthermore, in the tenth place in Europe, according to selling of automobiles are BMW 3 series (295 thousand) and the best selling are automobiles of Peugeot 407, which takes the first place with selling of 437 thousand automobiles in a year. Just a little bit less sales has Volswagen Golf (435 thousand) and it takes the second place in Europe (Europe's 10 2010).

The weight of cars depends on sort of automobiles, for instance BMW 3 series weigh 1865 kg, but BMW 3 series weigh 1560 kg. Moreover, Peugeot 407 has weight of 1624 kg and other sort of Peugeot 407 weigh 1675 kg. Additionally, Fiat Punto has weight of 1030 kg and it takes the last place by weight of all our studied automobiles. Furthermore, the weight of Opel Astra is around 1500 kg and the weight of Volswagen Golf is 1200 kg (Auto tau 2010).

2.1 Steel

By nature, as an industrialized process, steelmaking generates a variety of air emissions, including air toxics and greenhouse gasses (GHG). In 2003, the American Iron and Steel Institute joined Climate VISION, a voluntary program administered by DOE to reduce greenhouse gas intensity. Between 2002 and 2003, the industry reduced its energy intensity per ton of steel shipped by approximately 7 percent. Because of the close relationship between energy use and GHG emissions, the industry's aggregate CO2 emissions per ton of steel shipped were reduced by a comparable percentage during this period.

In 2003, 75 facilities in the sector reported air toxics releases of 2.1 million pounds. This represents a 70 percent decrease from volumes reported in 1994. Toxicity-weighted results for air toxics releases were reduced by 69 % over that same period. Steelmaking generates GHG emissions both directly and indirectly. For example, the basic oxygen furnace steelmaking process produces CO2 when transforming coke and iron ore into iron. Additionally, both minimills and integrated mills consume significant amounts of electricity, the generation of which often results in GHG emissions. Despite increased production of steel, between 1994 and 2003, the industry's GHG emissions fell by more than 25 %. Additionally, steel contains 70 % of cars body. (Sustainable steel 2010).

2.2 Plastic

Even if cars soon start running entirely on electricity or hydrogen, they'll still need 100 gallons or more of oil to make their plastic parts, such as seats, dashboards, bumpers, and engine components. And some day that plastic may be recycled back into fuel. Cars of old were mostly steel, but the use of lightweight alternatives has dramatically increased in the last couple of decades. Whereas almost no plastic could be found on a car from the 1950s, today's automobiles have more than 260 pounds (120 kilograms) of plastic on board, according to the transportation energy data book. "It is expected that high oil prices and strict CO2 standards will accelerate the growth in plastic use," says Aafko Schanssema from PlasticsEurope, a plastic industry group based in Belgium.

Although different plastics have different recipes, it takes roughly 0.4 gallons of crude oil to make 1 pound of plastic. Globally, around 8 percent of the oil that comes out of the ground is used to make plastic. Additionally, in Europe, the average car currently has closer to 11 percent plastic, Schanssema said (Life science 2010).

2.3 Rubber

Rubber is used to produce tires in car manufacturing and rubber considered 5 % of all automobile materials. Rubber powder from car tires, produced by the plant, is mixed with virgin rubber (15 % recycled rubber) for applications in re-treading compounds for tires and for the production of flexible rubber products. Up to now, each month 500 tons of passenger car tires are granulated. Most of this material is burnt in a cement kiln. Selected material has successfully been used for several applications such as indoor sporting floors. Interest has been showed by several retreading companies to buy the recovered rubber. The annual capacity of 10.000 tons will initially be utilized for 6000 tons passenger car tires. This quantity will gradually be raised till the total capacity has been reached. It is expected that this will be achieved in a period of 5 years.

2.4 Aluminium

The aluminum industry recognizes the need for a drastic reduction of the GHG emissions to counter ongoing climate changes and has taken appropriate actions: In the production of primary aluminum, continuous efforts to reduce specific GHG emissions led to significant savings: -7.7% between 2002 and 20051. Furthermore, the aluminum industry recycles all available scrap, saving 95% of primary energy input and GHG emissions. Light weighting is one of the most effective and directly impacts CO2 emissions, as 100kg saved on the mass of a car is equivalent to a reduction of 9 grams of CO2 per kilometer.

Today's cars contain 132 kg of aluminum

Besides well-known aluminum intensive cars like the Audi A8, which contains about 520 kg of aluminum or the Jaguar XJ, many cars contain significant amounts of light metals. A recent study by Knibb, Gormezano & Partners (KGP) in cooperation with the European Aluminum Association shows that the amount of aluminum used in new European cars has risen from 50 kg in 1990 to 132 kg in 2005 and is predicted to grow by another 25 kg by 2010. The study is based on the analysis of car models representing a European production volume of 15 million units in 2005. Key results are summarized in Figure 2 (Aluminum European 2010).

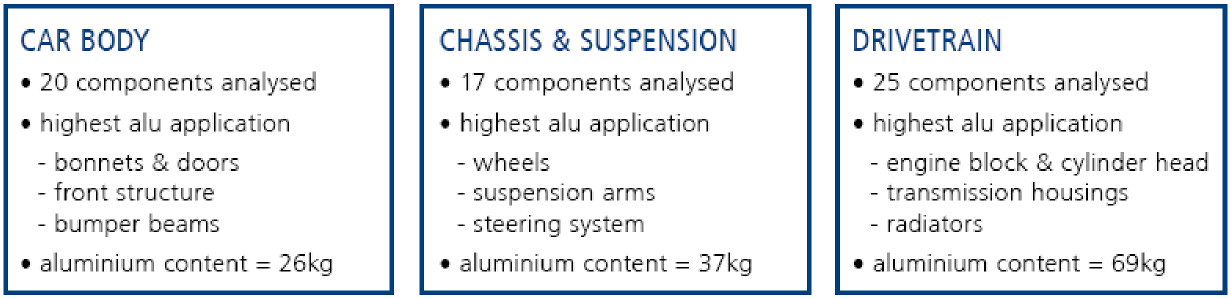


Figure 2.2 Study for cars produced in 2005 (Aluminum European)

2.5 Emissions during pre – manufacturing process.

Materials that compete with AHSS for automotive light-weighting are costly to the environment. This is especially important, since many of the most harmful gasses are present in the production of competitive materials. For example, aluminium, contributes high levels of perfluorocarbons, and magnesium is responsible for the emission of sulfur hexafluoride. GHG emissions from steel production consist of only carbon dioxide. Figure 2.3 below illustrates the drastically different levels of GHG emissions from the material production stage of competing automotive materials. Please notice that all of the GHG data is shown in carbon dioxide equivalents (CO2eq), which includes carbon dioxide plus the carbon dioxide equivalent of other emissions such as PFCs.

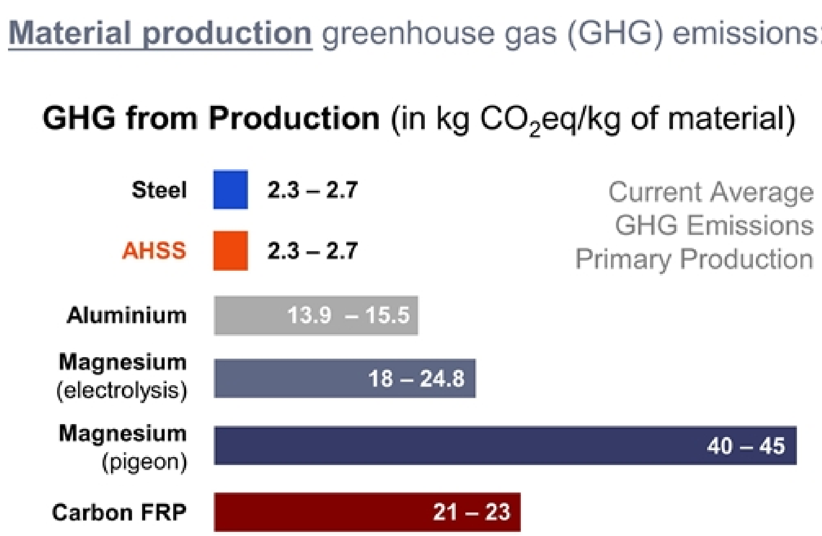


Figure 2.3 Material production GHG emissions (Life cycle 2010)

Alternative "materials such as aluminum, magnesium and plastics, may weigh less than advanced high-strength steel. However, producing those materials requires far more energy, thus creating 5 to 20 times more GHG emissions per kg of material than compared with steel.

Material production for alternative material vehicles will load the environment with significantly more GHG emissions than that of a steel vehicle and these override any benefits that may be gained through fuel efficiency improvements (Life cycle 2010).

1.1 Table. Emissions in kg of CO2 from raw material manufacturing

	Steel and iron	**Synthetic materials and plastic**	**Rubber**	**Gas, oil and grease**	**Glass**	**Non-ferrous metal**	**Aluminium**	**Lead**	**Foam and cables**	**Total, kg CO2**
Volswagen Golf	2100	864	2640	147,12	230,4	47,35	352,8	25,2	31,2	6258,07
BMW 3 series	3263,75	1342,8	4103	228,65	358,08	73,59	548,31	39,17	48,49	10005,84
Peugeot 407	2842	1169,28	3572,8	199,1	311,81	64,08	477,46	34,1	42,22	6512,98
Opel Astra	2625	1080	3300	183,9	288	59,19	441	31,5	39	7804,50
Fiat Punto	1802,5	741,6	2266	126,28	197,76	40,64	302,82	21,63	26,78	5526,01

From the table 1.1 it can be seen, that the biggest impact on environment during raw materal production phase is producing BMW 3 series (it takes 10005,84 kg CO2) and the lowest emissions are making Fiat Punto (it takes 5526,01). There are a lack of information about carbon dioxide emissions during pre-manufacturing processes. Therefore, all data for each raw material were calculated individually according to a mass of automobile, quantity of raw material which constitutes the automobile and the coeficient of different raw material.

3. Vehicle manufacturing

The industry has come a long way on all sustainability criteria, and sustainable mobility remains a key part of manufacturers' long-term plans.

During the last ten years of relative economic stability, manufacturers delivered fifty new CO_2 reduction technologies to market. Improved engine design, the use of lightweight new materials, development of alternatively-fuelled vehicles and in-vehicle driver aids, these examples have helped slash average new car CO_2 by almost 20% in just thirteen years. Policy makers have a responsibility to protect the interests of citizens and safeguard the natural environment. But they are also responsible for creating an environment in which businesses thrive. The interdependent nature of both objectives is today perhaps more evident than ever. (Tenth 2009)

In 2009 December, while coming to terms with the worst economic crisis in decades, car makers were presented with the new car CO_2 regulation, a hugely challenging framework and the latest in a line of over 80 European Directives and 115 UNECE pieces of legislation concerning motor vehicles. (Tenth 2009)

Reducing man-made CO_2 emissions is a complex issue. There are no simple solutions and no national boundaries. Every industry and individual must accept responsibility and embrace collective action. The automotive industry fully accepts the part it must play in finding technology solutions that continue to drive down CO_2 and other climate change emissions. It is actively working to reduce CO_2 emissions from cars and commercial vehicles in-use, but also from its production sites, logistics and transport operations. (ACEA 2009). On the figure 3.1 typical automobile manufacturing processes is shown:

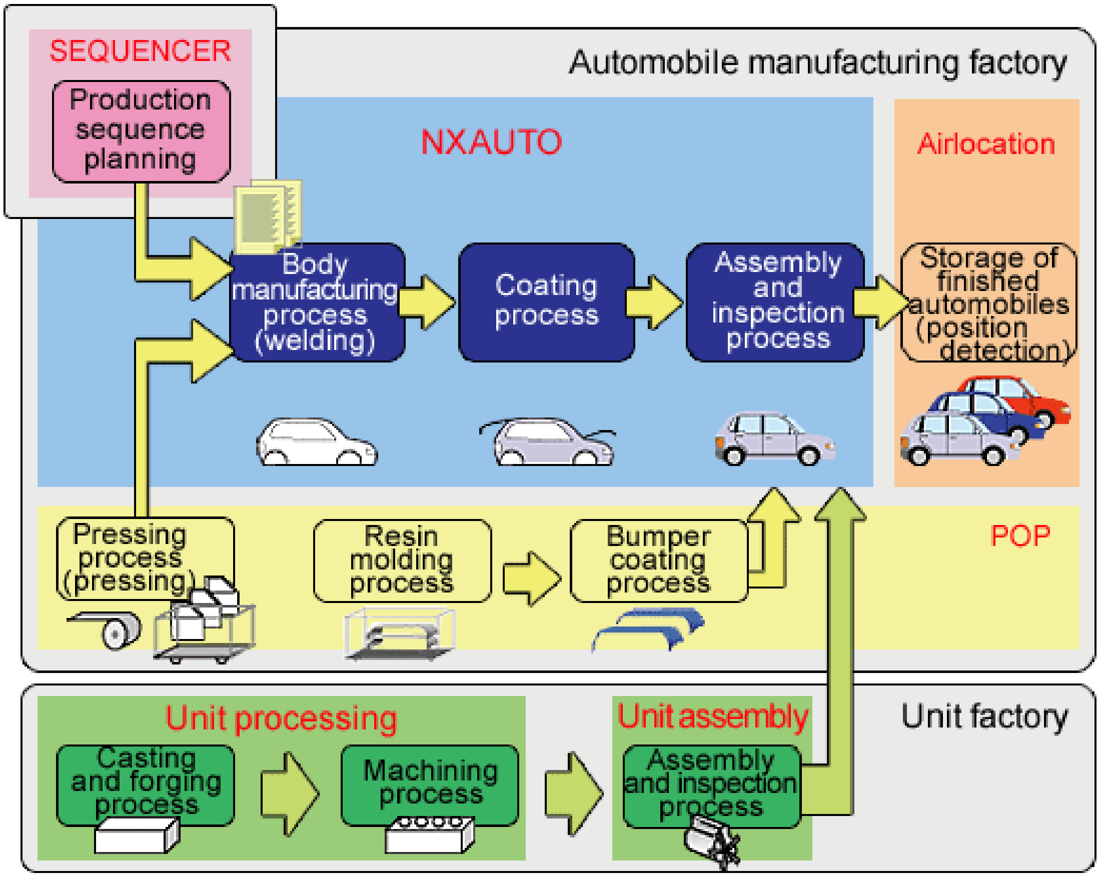


Figure 3.1 Automobile manufacturing (Solutions for... 2010)

Explanation of automobile manufacturing process

- *NXAUTO*: Controls the manufacturing process for vehicles based on real-time tracking.
- *SEQUENCER*: Accurately drafts production sequence plans for automobile manufacturing factories.
- *Air Location*: Controls the storage of completed automobile yards on a real-time basis.
- *POP*: Controls production instructions and result collection for the manufacturing process for sub-lines.
- *Unit processing*: Controls the casting, forging and processing processes for unit products in a lot production system.
- *Unit assembly*: Controls the assembly and inspection process for unit products in a mixed-flow production system.

On table 3.1 CO_2 emissions during manufacturing are shown.

Table 3.1. CO_2 emissions during production

No.	Sort of automobiles and vehicles	Manufacturing, kg CO_2/vehicle	Referencies
1.	VW Golf V, 2.0 TDI	227,19	VW sustainability Report 2009
2.	VW Golf V, 2.0 GTI		
3.	BMW 3 Series 320d	820	BMW sustainability report 2009
4.	BMW 3 Series 320i		
5.	PEUGEOT 407 1.6hdi	230	Peugeot Sustainability Report 2008
6.	PEUGEOT 407 2.0i		
7.	FIAT Punto 1.9 JTD	73,52	Fiat sustainability report 2008
8.	FIAT Punto 1.8i 16V		
9.	OPEL Astra 2.0 DTI 16V	242,34	Opel sustainability report 2008
10.	OPEL Astra 2.0 16V		

As we see on table 3.1. the biggest emitter from selected cars in manufacturing is BMW. The lowest polluter is Fiat Punto due to Fiat corporation is using a lot of implements, such as wind energy, more effective waste management, technical plant innovations (heat recovery systems, low emission energy sources). (Sustainability 2008).

Opel, Peugeot and Volkswagen manufacturing takes almost equal parts of CO_2 emissions.

On Figure 3.2. graphic view of comparison between selected cars is shown.

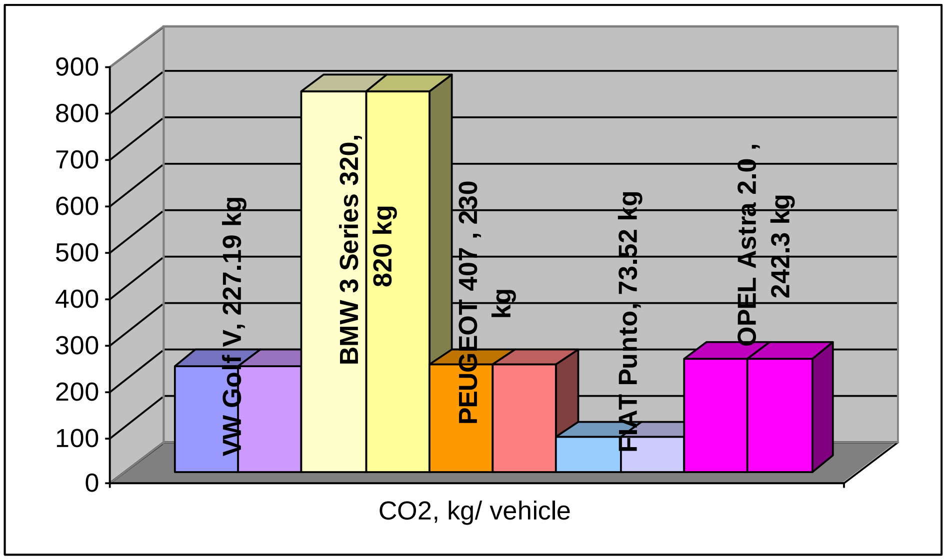


Figure 3.2. Comparison between selected cars

As we see on figure 3.2. – BMW CO_2 emissions are increased very significantly comparing it with other car models.

On table 3.2. total CO_2 emissions during pre-manufacturing and manufacturing processes in sum is shown.

Table 3.2. Total CO_2 emissions during pre-manufacturing and manufacturing processes

No.	Sort of automobiles and vehicles	Manufacturing, kg CO2/vehicle
11.	VW Golf V, 2.0 TDI	6485
12.	VW Golf V, 2.0 GTI	
13.	BMW 3 Series 320d	10825
14.	BMW 3 Series 320i	
15.	PEUGEOT 407 1.6hdi	6743
16.	PEUGEOT 407 2.0i	
17.	FIAT Punto 1.9 JTD	5599
18.	FIAT Punto 1.8i 16V	
19.	OPEL Astra 2.0 DTI 16V	8047
20.	OPEL Astra 2.0 16V	

As we see on table 3.2. the biggest emitter from selected cars in manufacturing is BMW. The lowest polluter is Fiat Punto due to Fiat group implemented technologies. The information were taken of automobiles home pages.

On Figure 3.3. graphic view of comparison between selected cars is shown.

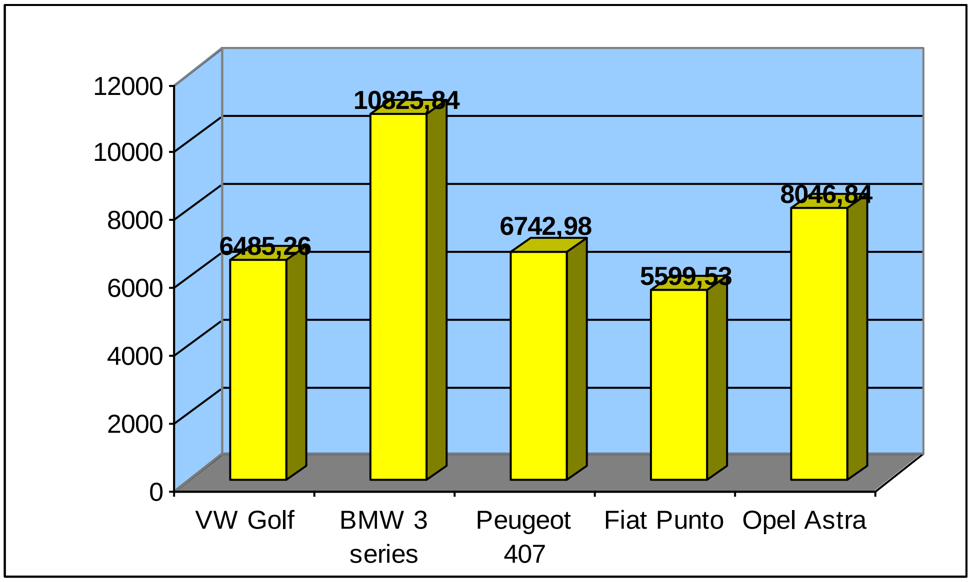


Figure 3.3. CO_2 emissions during manufacturing

As we see on figure 3.3. – BMW CO_2 emissions are increased very significantly comparing it with other car models.

4. Vehicle use

The main CO2 come from using. The table shows average emissions of CO2, but there are a lot of factors that can change the table: driving conditions (close though the sea, up in the mountains, colder or hotter climate) but we take an average data that the manufacturers present.

4.1 Table. Tailpipe emissions

Sort of automobiles and vehicles	Tailpipe		References
	Diesel, CO2 kg	Petrol, CO2 kg	
VW Golf V, 2.0 TDI	32700	-	
VW Golf V, 2.0 GTI	-	43200	(Volswagen... 2010)
BMW 3 Series 320d	35700	-	

BMW 3 Series 320i	-	38400	(BMW... 2010)
PEUGEOT 407 1.6hdi	38700	-	
PEUGEOT 407 2.0i	-	38700	(Peugeot 2010)
FIAT Punto 1.9 JTD	35700	-	
FIAT Punto 1.8i 16V	-	33300	(Fiat... 2010)
OPEL Astra 2.0 DTI 16V	40800	-	
OPEL Astra 2.0 16V	-	66900	(Opel... 2010)

It is accepted, that the average of the distance, which the car goes on its exploitation time is 300000 km. From the table 4.1 it can be seen, that the biggest emissions of CO2 to the atmosphere are from the Opel Astra and exhaust are 40800 kg CO2 using diesel and 66900 kg CO2 using petrol.

There is some information about CO2 emissions from use part in Europe:

- **Limit value curve**: the fleet average to be achieved by all cars registered in the EU is 130 grams per kilometer (g/km). A so-called limit value curve implies that heavier cars are allowed higher emissions than lighter cars while preserving the overall fleet average.
- **Phasing-in of requirements**: in 2012, 65% of each manufacturer's newly registered cars must comply on average with the limit value curve set by the legislation. This will rise to 75% in 2013, 80% in 2014, and 100% from 2015 onwards (Environment, air... 2010).

Greenest and meanest vehicles

Vehicles are analyzed on the basis of a “Green Score,” a singular measure that incorporates unhealthy tailpipe emissions, fuel consumption, and emissions of gases that cause global warming.

The “*greenest vehicle*” title goes once again to Honda’s natural gas-powered Civic GX, while the Toyota Prius and the Honda Civic Hybrid claim spots two and three. New arrivals to the “Greenest” list this year are the Honda Insight, the Ford Fusion/Mercury Milan Hybrid (named the 2010 North American Car of the Year), and the Hyundai Accent Blue. The remainder of the “Greenest” list is comprised largely of highly fuel-efficient conventional vehicles such as

Smart Fortwo Convertible at number four and the Chevrolet Cobalt XFE and its Pontiac G5 XFE twin at number ten.

Just missing out on inclusion in the top-12 "Greenest" again this year are the diesel-powered Volkswagen Jetta and Jetta Sportwagen, part of a crop of “clean diesels” introduced in the United States last year. “While clean diesels once again perform well on our annual ranking, high prices both for the vehicles and for diesel fuel have kept them from really catching on thus far. They’re not having the impact in the U.S. that they have had in Europe, and as a result, manufacturers are scaling back production and promotion of diesels,” said Vaidyanathan.

The “*Meanest*” list this year remains largely unchanged from 2009. It is comprised once again of a variety of heavy-duty trucks and SUVs and luxury European vehicles. The Lamborghini Murcielago tops the list this year with a Green Score of 18.

5. Automobile disposal/recycle

Automobile manufacturing has increased in the last 20 years, reaching about 58 million units
(Excluding commercial vehicles) in 2000. According to estimates by the Organization for Economic Cooperation and Development (OECD), the total number of vehicles in OECD countries was expected to grow by 32% from 1997 to 2020. Automobile production is more or less equally distributed between North and South America, Europe, and Asia. Today, recycling of cars is driven not only by economic and technological factors but also by social and environmental concerns. In other words, the automobile industry is shifting toward sustainable waste management (End-of life 2003).

Automobiles are the most recycled consumer product. Each year, the steel industry recycles more than 14 million tons of steel from end-of-life vehicles. This is equivalent to nearly 13.5 million automobiles. When comparing the amount of steel recycled from automobiles each year to the amount of steel used to produce new automobiles that same year, automobiles maintain a recycling rate of nearly 100 percent (Recycling scrapped 2010).

The Directive on end-of-life vehicles (2006/2015) aims to reduce the amount of waste from vehicles (cars and vans) when they are finally scrapped. In particular, it includes tightened environmental standards for vehicle treatment sites; requires that last owners must be able to dispose of their vehicle free of charge from 2007; restricts the use of hazardous substances in both new vehicles and replacement vehicles parts; and sets rising reuse, recycling and recovery targets for the setting (Recycling end-of-life 2009).

The End of Life Vehicles (ELV) Directive (Fig. 5.1) aims to reduce the amount of waste produced from vehicles when they are scrapped. Around two million vehicles reach the end of their life in the UK each year. These vehicles are classed as hazardous waste until they have been fully treated (End-of-Life 2010).

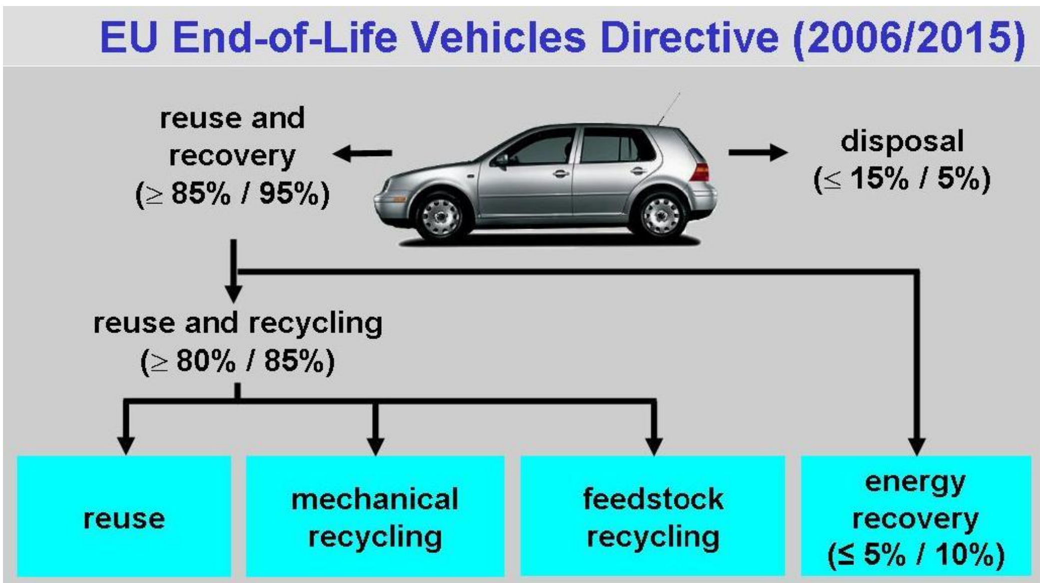


Figure 5.1. EU End-of-Life Vehicles Directive (End-of-Life…2010)

The directive requires ELV treatment sites to meet stricter environmental standards.

The last owner of a vehicle must be issued with a Certificate of Destruction for their vehicle and they must be able to dispose of their vehicle free of charge. Vehicle manufacturers and importers must cover all or most of the cost of the free take-back system**.**

It also sets higher reuse, recycling and recovery targets and limits the use of hazardous substances in both new vehicles and replacement vehicle parts (End-of-Life…2010).

5.1 Recycling of individual components

Treatment operations in order to promote recycling (according to Directive 2000/53/EC of the European parliament and of the council) (Official Journal 2000):

- removal of catalysts;

- removal of metal components containing copper, aluminum and magnesium if these metals are not segregated in the shredding process;
- removal of tires and large plastic components (bumpers, dashboard, fluid containers, etc), if these materials are not segregated in the shredding process in such a way that they can be effectively recycled as materials;
- removal of glass.

Metals

Scrap metal recycling is one of the most recyclable products. Most metals only have to be melted down and then reformed into other products, making its life cycle potentially endless. Recycling makes a substantial saving on landfill space requirements and it helps conserve the world's resources. To take steel as an example, melting down one tonne of recycled steel cans uses only 25% of the energy needed to melt enough ingredients to make one tonne of all-new steel. Using old steel cans to make new steel also preserves energy and resources. For every tonne of scrap steel recycled, around 1.5 tonnes of iron ore, one tonne of coke and half a tonne of limestone are saved in the production of a tonne of steel (Scrap metal 2010).

Currently about 98% of the metals in a car are recycled. These metals are recovered by the vehicle shredding industry and subsequently utilized by the steel industry and re-smelting plants (Car recycling…2010).

Plastics

The most common automotive plastics types are polypropylene (PP), polyethylene (PE), polyurethane (PU) and polyvinylchloride (PVC). PP accounts for approximately 41% of all car plastics (common in bumpers, wheel arch liners and dashboards), and like PE and PU (most common in seat foam) it is easily recycled (Car recycling 2010).

Glass

Glass constituting approximately 3% of a vehicles weight, in excess of 55,000 tonnes of automotive scrap glass were theoretically available for recycling (Car recycling 2010).

Rubber

Tires account for around 3.5% of the weight of an average, and as a controlled waste under the Environmental Protection Act 1990, a Duty of Care is placed upon waste producers to ensure that waste material is disposed of safely through registered carriers to licensed sites. According to the Used Tyre Working Group's 2001 survey 22% were recycled, 8.3% went to energy recovery, 9.9% were retreaded, 16% were reused and 3.3% were used in landfill engineering. The remainder (approximately 40%) will have been land filled, stockpiled or illegally disposed of (Vehicle and 2000).

Current recycling rates vary from country to country due to differences in the recycled/recovered materials markets, labor costs, landfill costs, and the levels of quality and professionalism in collection and dismantling, at treatment facilities and in technology. This explains the necessity for matching the early stages of Design for Recycling with current economical sustainable practices (Car recycling 2010).

5.2 Recycling processes of automobiles

BMW 3 series

Analysis of the work processes needed to dispose of and recycle today's end-of-life vehicles has resulted in new, more effective methods, in purpose-designed tools and in optimizing dismantling processes. The experience gained and the achievements recorded by this exemplary international operation are passed on and disseminated though its dual role as a dismantling training centre (BMW Group 2003).

Each year the European Centre of the BMW Group personnel handles some 1,800 vehicles in all equivalent to about 2,361 metric tons weight generating amongst others:

- 1,700 metric tons of bodyshells;
- 78 metric tons of operating fluids;
- 500 metric tons of used parts (starter, engine);
- 30 metric tons of plastics;
- 22 metric tons of non-ferrous metals;
- 31 metric tons of batteries.

The BMW Group, also from Germany, carried out a large-scale trial involving 501 prototypes during 2007 in order to obtain detailed information about the 'whole recycling process' relating to their BMW vehicles and compliance with legal requirements (Fig. 5.2).

The outcome of the BMW Recycling Trial				
Material fraction (products)	Recycling (%)	Recovery (%)	Reuse (%)	Disposal (%)
Pre-treatment and dismantling	4,78	1,66	8,70	–
Metals directly recyclable	62,55	–	–	–
Metal-containing composites	1,83	–	–	1,88
Secondary fuel products	–	8,03	–	–
Plastics, products with high plastic content	4,53	–	–	4,15
Disposal products	–	–	–	1,98
Total	73,69 (78,09)	9,69 (10,27)	8,70 (9,23)	8,01 (8,47)
Back up samples		0,08		

Fig 5.2 The outcome of the BMW Recycling Trial (Car Recycling…2008)

The experiment shows that 92.08% was reused, recycled and recovered. With respect to the total vehicle curb weight according to the ELV regulations, 97.59% reuse, recycling and recovery was achieved, with reuse and recycling amounting to 87.32%. Taking into consideration dismantled and reused components and metals generated by processing, total metal output were 78.59% (564.9 tonnes) (Car Recycling 2008).

Volkswagen Golf

Old catalytic converters have valuable metals like platinum and rhodium extracted and used in new ones (Recycling for 2010).

German TÜV NORD agency has certified that more than 40 percent of the mass of a new Golf is made from recycled materials. That's over 1,161 lbs of metal, glass and fluids. The vast majority, over 1,100 lbs, of that is metals such as steel and aluminum which are readily recyclable and, in fact, much of the metal used in many new cars is recycled scrap.

The investigation showed that 527 kg of secondary raw materials, or over 40 percent of the vehicle weight, are used in the new Golf, thus conserving resources.

The systematic use of recyclates at Volkswagen represents a careful and environmentally compatible approach to primary raw materials and reflects the capabilities of modern vehicle production. 501 kg of metal recyclates are used in the Golf, thus making an important contribution to conserving resources. Plastics account for 15 kg of the total recyclate weight, glass for 9 kg and operating fluids for 2 kg. TÜV NORD has certified these results. Some 5,000 parts were assessed during the audit (VW MK…2006).

Opel Astra

Opel began coding plastic parts and had three materials recycling loops:

- PP from battery cases and bumpers to make new fender liners;
- Polycarbonate RBT from old painted bumpers made into new spoiler supports;
- Converting ground-up urethane foam seating material into sound-insulating mats. Reducing polymer variety and eliminating thermo sets are key to Opel's recycling plan (Opel's Recycling 2010).

Fiat Punto

500 tons of plastics and 100 tons of glass are recovered during the recycling process of Fiat Punto. The ultimate goal is to recycle all scrapped Fiat Punto automobiles of which there were almost 1.2 million in Italy (Fiat Punto 2010).

Peugeot 407

Today, at least 90% of every new Peugeot is recyclable, including the metals, glass, fluids, plastic materials and rubber (Peugeot 2010).

5.3 Calculation of carbon footprint in disposal phase

In table 5.1 are presented carbon footprint during recycling and landfilling processes.

Table 1. *Emissions of CO2 during recycling and landfilling processes*

Steel and iron[1]	Synthetic material and plastics[2]	Rubber[3]	Gas, oil and grease[4]	Glass[5]	Non-ferrous metal[6]	Alu mini um[7]	Lead[8]	Foam and cables[9]	Total (Kg)	Referencies
VW GOLF EMISSIONS DURING RECYCLING PROCESSES										**1** - (CO_2 Emissions...2010)
1799.3	428.4	168.5	14.68	10.24	47.2	2184	1014	1360	**7026.02**	
VW Golf EMISSIONS DURING LANDFILLING PROCESSES										**2-** (Time for...2010)
317.5	75.6	47.5	2.6	13.14	13.28	616	286	240	**1611.62**	
BMW 3 SERIES EMISSIONS DURING RECYCLING PROCESSES										**3 -** (Redwood rubber...2010)
2566	611	261	20.9	17.35	79.9	3484	6120	2854.8	**16014.95**	**4-** (Aycaguer, A., et *al.* 2001)
BMW 3 SERIES EMISSIONS DURING LANDFILLING PROCESSES										**5-** (Carbon impact...2010)
723.86	172.3	74.7	5.96	20.42	14.1	616	1080	805.2	**3512.54**	
PEUGEOT 407 EMISSIONS DURING RECYCLING PROCESSES										**6-** (Methodology for...2009)
2578	613.87	263	20.7	16	7.9	1440	1260	1317.6	**7517.07**	**7-** (Recycling - From...2009)
PEUGEOT 407 EMISSIONS DURING LANDFILLING PROCESSES										
286.74	68.21	29.32	2.69	17.78	0.95	160	140	146.4	**852.09**	**8-** (Fundamentals of...2002)
FIAT PUNTO EMISSIONS DURING RECYCLING PROCESSES										**9-** (Recycling - From...2009)
2381	389.3	166.5	13.3	10.19	46.7	1215	1089	1188	**6498.99**	
FIAT PUNTO EMISSIONS DURING LANDFILLING PROCESSES										
265	43.3	18.9	1.52	11.32	5.21	135	121	140	**741.25**	
OPEL ASTRA EMISSIONS DURING RECYCLING PROCESSES										
1021	567	243	19.44	14.7	68.04	1350	1179	1080	**5542.18**	
OPEL ASTRA EMISSIONS DURING LANDFILLING PROCESSES										

113	63	27	2.16	16.43	7.56	150	131	120	**630.15**	

Due to lack of information about carbon dioxide emissions during recycling and land filling processes all data for each material were calculated individually. In automobiles companies' homepages were no information about emissions emitted during recycling and land filling processes.

According "The End of Life Vehicles (ELV) Directive" in the EU (Fig.5.1) 80 - 95 % of automobile must be reused or recycled. Other non - recyclable parts of automobile go to landfills.

At table 5.1 calculated data are high approximate. The sources of information about how much CO_2 each material produce during disposal are presented at the last column in the right.

The total Volkswagen Golf - (1200 kg) emissions during recycling processes - 7026.02 Kg and 1611.62 Kg of CO_2 are emitted from the landfills.

The total BMW 3 series – (1865 kg) emissions during recycling processes- 16014.95 Kg, emissions from the landfills -3512.54 Kg.

The total Peugeot 407 – (1624 kg) emissions during recycling processes- 7517.07 Kg and the total emissions from the landfills- 852.09Kg.

The total Fiat Punto – (1030 kg) emissions during recycling processes- 6498.99Kg, total emissions from the landfills- 741.25kg.

The total Opel Astra – (1500 kg) emissions during recycling processes- 5542.18kg and the total emissions from the landfills- 630.15kg

The summary of total CO_2 emissions during automobiles is presented below (Table 5.2).

Table 5.2. *Total CO_2 emissions during automobiles* (Summary of total emissions from table 5.1)

Automobile	**CO_2 TOTAL DISPOSAL** (Kg)
VW GOLF	8638
BMW 3 SERIES	**19527**
PEUGEOT 407	8369

OPEL ASTRA	**6172**
FIAT PUNTO	7240

The highest emissions are emitted from BMW 3 series automobiles, the lowest emissions - from Opel Astra. The CO_2 emissions are presented per one automobile. Notice, that BMW 3 series automobile is the heaviest from all our calculated automobiles. It is possible to say, that CO_2 depend direct on automobile weight.

6. Carbon Footprint

As fossil energy carriers play the major role for energy supply, any of the above steps is associated with the generation and emission of greenhouse gases (GHG), such as carbon dioxide, methane, nitrous oxide, etc., contributing in turn to the global warming effect, which is measured as the product carbon footprint (PCF).

Life cycle assessment according to ISO 14044 (also covered in the BSI PAS2050) is the state-of-the art methodology to determine your product carbon footprint. Facilitating such a "cradle-to-grave" carbon footprint analysis of your product will disclose your real product carbon footprint (PCF), reveal reduction potentials and discover negative trade-offs, i.e. the shifting of environmental burdens from one stage of the life cycle to another.

Table 6.1 Energy produced and used

for the extraction of raw materials	6 %
for the production of the car	4 %
for running the car during its life tim	90 %

Table 6.2 Air emissions

Carbon dioxide	36 000 kg
Carbon monoxide	413 kg
Volatile organic compounds (VOC)	192 kg
Sulfur dioxide	34 kg
Nitrogen oxides	28 kg

From the Table 6.1 and 6.2 it can be seen, that the basic air pollutants from car life cycle is carbon dioxide, the mass of 36 000 kg GHG are emitted to the atmosphere.

CONCLUSIONS

GHG are emitted to the atmosphere not just from tailpipe, it is important to evaluate total life cycle phase of automobile: material production, vehicle manufacturing, use phase and recycling/disposal. The biggest impact on environment with CO2 emissions from automobile life cycle is from use phase.

CO2 emissions during pre-manufacturing of the car depend not always on quantities of materials used. The biggest amount of the products used in the car production is steel ~70 % of the entire car, but CO2 emissions do not depend on this. e.g during raw material manufacturing of the chosen cars the biggest CO2 emissions are from rubber which includes~ 5 % of total weight.

The biggest impact on environment during raw material production phase is producing BMW 3 series (it takes 10006 kg CO2) and the lowest emissions are making Fiat Punto (it takes 5526.01 kg CO2).

During manufacturing CO2 emissions depend on many factors: energy consumption management, waste management, material consumption. The lowest CO2 emissions from the selected cars (Volkswagen Golf, BMW 3 series, Fiat Punto, Peugeot 407 and Opel Astra) were observed for Fiat Punto (5600 kg).

The higher CO2 emissions during tailpipe of diesel car come from OPEL Astra 2.0 DTI 16V, the amount of CO2 emissions is 40800 kg (an average usage of the car is 300000 km).

The higher CO2 emissions during tailpipe of petrol car come from OPEL Astra 2.0 16V, the amount of CO2 emissions is 66900 kg (an average usage of the car is 300000 km).

The highest emissions during total disposal are emitted from BMW 3 series automobiles (19527.49 kg), the lowest emissions - from Opel Astra (7240.24kg).

Due to lack of information about carbon dioxide emissions during life cycle phases all data for each processes were calculated individually. In automobiles companies' homepages were not all information about emissions emitted during life cycle phase

REFERENCES

Aycaguer, A., Lev - On, M., Winer, M. A. 2001. Reducing Carbon Dioxide Emissions with Enhanced Oil Recovery Projects: A Life Cycle Assessment Approach. [Online] 2010. [Cited on February 12]. Available from the Internet: < http://pubs.acs.org/doi/abs/10.1021/ef000258a>.

A study of the carbon footprint of car transport with Irish Ferries [online]. 2008. [cited 13 February 2010]. Available from internet: <http://www.carbontracking.com/reports/irish_ferries_emissions_calculation.pdf>.

Aluminium European association. EAA report “Sustainability of the European aluminium industry 2006” [online]. 2010. [cited 19 February 2010]. Available from internet: <http://www.eaa.net/>.

Aliuminium Recycling [online]. 2010. [cited 13 February 2010]. Available from internet: <http://www.oea-alurecycling.org/de/verband/oea_eaa_aluminium_recycling.pdf>.

Auto tau [online]. 2010. [cited 13 February 2010]. Available from internet: <http://www.autotau.lt/old/>.

Automobiles and emissions [online]. 2010. [cited 13 February 2010]. Available from internet: <http://www.epa.gov/otaq/consumer/05-autos.pdf>.

BMW home page [online]. 2010. [cited 13 February 2010]. Available from internet:<http://www.bmw.lt/lt/en/newvehicles/3series/coupe/2006/allfacts/engines/engine_data.html>.

BMW Group. [Online] 2003. [Cited on February 12]. Available from the Internet: <http://www.bmw.com/ie/en/_teaserpool/small_standard/owners/pdf/BMWGroup_Recycling.pdf>.

Carbon impact : PET or glass bottle. [Online] 2010. [Cited on February 12]. Available from the Internet: http://www.witts.org/Eva_acc/env_account_19_jun08/wista_eva_aac_casestudy.htm>.

Car Recycling and Environmental Improvement in Western Europe [online] 2010. [Cited on February 12]. Available from the Internet: <http://www.p2pays.org/ref/24/23758.pdf>.

Car Recycling Europa [online] 2010. [Cited on February 12]. Available from the Internet: <http://www.toyota.de/Images/Car_Recycling_Brochure_EN_tcm281-210236.pdf>.

Car Recycling: still striving for top gear [online] 2008. [Cited on February 12]. Available from the Internet: <http://www.icm.ch/pdf/pressarticles/press_recycling_iarc_08.pdf>.

CO_2 Emissions and the Steel Industry's available Responses to the Greenhouse Effect. [Online] 2010. [Cited on February 12]. Available from the Internet: < http://www.ulcos.org/en/docs/Ref16%20-%20Sdiego.pdf>.

Development and Applications of GREET 2.7 — The Transportation Vehicle-Cycle Model. Available from internet: <http://www.transportation.anl.gov/pdfs/TA/378.pdf>.

End-of-Life Vehicle Recycling in the European Union. 2003. [Cited on February 12]. Available from the Internet: <http://www.revultec.com/PDF/EUend-of-lifeVehicleRecyclingPDF.pdf>.

End-of-Life Vehicle Directive [online] 2010. [Cited on February 12]. Available from the Internet: <http://www.environment-agency.gov.uk/business/regulation/31887.aspx>.

Environment, air, transport [online]. 2010. [cited 13 February 2010]. Available from internet: <http://ec.europa.eu/environment/air/transport/co2/co2_home.htm>.

Environment: Life cycle assessment [online]. 2010. [cited 13 February 2010]. Available from internet: <http://www.worldautosteel.org/Environment/Life-Cycle-Assessment.aspx>?>.

Europe's 10 best selling [online]. 2010. [cited 20 February 2010]. Available from internet: <http://www.autospies.com/news/Europe-s-10-Best-Selling-Cars-25736>.

Fiat home page [online]. 2010. [cited 13 February 2010]. Available from internet: <http://www.fiat.lt/showroom_gama.php?m_id=25>.

Fiat Punto [online] 2010. [Cited on February 12]. Available from the Internet: <http://www.autotip.lt/fiat-punto>.

Fundamentals of the Recycling of Lead-Acid Batteries [online]. 2002. [cited 13 February 2010]. Available from internet: <http://www.gtz.de/de/dokumente/en-recycling-of-batteries.pdf>.

Golf home page [online]. 2010. [cited 13 February 2010]. Available from internet: <http://www.volkswagen.co.uk/#/new/golf-vi/configure/787/engine-and-transmission>.

Green auto [online]. 2010. [cited 19 February 2010]. Available from internet: <http://green.autoblog.com/2009/03/02/vw-mk-vi-golf-made-from-over-40-recycled-materials/>.

Greeners cars [online]. 2010. [cited 12 February 2010]. Available from internet: <http://www.greenercars.org/highlights_meanest.htm>.

Life science [online]. 2010. [cited 20 February 2010]. Available from internet: <http://www.livescience.com/technology/090526-car-chemistry.html>.

Life cycle assessment explained [online]. 2010. [cited 12 February 2010]. Available from internet: < http://www.pre.nl/Life_cycle_assessment/life_cycle_assessment.htm>.

Latest technologies keep a low profile in this years greenest vehicles [online]. [cited 12 February 2010]. Available from internet: <http://www.greenercars.org/2010%20Press%20Release.pdf2>.

Methodology for the free allocation of emission allowances in the EU ETS post 2012 [online]. [cited 12 February 2010]. Available from internet: <http://ec.europa.eu/environment/climat/emission/pdf/bm/BM%20study%20-%20Non%20ferrous%20metals.pdf>.

Official Journal. [online] 2000. [Cited on February 12]. Available from the Internet: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:269:0034:0042:EN:PDF>.

Opel home page [online]. 2010. [cited 13 February 2010]. Available from internet: <http://www.opel.lt/site/showroom/astra/documents1.html>.

Opel's Recycling-oriented design [online] 2010. [Cited on February 12]. Available from the Internet:<http://www.gm-elv.com/page/opel/enIE/1>.

Peugeot [online] 2010. [Cited on February 12]. Available from the Internet: <http://www.peugeot.com/en.aspx>.

Peugeot home page [online]. 2010. [cited 13 February 2010]. Available from internet: <http://www.peugeot.com/en/products/cars/peugeot-407.aspx>.

Products carbon footprint [online]. 2010. [cited 13 October 2010]. Available from internet: <http://www.pe-international.com/consulting/carbon-footprint/product-carbon-footprint/>.

Recycling end-of-life vehicle glazing [online] 2009. [Cited on February 12]. Available from the Internet: <http://www.glassforeurope.com/images/cont/80_76720_file.pdf>.

Recycling for a brighter future [online] 2010. [Cited on February 12]. Available from the Internet:<http://www.volkswagen.co.uk/volkswagen-world/environment/product-lifecycle/recycling>.

Recycling – From E-Waste to Resources [online] 2010. [Cited on February 12]. Available from the Internet:< http://www.unep.org/PDF/PressReleases/EWaste_publication_screen_FINALVERSION-sml.pdf>.

Recycling scrapped automobiles. Recycling steel and iron used in automobiles [online]. 2010. [Cited on February 12]. Available from the Internet: <http://www.recycle-steel.org/PDFs/brochures/auto.pdf> .

Redwood rubber. [Online] 2010. [Cited on February 12]. Available from the Internet: < http://www.redwoodrubber.com/benefits.html> .

Scrap Metal Recycling [online] 2010. [Cited on February 12]. Available from the Internet: <http://www.sprep.org/solid_waste/documents/Solid%20Waste/Guidelines/The%20Scrap%20Metal%20Recycling.pdf>.

Solutions for the automobile manufacturing industry [online]. [cited 12 February 2010]. Available from internet: <http://www.hitachi.co.jp/Div/omika/en/solution/industry/industry_3.html>.

Sustainable steel [online]. 2010. [cited 13 February 2010]. Available from internet: <http://www.sustainable-steel.org/emreduction.html>.

Time for change. [Online] 2010. [Cited on February 12]. Available from the Internet: < http://timeforchange.org/plastic-bags-and-plastic-bottles-CO2-emissions>.

Vehicles and tyres recycling information sheet [online]. 2010. [Cited on February 12]. Available from the Internet: < http://www.wasteonline.org.uk/resources/InformationSheets/vehicle.pdf>.

Vehicle Recycling. Focusing on Sustainability [online] 2010. [Cited on February 12]. Available from the Internet: <http://www.bmwgroup.com/publikationen/e/2009/pdf/2009_Vehicle_Recycling_Focusing_on_Sustainability.pdf> .

VW MK VI Golf made from over 40% recycled materials [online] 2009. [Cited on February 12]. Available from the Internet: <http://green.autoblog.com/2009/03/02/vw-mk-vi-golf-made-from-over-40-recycled-materials/>.

Conclusion

Carbon dioxide is emitted to the atmosphere not just from the tailpipe of automobiles; hence it is important to evaluate total life cycle of automobiles: material production, vehicle manufacturing, use phase and recycling/disposal. Although technology is available to measure CO2 emission and legislations are in place to regulate this problem through the course of our research it was also determined that especially in the United States, there is a profound lack of reliable and ‘official’ data. Despite the fact that in the past couple years more information is being made available by the US government, the United States is clearly behind in advancing the cause to reduce carbon emission and to change consumer conceptions about fuel use and transportation. This lack of substantiated information made this a very complicated and at times, a frustrating project, and it is this lack of information that what we hope to emphasize. For the fact that a small yet determined group of students were able to come up with meaningful numbers despite this deficiency, and for the fact that the European Union mandates automobile manufacturers to disclose such information, demonstrates that this is not an impossible task. However, the availability of such information and its presentation is fundamental to the central cause of actualizing real and substantial change. This lack of information is also apparently the primary reason why the United States is one of the major contributors to GHG emissions and global climate change and why we are so behind in the global effort to reverse our catastrophic course. None of such information is based on actual measured data, and in many cases, including an official Korean government website, the method of how certain carbon emissions were calculated are not made available. Many rough estimates were given, yet none were fully conclusive or substantiated.

Working as an intercontinental team during the course of this project, we were able to successfully overcome obstacles ranging from difficulties in communication due to technical complications, to issues with work ethics. Being a first semester IPRO, and with team members having no previous background on the subject matter, we spent a lot of time researching how to approach the problem. Our main goal of producing a user-friendly way of showing the whole carbon emissions to the consumers was met, but due to time constrains, we were unable to implement any designs or models. From our collected and calculated data, we found that the Nissan Leaf which is an electric vehicle (ZEV vehicle), does not pollute through tailpipe emissions, but emits CO_2 through the recharging of the vehicle and through manufacturing as well. Also, the BMW 3 series is seen to emit a lot of C02 during manufacturing with 820,000kgC02/vehicle while the Fiat Punto emits significantly less (73,520kgC02/vehicle) due to low emission energy sources.

As mentioned a major difficulty we had was with the collection of data. We found varying information from different sources, but not all of the data we required was available. Seeing how our Lithuanian counterparts managed to find specific data, data which is given openly to the European market, while it isn't available here in the United States, it stands as a recommendation to see how the regulating laws change and see if this data is released openly to the public. We would therefore recommend that for further analysis, our future team members consider a greater use of an advanced tool, such as Argonne's GREET model to significantly help in increasing the accuracy of these values. They should also consider designing a windscreen sticker containing C02 information on the lifetime of an automobile that would aid the average consumer in making knowledgeable decisions.

.